

**227th AAS Meeting**  
**Kissimmee, FL – January, 2016**  
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## 103 – Supernovae: Surveys and Detections

### 103.01 – Supernovae by the Hundreds: the LCOGT Supernova Key Project

The LCOGT Supernova Key Project is a three year project to obtain lightcurves and spectra of 600 supernovae. To do this, it has been awarded 2900 hours per year on the 9 one meter and 2 two meter robotic telescopes of the Las Cumbres Observatory Global Telescope network (LCOGT). At the midway point of the Key Project, it is on track to achieving its goals. I will discuss recent insights into supernova progenitors, exotic individual supernovae, and some of the large samples of supernovae studied by the project.

**Author(s):** Dale Andrew Howell<sup>1</sup>, Iair Arcavi<sup>1</sup>, Griffin Hosseinzadeh<sup>1</sup>, Curtis McCully<sup>1</sup>, Stefano Valenti<sup>2</sup>  
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**Contributing team(s):** LCOGT Key Project

### 103.02 – Exploring Type II Supernova Diversity with the LCOGT Sample

High quality, multi-color collections of Type II supernova (SN II) light curves are scarce because they often remain active for hundreds of days, making follow-up time-consuming and catching the rise and fall in one observing season challenging. In light of these difficulties the diversity of SNe II is not fully understood. Here I present multi-band ultraviolet and optical photometry of 12 SNe II followed by the Las Cumbres Observatory Global Telescope Network (LCOGT) during 2013-2014. The resultant light curves are compared to objects from the literature and the nature of Type IIP and Type IIL supernova diversity is explored. While SNe IIL are found to be on average more luminous than SNe IIP, the former does not appear to produce on average more radioactive nickel than the latter. SNe IIP and IIL are also not distinguishable by the luminosity of their progenitor stars. Finally, optical-wavelength nebular spectra obtained for several of our SNe IIL are found to be consistent with expectations of progenitors in the 12-15  $M_{\odot}$  range. As a consequence, SNe IIL appear not to account for the lack of massive red supergiants as SN II progenitors.

**Author(s):** Stefano Valenti<sup>2</sup>, Dale Andrew Howell<sup>1</sup>, Iair Arcavi<sup>1</sup>, Curtis McCully<sup>1</sup>, Griffin Hosseinzadeh<sup>1</sup>  
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### 103.03D – Fast and Furious: Rapid Response to Young Supernovae

Observations of supernovae within a few days of their explosion provide entirely diagnostics to probe the nature of supernova progenitors. Since 2013, I have used the intermediate Palomar Transient Factory (iPTF) to systematically study extraordinarily young supernovae. In this talk, I will give an overview of iPTF survey design, summarize the design and implementation of the near real-time discovery pipeline and then describe the rapid-response follow-up. The highlights from my thesis are: 1) We observed a strong declining UV emission from a low-velocity Type Ia supernova which is consistent with the expected emission from a supernova slamming into a companion star. Evidently some Type Ia supernovae arise from the so-called "single degenerate" channel. 2) We identified the first progenitor candidate of a Type Ib supernova in the pre-explosion HST images. Our multi-wavelength observations of this young Type Ib supernova constrain its progenitor to be smaller than several solar radii and with strong mass loss, consistent with our current ideas that the progenitor should be a Wolf-Rayet star. I will end my talk with prospects for this field with the upcoming Zwicky Transient Facility.

**Author(s):** Yi Cao<sup>1</sup>, Shrinivas R. Kulkarni<sup>1</sup>, Peter E. Nugent<sup>2</sup>, Mansi M. Kasliwal<sup>1</sup>  
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### 103.04 – A New Type of X-ray Transient?

During an extension of the Chandra Deep Field-South (CDF-S) survey to 7Ms, a relatively bright transient event in a region with no

previous X-ray emission. The X-ray light curve of the event is significantly fainter than the X-ray afterglows associated with known Gamma-ray Bursts (GRBs). Several deep optical follow-up constraints rule out a variety of possible explanations (known supernovae, GRBs, most Galactic transients). Although the implied rates are uncertain, similar events could potentially be more common than currently observable GRBs.

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**Contributing team(s):** CDFS Transient Team

### 103.05D – Peculiar Transients as Probes of Stellar Evolution and Mass-Loss

Multi-wavelength observations of supernovae not only probe the explosion mechanism, but also carry information about the configuration of the star at the moment of collapse and the mass-loss history of the progenitor system in the years immediately preceding its death. The study of supernovae therefore offers us one of our only observational views of the final stages of stellar evolution. As a result, the discovery by wide-field dedicated surveys of new classes of astronomical transients at an ever-increasing rate has both expanded the types of stellar systems that we can directly probe and challenged some of our existing views of how these uncertain final stages proceed. In this talk I will discuss my thesis work on several types of new and peculiar astronomical transients and what their properties, intrinsic rates, and explosion environments are teaching us about stellar evolution and stellar death.

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**Contributing team(s):** Pan-STARRS1 CFA/JHU Transient Team

### 103.06 – Supernova Host Galaxy Identification: Applications for the Dark Energy Survey and Future Surveys

Host galaxy identification is a crucial step for modern supernova (SN) surveys, which will discover SNe by the thousands. Spectroscopic resources are very limited, and so in the absence of real-time SN spectra these surveys must rely on host galaxy spectra to obtain redshifts which are then used for photometric classification of SNe. In addition, SN luminosities are known to correlate with host galaxy properties. Therefore, reliable identification of host galaxies is essential for cosmology and SN science. Using both real and simulated galaxy catalog data, including information about galaxy position, shape, orientation, and redshifts, we develop and test methods for matching SNe to their host galaxies. We use an automated algorithm that is run on catalog data and assigns host galaxies to simulated SN positions. We present the results of this algorithm and demonstrate how including a machine learning component, run after the initial matching algorithm, boosts the accuracy of the matching.

**Author(s):** Ravi Gupta<sup>1</sup>, Stephen Kuhlmann<sup>1</sup>, Eve Kovacs<sup>1</sup>, Harold Spinka<sup>1</sup>, Daniel Goldstein<sup>3</sup>, Camille Liotine<sup>1</sup>, Katarzyna Pomian<sup>1</sup>, Richard Kessler<sup>4</sup>, Christopher D'Andrea<sup>2</sup>, Mark Sullivan<sup>6</sup>, Masao Sako<sup>5</sup>, Robert Nichol<sup>2</sup>, Andreas Papadopoulos<sup>2</sup>  
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**Contributing team(s):** The Dark Energy Survey

### 103.07 – The Multiply Imaged Strongly Lensed Supernova Refsdal

In 1964, Sjur Refsdal first considered the possibility that the light from a background supernova could traverse multiple paths around a strong gravitational lens towards us. He showed that the arrival times of the supernova's light would depend on the cosmic expansion rate, as well as the distribution of matter in the lens. I will discuss the discovery of the first such multiply imaged supernova, which exploded behind the MACS J1149.6+2223 galaxy cluster. We have obtained *Hubble Space Telescope* grism and ground-based spectra of the four images of the supernova, which form an Einstein Cross

configuration around an elliptical cluster member. These spectra as well as rest-frame optical light curves have allowed us to learn about the properties of the peculiar core-collapse supernova explosion, and contain information about the lenses' matter distribution as well as their stellar populations. A delayed image of the supernova is expected close to the galaxy cluster center as early as Fall 2015, and will serve as an unprecedented probe of the potential of a massive galaxy cluster.

**Author(s):** Patrick Kelly<sup>1</sup>

**Institution(s):** 1. California - Berkeley, University of

## 104 – AGN, QSO, Blazars: Origins, Evolution, Growth and Masses

### 104.01 – The Fossil Record of Black Hole Seeds, with Spatially Resolved Spectroscopy

I will present the first robust measurement of black hole occupation over a wide range of host galaxy mass ( $8 < \log(M^*/M_{\text{sun}}) < 12$ ) at  $0 < z < 2.5$ . A complete AGN census is made possible by using HST spatially resolved spectroscopy, which reliably distinguishes a nuclear AGN from extended star formation and largely avoids the star-formation dilution bias plaguing traditional low-mass AGN selection. The observations suggest bimodal seed formation: while many low-mass galaxies host massive black holes, their black hole occupation is  $\sim 10\%$  that of massive galaxies. The measured black hole occupation qualitatively agrees with theoretical models of black hole formation, with massive direct-collapse seeds forming only in massive halos and black hole formation confined to lower-mass Pop III remnants in small halos.

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**Institution(s):** 1. Penn State

**Contributing team(s):** CANDELS, 3D-HST

### 104.02 – The Observed Evolution of the Black-Hole-Host Mass Relation to $z \sim 3.5$

We present our Keck/MOSFIRE project to probe basic black hole and host galaxy properties in a sample of faint Active Galactic Nuclei (AGN) at  $z \sim 2.1\text{--}3.7$ , selected through the extensive X-ray Chandra coverage of the COSMOS field. Compared with previous studies of unobscured AGN at these high redshifts, our sources have lower AGN luminosities, corresponding to significantly higher number densities, of order  $\sim 10^{-6}\text{--}10^{-5} \text{ Mpc}^{-3}$ . The new K-band data covers the spectral region surrounding the broad H $\beta$  or H $\alpha$  emission lines, and enables the estimation of black hole masses ( $M_{\text{BH}}$ ) and accretion rates (in terms of  $L/L_{\text{Edd}}$ ). The lower AGN luminosities also allow for robust determinations of the host galaxies stellar masses, therefore enabling us to trace the evolution of the BH-to-stellar mass ratio ( $M_{\text{BH}}/M^*$ ) to  $z \sim 3.5$ . Compared with the rarer, higher-luminosity quasars targeted in previous studies, we find that the 12 AGN in our sample have lower  $M_{\text{BH}}$  ( $\sim 5 \times 10^8 M_{\text{sun}}$ ), but similar accretion rates ( $L/L_{\text{Edd}} \sim 0.1\text{--}0.5$ ). The BH-to-stellar mass ratio,  $M_{\text{BH}}/M^*$ , has a large scatter, with several sources reaching extremely high ratios of  $M_{\text{BH}}/M^* \sim 10\%$  - higher by at least an order of magnitude than what is observed in the local Universe. The typical mass ratio for our sample is consistent with a trend of  $M_{\text{BH}}/M^* \sim (1+z)^2$ . I will highlight some intriguing sources in the sample, and will briefly discuss the implications of our findings to the co-evolution of SMBHs and their host galaxies.

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### 104.03 – HST images of FeLoBAL quasars: Testing quasar-galaxy evolution models

We present preliminary results from an HST imaging study of

FeLoBAL quasars, which have extremely low-ionization Broad Absorption Line (BAL) outflows and might be a young quasar population based on their red colors, large far-IR luminosities (suggesting high star formation rates), and powerful outflows. Some models of quasar - host galaxy evolution propose a triggering event, such as a merger, to fuel both a burst of star formation and the quasar/AGN activity. These models suggest young quasars are initially obscured inside the dusty starburst until a "blowout" phase, driven by the starburst or quasar outflows like FeLoBALs, ends the star formation and reveals the visibly luminous quasar. Despite the popularity of this evolution scheme, there is little observational evidence to support the role of mergers in triggering AGN or the youth of dust-reddened quasars (such as FeLoBALs) compared to normal blue quasars.

Our Cycle 22 HST program is designed to test the youth of FeLoBAL quasars and the connection of FeLoBALs to mergers. We obtain WFC3/IR F160W images of 10 FeLoBAL quasars at redshift  $z \sim 0.9$  (covering  $\sim 8500 \text{ \AA}$  in the quasar rest frame). We will compare the host galaxy morphologies and merger signatures of FeLoBALs with normal blue quasars (which are older according to the evolution model) and non-AGN galaxies matched in redshift and stellar mass. If FeLoBAL quasars are indeed in a young evolutionary state, close in time to the initial merging event, they should have stronger merger features compared to blue quasars and non-AGN galaxies. Preliminary results suggest that this is not the case - FeLoBAL quasars appear to reside in faint, compact hosts with weak or absent merger signatures. We discuss the implications of these results for galaxy evolution models and other studies of dust-reddened quasar populations.

**Author(s):** Hanna Herbst<sup>4</sup>, Fred Hamann<sup>4</sup>, Carolin Villforth<sup>3</sup>, Paola Caselli<sup>1</sup>, Anton M. Koekemoer<sup>2</sup>, Sylvain Veilleux<sup>5</sup>

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### 104.04 – Dual AGNs in Mergers: An X-ray and IR investigation

Since the vast majority of galaxies contain supermassive black holes (SMBHs) and galaxy interactions trigger nuclear gas accretion, a direct consequence of the hierarchical model of galaxy formation would be the existence of binary active galactic nuclei (AGNs). The existence, frequency, and characteristics of such binary AGNs have important astrophysical implications on the SMBH mass function, the interplay between SMBHs and the host galaxy, and the M-sigma relation. Despite decades of searching, and strong theoretical reasons that they should exist, observationally confirmed cases of binary AGNs are extremely rare, and most have been discovered serendipitously. Using the all-sky WISE survey, we identified a population of over one hundred strongly interacting galaxies that display extreme red mid-infrared colors thus far exclusively associated in extragalactic sources with powerful AGNs. In this talk, I will summarize follow-up X-ray and near-IR spectroscopic observations of this population that reveal a population of optically quiescent dual AGNs at kpc scales. These observations demonstrate that mid-IR surveys are an ideal pre-selection strategy in finding dual AGNs in the most advanced mergers.

**Author(s):** Shobita Satyapal<sup>1</sup>, Nathan Secrest<sup>3</sup>, Barry Rothburg<sup>2</sup>, Sara L. Ellison<sup>4</sup>, Paul McNulty<sup>1</sup>

**Institution(s):** 1. George Mason University, 2. Large Binocular Telescope Observatory, 3. Naval Research Laboratory, 4. University of Victoria

### 104.05D – Understanding AGNs in the Local Universe through Optical Reverberation Mapping

I present the results of observational projects aimed at measuring the mass of the black hole at the center of active galactic nuclei (AGNs) and understanding the structure and kinematics of the broad-line emitting gas within the black hole's sphere of influence.

The first project aims to measure the black hole mass in the Kepler-field AGN KA1858. We obtained simultaneous spectroscopic data from the Lick Observatory 3-m telescope using the Kast Double

Spectrograph and photometry data from five ground-based telescopes, and used reverberation mapping (RM) techniques to measure the emission-line light curves' lags relative to continuum variations. We obtained lags for H-beta, H-gamma, H-delta, and He II, and obtained the first black hole mass measurement for this object. Our results will serve as a reference point for future studies on relations between black hole mass and continuum variability characteristics using Kepler AGN light curves.

The second project, in collaboration with the AGN STORM team, aims to understand the structure and dynamics of the broad line region (BLR) in NGC 5548 in both UV and optical wavelengths. To supplement 6 months of HST UV observations, we obtained simultaneous optical spectroscopic data from six ground-based observatories. We obtained emission-line lags for the optical H-beta and He II lines as well as velocity-resolved lag measurements for H-beta. We also compared the velocity-resolved lags for H-beta to the UV emission lines C IV and Ly-alpha and found similar lag profiles for all three lines.

Finally, I will discuss my contributions to two other collaborations in AGN RM. A key component in RM is monitoring continuum variability, which is often done through ground-based photometry. I will present a pipeline that performs aperture photometry on any number of images of an AGN with WCS coordinates and immediately produces relative light curves. This pipeline enables quick looks of AGN variability in real time and has been used in the LAMP 2011 and the LCOGT Key Project collaborations. It is also applicable to large archival datasets in preparation for survey campaigns in the near future.

**Author(s):** Liuyi Pei<sup>1</sup>

**Institution(s):** 1. University of California Irvine

#### 104.06 – Active Galactic Nuclei flicker on a characteristic timescale of 105 years: implications for black hole growth and AGN feedback

The total duration of quasar phases has been estimated to be on the order of 100 Myr to 1 Gyr. However, black hole accretion may not be a smooth process and a long-lasting growth phase may actually be composed of many brief 105 year accretion bursts, interspersed by low-Eddington phases and even quiescence. I present an observational argument for the 105 year timescale, discuss its implications as well as current observational efforts to map out the entire AGN lifecycle.

**Author(s):** Kevin Schawinski<sup>1</sup>, Michael Koss<sup>1</sup>, Lia F. Sartori<sup>1</sup>, Simon Berney<sup>1</sup>

**Institution(s):** 1. ETH Zurich

#### 104.07 – Improving Calibration of the $M_{BH} - \sigma^*$ Relation for AGN with the BRAVE Program

The  $M_{BH} - \sigma^*$  relation for AGN, which relates the mass of the central supermassive black hole ( $M_{BH}$ ) to the bulge stellar velocity dispersion ( $\sigma^*$ ) of the host galaxy, is a powerful tool for studying the evolution of structure across cosmic time. Accurate calibration of this relation is essential and much effort has been put into improving  $M_{BH}$  determinations, however calibration remains difficult because many AGN are hosted by late-type galaxies with significant kinematic substructure such as bars, disks and rings. Kinematic substructure is known to contaminate and bias  $\sigma^*$  determinations from long-slit spectroscopy, ultimately limiting the utility of the  $M_{BH} - \sigma^*$  relation. We present the first results from the BRAVE program, the goal of which is to use integral-field spectroscopy to more accurately determine  $\sigma^*$  for the calibrating sample of  $\sim 30$  reverberation-mapped AGN. We have used the new HexPak IFU at WIYN to observe eight nearby, low-inclination AGN in this sample. We present first results from these observations and discuss how the line of sight velocity distribution may be used to identify and correct for contamination by kinematic substructure, in order to more accurately determine  $\sigma^*$  for calibration of the  $M_{BH} - \sigma^*$  relation for AGN.

**Author(s):** Merida Batiste<sup>1</sup>, Misty C. Bentz<sup>1</sup>

**Institution(s):** 1. Georgia State University

#### 104.08 – A Stellar Dynamical Black Hole Mass for Broad-Lined Seyfert Galaxy NGC 6814 and Comparison to Results from Reverberation Mapping

We present a stellar dynamical mass for the supermassive black hole in the nearby ( $z=0.005$ ) broad-lined Seyfert galaxy NGC 6814 and compare it to the published reverberation-based mass. NGC 6814 is only the third galaxy for which the comparison of these two techniques has been accomplished in the same galaxy. Though stellar dynamical modeling is currently thought to be the most direct way of measuring a SMBH mass, it is quite limited because it can only be performed on nearby galaxies that have a spatially resolvable (or nearly so) black hole gravitational sphere of influence. In contrast, reverberation mapping, which relies on time resolution and not spatial resolution, can be used to constrain black hole masses in even the most distant quasars. Reverberation masses, however, carry with them an uncertainty based on the unknown geometry of the photoionized broad line region. This uncertainty affects our ability to accurately measure masses of AGN not just for reverberation masses, but also for the thousands of masses that rely on the reverberation sample for their calibration. This comparison of the mass of the central supermassive black hole in NGC 6814 using both stellar dynamical and reverberation mapping techniques is part of a larger effort to directly compare these techniques in several galaxies. The more galaxies for which this comparison can be performed, the better we will be able to understand the scatter and potential biases in black hole masses and therefore supermassive black hole evolution across cosmic time.

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#### 105 – Stars I: Age, Rotation and Activity

##### 105.01 – A self-consistent dynamo model for fully convective stars

The tachocline region inside the Sun, where the rigidly rotating radiative core meets the differentially rotating convection zone, is thought to be crucial for generating the Sun's magnetic field. Low-mass fully convective stars do not possess a tachocline and were originally expected to generate only weak small-scale magnetic fields. Observations, however, have painted a different picture of magnetism in rapidly-rotating fully convective stars: (1) Zeeman broadening measurements revealed average surface field of several kiloGauss (kG), which is similar to the typical field strength found in sunspots. (2) Zeeman-Doppler-Imaging (ZDI) technique discovered large-scale magnetic fields with a morphology often similar to the Earth's dipole-dominated field. (3) Comparison of Zeeman broadening and ZDI results showed that more than 80% of the magnetic flux resides at small scales. So far, theoretical and computer simulation efforts have not been able to reproduce these features simultaneously. Here we present a self-consistent global model of magnetic field generation in low-mass fully convective stars. A distributed dynamo working in the model spontaneously produces a dipole-dominated surface magnetic field of the observed strength. The interaction of this field with the turbulent convection in outer layers shreds it, producing small-scale fields that carry most of the magnetic flux. The ZDI technique applied to synthetic spectropolarimetric data based on our model recovers most of the large-scale field. Our model simultaneously reproduces the morphology and magnitude of the large-scale field as well as the magnitude of the small-scale field observed on low-mass fully convective stars.

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## 105.02 – A Light Curve Probe of Stellar Surface Convection and Measure of Stellar Surface Gravity

We recently found that high quality light curves, such as those obtained by NASA's Kepler, K2, and the soon-to-be-launched TESS missions, may be used to measure stellar surface gravity via granulation-driven light curve “flicker.” Here, we describe our updated and extended the relation, which is now calibrated against a more robust set of asteroseismically derived surface gravities and which we apply to over 28,000 Kepler stars. We discuss how we treat phenomena, such as exoplanet transits and shot noise, that adversely affect the measurement of flicker, and we explore the limitations of the technique. We suggest that flicker may be used to probe convection in stars with surface gravities as low as 1.5, and we show that, in concert with asteroseismically measured surface gravities, it might be used to examine differences in the convective properties of red giant, red clump, and secondary clump stars. Finally, we highlight further applications of flicker, such as astrodensity profiling or its use in studying other types of stars with convective outer layers.

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## 105.03 – The evolution of chromospheric activity in middle-aged Sun-like stars

Ages of stars are difficult to infer because stars change very little during the majority of their lifetimes. However, stars are observed to spin down over time due to magnetic braking, which weakens the magnetic dynamo as well. This spin down has led to a new age dating method called gyrochronology, which has been successfully calibrated for Sun-like stars up to 2.5 Gyr, but is still undetermined at older ages and lower masses. The decay of magnetic activity has also been utilized to empirically calibrate an age relationship at ages less than 600 Myr with nearby young star clusters (e.g. Hyades), and pinned down at 4 Gyr with M67, but the relationship is basically unconstrained at intermediate ages and sub-Solar masses. Advances in observational facilities have brought distant clusters into view, while the discovery of Ruprecht 147 has provided a new benchmark that is the oldest nearby cluster (3 Gyr, 300 pc, Curtis et al. 2013), and which provides a bridge across this historic age gap. I will present new, high quality chromospheric activity data for NGC 752 at 1.5 Gyr and Ruprecht 147 at 3 Gyr. The stars of Ruprecht 147 will demonstrate the typical activity level and variability experienced by the Sun at a time when multicellular life first evolved on Earth. I will also re-evaluate the M67 data by considering contamination by the interstellar medium, with implications for the frequency of Maunder Minima. Finally, I will discuss a new opportunity to investigate stellar spin down and variability in low mass KM dwarfs with the K2 Survey of Ruprecht 147, which will have just concluded in late December 2015.

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## 105.04D – Stellar ages from stellar rotation

Gyrochronology, the method of inferring stellar ages from rotation periods and masses, or mass proxies, has the potential to provide ages for thousands of stars observed by space photometry missions like Kepler, K2 and TESS. However, asteroseismic age measurements for solar-like oscillators observed by the Kepler spacecraft have revealed unexpected behaviour of stars at late ages: old stars appear to be rotating too rapidly given their age and mass. New gyrochronology models are required in order to explain this behaviour. Fundamental to the continued advancements of our understanding of gyrochronology is the inference of precise and accurate rotation periods for old, inactive and slowly rotating stars in the Kepler, K2 and TESS data sets. We have developed new methods for rotation period inference that are suited to detecting low-amplitude signals in noisy time-series as well as new gyrochronology models which describe the Kepler asteroseismic

sample, allowing the age of a star to be inferred from its rotation period and mass proxy alone.

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## 105.05D – Insight into the structure and physics of M dwarf stars through determination of the rotation, metallicities, and radii of the nearby population

Despite the prevalence of M dwarfs, their fundamental properties—their sizes, compositions, and ages—are not well-constrained. Empirical determination of these properties is important for gaining insight into their stellar structure, magnetic field generation, and angular momentum evolution. Knowledge of the stellar parameters is also key to characterizing planetary systems. I used observations to empirically constrain the properties of nearby, mid-to-late M dwarfs targeted by the MEarth transiting planet survey. I obtained low-resolution (R=2000) NIR spectra of 450 M dwarfs using SpeX on IRTF. I measured their absolute radial velocities with an accuracy of 4 km/s by exploiting telluric lines to establish an absolute wavelength calibration, and developed techniques to estimate M dwarf metallicities from K-band spectral line equivalent widths (EWs) or 2MASS colors to 0.15 dex. Using stars with interferometric radii, I showed that H-band EWs can be used to infer K and M dwarf temperatures to 69K, and radii to 0.027R<sub>sun</sub>. I applied these relations to planet-hosting stars from Kepler, showing that the typical planet is 15% larger than is inferred if adopting other stellar parameters. Using photometry from the MEarth-North Observatory, I measured rotation periods from 0.1 to 150 days for 350 M dwarfs. There is a prevalence of stable spot patterns, and no correlation between period and amplitude for fully-convective stars. Using galactic kinematics as a proxy for age, I demonstrated a smooth age-rotation relation. I found that rapid rotators (P<10 days) are <2 Gyr, and that the slowest are on average 5+3 Gyr old. I will discuss the extension of this work to the southern hemisphere, which utilizes FIRE on Magellan and the MEarth-South Observatory. MEarth acknowledges funding from the NSF, the David and Lucile Packard Foundation and the John Templeton Foundation. ERN was supported by the NSF GRFP. This work includes observations obtained at the Infrared Telescope Facility, operated by the U. of Hawaii, and the Magellan Telescopes at Las Campanas Observatory, Chile. I recognize the significant role of Mauna Kea within the indigenous Hawaiian community, and acknowledge the opportunity to conduct these observations.

**Author(s):** Elisabeth R. Newton<sup>1</sup>  
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## 105.06D – What Makes Red Giants Tick? Linking Tidal Forces, Activity, and Solar-Like Oscillations via Eclipsing Binaries

Thanks to advances in asteroseismology, red giants have become astrophysical laboratories for studying stellar evolution and probing the Milky Way. However, not all red giants show solar-like oscillations. It has been proposed that stronger tidal interactions from short-period binaries and increased magnetic activity on spotty giants are linked to absent or damped solar-like oscillations, yet each star tells a nuanced story. In this work, we characterize a subset of red giants in eclipsing binaries observed by *Kepler*. The binaries exhibit a range of orbital periods, solar-like oscillation behavior, and stellar activity. We use orbital solutions together with a suite of modeling tools to combine photometry and spectroscopy in a detailed analysis of tidal synchronization timescales, star spot activity, and stellar evolution histories. These red giants offer an unprecedented opportunity to test stellar physics and are important benchmarks for ensemble asteroseismology.

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## 106 – Recent Developments in Extrasolar Planet Detection

### 106.01 – Multiwavelength Transit Observations of the Candidate Disintegrating Planetesimals Orbiting a White Dwarf

At the time of writing of this abstract, an intriguing white dwarf system is shortly to be announced that is believed to be orbited by up to six or more disintegrating, planetesimals in short-period orbits. We report a wealth of multiwavelength, ground-based photometry of this system, and detect multiple transits of up to 30% of the stellar flux. The transits display the variable transit depths and transit profiles featuring longer egresses than ingresses that we have come to associate with disintegrating planets/planetesimals. Our photometry confirms that this white dwarf is indeed being orbited by multiple planetesimals, with at least one object, and likely more, having orbital periods of  $\sim 4.5$  hours; we are unable to confirm the specific periods that have been reported, thus bringing into question the long-term stability of the planetesimals' orbits. Lastly, our multiwavelength transit photometry allows us to place a limit on the particle size in the cometary tails trailing these planetesimals, helping to determine the mechanism (collisions, tidal disruption, a Parker wind, etc.) that has led to both the cometary tails and the arrival of these planetesimals in such short period orbits.

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### 106.02 – Infrared emission from highly irradiated planets in orbit around hot white dwarfs

An intensive search for terrestrial mass planets in the habitable zone around white dwarfs is currently in progress. Before such planets become habitable, they reside in regions that receive significant insolation from their host white dwarf as it cools from high effective temperatures. A consequence of this is that such irradiated planets are potentially observable in the infrared. We detail how these planets may be currently observable, and future possibilities for constraining the frequency of planets in short period orbits around post-main sequence stars.

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### 106.03 – Confirmation of the Planetary Origin of the Gravitational Microlensing Event OGLE-2006-BLG-0169

We present Hubble Space Telescope (HST) Wide Field Camera 3 (WFC3) observations of the source and lens stars for planetary microlensing event OGLE-2005-BLG-169, which confirm the relative proper motion prediction due to the planetary light curve signal observed for this event. This (and the companion Keck result) provide the first confirmation of a planetary microlensing signal, for which the deviation was only 2%. The follow-up observations determine the flux of the planetary host star in multiple passbands and remove light curve model ambiguity caused by sparse sampling of part of the light curve. This leads to a precise determination of the properties of the OGLE-2005-BLG-169Lb planetary system.

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### 106.04 – Mass ratio of the 2 pc binary brown dwarf LUH 16 and limits on planetary companions from astrometry

We analyse FORS2/VLT I-band imaging data to monitor the motions of both components in the nearest known binary brown dwarf WISE

J104915-57-531906.1AB (LUH 16) over one year. The astrometry is dominated by parallax and proper motion, but with a precision of 0.2 mas per epoch we accurately measure the relative position change caused by the orbital motion of the pair. This allows us to directly measure a mass ratio of  $q = 0.78 \pm 0.10$  for this system. We also search for the signature of a planetary-mass companion around either of the A and B component and exclude at  $3\sigma$  the presence of planets with masses larger than 2 M<sub>J</sub> and orbital periods of 20-300 d. We update the parallax of LUH 16 to  $500.51 \pm 0.11$  mas, i.e. just within 2 pc. This study yields the first direct constraint on the mass ratio of LUH 16 and shows that the system does not harbour any close-in giant planets.

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### 106.05 – An Accreting Protoplanet: Confirmation and Characterization of LkCa15b

We present a visible light adaptive optics direct imaging detection of a faint point source separated by just 93 milliarcseconds ( $\sim 15$  AU) from the young star LkCa 15. Using Magellan AO's visible light camera in Simultaneous Differential Imaging (SDI) mode, we imaged the star at Hydrogen alpha and in the neighboring continuum as part of the Giant Accreting Protoplanet Survey (GAPplanetS) in November 2015. The continuum images provide a sensitive and simultaneous probe of PSF residuals and instrumental artifacts, allowing us to isolate H-alpha accretion luminosity from the LkCa 15b protoplanet, which lies well inside of the LkCa15 transition disk gap. This detection, combined with a nearly simultaneous near-infrared detection with the Large Binocular Telescope, provides an unprecedented glimpse at a planetary system during epoch of planet formation.

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### 106.06D – Probing Planetary Formation and Evolution Through Occultations

The circumstellar environments of young stellar objects (YSOs) involve complex dynamical interactions between dust and gas that directly influence the formation of planets. However, our understanding of the evolution from the material in the circumstellar disk to the thousands of planetary systems discovered to date, is limited. One means to better constrain the size, mass, and composition of this planet-forming material is to observe a YSO being eclipsed by its circumstellar disk. Through this dissertation project, we are discovering and characterizing both disk eclipsing systems and exoplanets using the Kilodegree Extremely Little Telescope (KELT) project. KELT is a photometric survey for transiting planets orbiting bright stars ( $8 < V < 11$ ); such bright planet host targets are well-suited for atmospheric characterization of the planets. KELT has discovered 15 planets transiting stars brighter than  $V \sim 11$  to date. I will present some of the recently discovered planets from the survey and discuss their potential to advance our understanding of planetary atmospheres. In addition, KELT provides photometric monitoring of  $\sim 3$  million stars, presenting the opportunity to perform multi-year studies of stellar variability generally and rare disk occultations specifically. Using time-series photometry from KELT we are conducting the Disk Eclipse Search with KELT (DESK) survey to look for disk eclipsing events, specifically in young stellar associations. To date, the survey has discovered and analyzed four previously unknown large dimming events around the stars RW Aurigae, V409 Tau, AA Tau, and TYC 2505-672-1, the latter now representing the longest-period eclipsing object known (period  $\sim 69$  years). I will describe our results for planet atmosphere characterization and for protoplanetary disk structure and composition, and discuss how to search for these kinds of systems in future surveys such as LSST.

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**Contributing team(s):** The KELT Team

### 106.07 – How to Image Exoplanets at Solar System Scales

Binaries are typically excluded from direct imaging exoplanet surveys. However, the recent findings of Kepler and radial velocity programs show that planets can and do form in binary systems. Here, we suggest that visual binaries offer unique advantages for direct imaging. We show that Binary Differential Imaging (BDI), whereby two stars are imaged simultaneously at the same wavelength within the isoplanatic patch at high Strehl ratio, offers improved point spread function (PSF) subtraction that can result in increased sensitivity to planets close to each star. We demonstrate this by observing a young visual binary separated by  $\sim 4$  arcseconds with MagAO/Clio-2 at  $3.9 \mu\text{m}$ , where the Strehl ratio is high, the isoplanatic patch is large, and giant planets are bright. Comparing BDI to angular differential imaging (ADI), we find that BDI's 5-sigma contrast is  $\sim 0.5$  mags better than ADI's within  $\sim 1$  arcsecond for the particular binary we observed. Because planets typically reside close to their host stars, BDI is a promising technique for discovering exoplanets in stellar systems that are often ignored. BDI is also 2-4x more efficient than ADI and classical reference PSF subtraction, since planets can be detected around both the target and PSF reference simultaneously. We are currently exploiting this technique in a new MagAO survey for giant planets in 140 young nearby visual binaries. BDI on a space-based telescope would not be limited by isoplanatism effects and would therefore be an even more powerful tool for imaging and discovering planets.

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### 106.08 – Finding the Needles in the Haystacks: Feasibility of Exomoon Detection and Spectral Recovery

Although nearly two thousand exoplanets have been discovered and confirmed to date, exomoons have yet to be detected orbiting these planets. The detection of an exomoon would give insight into planetary formation and possibly increase the habitable real estate in a planetary system. Current telescopes are not capable of spatially resolving an exoplanet and its exomoon, or of separating the two blended spectra in a combined light measurement. However, previous work has shown that there is a wavelength dependent photometric centroid shift between a planet and its moon due to the weighted nature of the center of light (Agol et al. 2015). This spectroastrometric shift is highest in bands where the planet is dim and the moon is relatively bright, which can happen if it differs compositionally from its planet.

As part of the "Finding the Needles in the Haystacks" project, we generated a realistic spatial / spectral model of an Earth-like exomoon orbiting a warm Jupiter in the habitable zone of a Sun-like star, including plausible exozodiacal dust structure. Preliminary results show that the presence of an Earth-like exomoon can produce centroid shifts greater than a milliarcsecond at some wavelengths, enabling the detection of the Earth-like exomoon even in the presence of dust. However, extracting the spectrum of the Earth-like exomoon proved challenging, even when employing a simple telescope simulation devoid of coronagraphic effects, and further work will be needed to determine if it is possible even with 12-meter-class space telescopes.

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**Contributing team(s):** The Haystacks Team

## 108 – Gas and Dust Content in Distant Galaxies

### 108.01 – The Evolutionary Connection Between $z \sim 2-3$ Submillimeter Galaxies and AGN as Probed by Molecular Gas Excitation

Theoretical work has suggested that active galactic nuclei (AGN) play an important role in quenching star formation in massive galaxies. Direct evidence for AGN affecting the molecular ISM has so far been limited to detections of molecular outflows in low-redshift systems and extreme excitation regions which represent a tiny fraction of the total gas. Indirect evidence for AGN's impact on their host galaxies' cold gas phase may be provided by measurements of the gas excitation and dynamics. At  $z \sim 2-3$ , the peak epoch of star formation and AGN activity, previous observations of the CO(1-0) line revealed that submillimeter galaxies (SMGs) have multi-phase molecular gas, including substantial reservoirs of cold-phase gas. However, the entirety of the molecular gas in AGN-host galaxies appears highly excited, potentially supporting an evolutionary connection between these two populations. I will present a new VLA sample that nearly doubles the number of CO(1-0) detections in  $z \sim 2-3$  SMGs and AGN-host galaxies that allows us to better compare the cold gas properties of these systems and further investigate evidence for the effects of AGN on the star-forming molecular gas.

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### 108.02D – The Luminous Polycyclic Aromatic Hydrocarbon Emission Features: Applications to High Redshift Galaxies and Active Galactic Nuclei

For decades, significant work has been applied to calibrating emission from the ultra-violet, nebular emission lines, far-infrared, X-ray and radio as tracers of the star-formation rate (SFR) in distant galaxies. Understanding the exact rate of star-formation and how it evolves with time and galaxy mass has deep implications for how galaxies form. The co-evolution of star-formation and supermassive black hole (SMBH) accretion is one of the key problems in galaxy formation theory. But, many of these SFR indicators are influenced by SMBH accretion in galaxies and result in unreliable SFRs. Utilizing the luminous polycyclic aromatic hydrocarbon (PAH) emission features, I provide a new robust SFR calibration using the luminosity emitted from the PAHs at  $6.2 \mu\text{m}$ ,  $7.7 \mu\text{m}$  and  $11.3 \mu\text{m}$  to solve this. The PAH features emit strongly in the mid-infrared (mid-IR;  $5-25 \mu\text{m}$ ) mitigating dust extinction, containing on average 5-10% of the total IR luminosity in galaxies. I use a sample of 105 star-forming galaxies covering a range of total IR luminosity,  $L_{\text{IR}} = L(8-1000 \mu\text{m}) = 10^9 - 10^{12} L_{\odot}$  and redshift  $0 < z < 0.4$ , with mid-IR spectroscopy from the *Spitzer* Infrared Spectrograph (IRS), and data covering other SFR indicators (H $\alpha$  emission and rest-frame  $24 \mu\text{m}$  continuum emission). The PAH luminosity correlates linearly with the SFR as measured by the H $\alpha$  luminosity (corrected for attenuation using the mono-chromatic rest-frame  $24 \mu\text{m}$  emission), with a tight scatter of  $< 0.15$  dex. The scatter is comparable to that between SFRs derived from the Pa $\alpha$  and dust-corrected H $\alpha$  emission lines. We present a case study in advance of *JWST*, which will be capable of measuring SFRs (from  $8 \mu\text{m}$  rest-frame photometry, i.e. PAHs) in distant galaxies ( $z \leq 2$ ) with *JWST*/MIRI to SFRs as low as  $\sim 10 M_{\odot} \text{yr}^{-1}$ , because the PAH features are so bright. We use *Spitzer*/IRS observations of PAH features in lensed star-forming galaxies at  $1 < z < 3$  to demonstrate the utility of the PAHs to derive SFRs that agree with those available from Pa $\alpha$ . This new SFR indicator will be useful for probing the peak of the SFR density in the universe ( $1 < z < 3$ ) and for studying the co-evolution of star-formation and supermassive blackhole accretion contemporaneously in a galaxy.

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### 108.03 – Dust-obscured star formation in the Frontier Fields: New observations from the Large

## Millimeter Telescope

Millimeter observations are crucial to complete the census of star formation in the Universe since we know that the majority occurs behind dust. We present a new 1.1 mm survey of two of the *HST* Frontier Fields clusters taken with AzTEC on the Large Millimeter Telescope. The clusters act as cosmic telescopes to amplify lower-luminosity galaxies, probing further down the millimeter luminosity function than possible with blank-field observations, and detecting dust in galaxies with star formation rates as low as <10 solar masses per year. We present our deep number counts, including detailed simulations to account for the magnifications, and the multi-wavelength properties of our millimeter detections. We discuss the nature of these sources relative to previous (sub)millimeter surveys. Finally, we highlight the discovery of dust in multiply-imaged systems that allows us to measure the dust-obscured star formation in the typical galaxies that dominated the star formation rate density.

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### 108.04 – The role of AGN and star-forming in powering dusty galaxies

I will summarize recent work on understanding the relative role of AGN and star-formation in powering the IR emission of galaxies. The approach is two pronged. First, comparing GADGET+Sunrise hydrodynamic simulations with observations of IR-luminous galaxies at  $z \sim 0.3-3$ . Through this, we assess the relative roles of stars and AGN in heating the dust and test explicitly how well do the emergent IR SEDs encode this information. The second approach is to use our new MCMC-based galaxy evolution modelling code, SurveySim, to model the evolution of the luminosity function of IR galaxies, while the relative role of star-forming galaxies, AGN, and composites are fitting parameters.

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### 108.05D – COPSS: The CO Power Spectrum Survey

Molecular gas is a vital component of galactic evolution and star formation, but its abundance in normal star-forming galaxies in the early Universe is poorly understood. Direct detection methods have been able to probe only the most luminous of galaxies at  $z \sim 3$ , missing the vast population of Milky Way progenitors and "building block" galaxies that are expected to bear the bulk of the molecular gas of the early Universe. Using the technique of "intensity mapping", where measurements of different 3D Fourier modes are used to construct a power spectrum, these smaller galaxies can be detectable as an integrated ensemble.

We present results from the CO Power Spectrum Survey (COPSS), an intensity mapping experiment performed with the Sunyaev-Zel'dovich Array (SZA). The SZA, a  $3.5\text{m} \times 8$ -element subset of the Combined Array for Research in Millimeter-wave Astronomy, is capable of observing CO ( $J=1 \rightarrow 0$ ) at  $z=2.3-3.3$ . We present final results from the first phase of this project, utilizing an archival dataset (covering 44 fields in 1400 hours observing time). With these data, we constrain the CO power spectrum to  $P_{\text{CO}} < 2.6 \times 10^4 \mu\text{K}^2 (\text{Mpc}/h)^3$  at  $z \sim 3$ , excluding the model of Lidz et al. (2011) and putting significant constraints on one of two models from Pullen et al. (2013) at this redshift. With this limit, we are able to constrain the cosmic molecular gas density to  $\rho_{\text{H}_2}(z \sim 3) < 2.8 \times 10^8 M_{\odot} \text{Mpc}^{-3}$ . We also present current results from the second phase of this project, a 5000-hour observing campaign with the SZA, which increases our sensitivity by more than an order of magnitude.

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**Contributing team(s):** SZA, CARMA, COPSS

### 108.06 – The evolution of morphology and star

## formation across 12 Gyrs: Quiescent disks or dust-obscured star formation?

The average morphology of the most massive galaxies change dramatically with cosmic time. At  $z > 1.5$ , the most massive galaxies are characterized by an exponential light distribution, while galaxies at lower redshift are spheroidal with a de Vaucouleur light profile. This morphological transformation is accompanied by a drastic change in star formation activity. The mechanism(s) responsible for these two transformations are unknown. This work combines ALMA observations of the gas and dust content with CANDELS optical/NIR data of five carefully selected samples of galaxies. Using a mean abundance matching technique, each of the five samples contain galaxies that are likely to be the progenitors of a galaxy of a given stellar mass at  $z=0$ . Preliminary results suggests that for a given mass sample, the median star formation activity decreases at an earlier epoch than the change of median morphology (as measured by the Sersic index). This is more pronounced for progenitors of the most massive descendants. The implication is that at redshifts  $z \sim 1-2$  there should be a large population of quiescent disk galaxies. An alternative is that these disk galaxies enter a phase of dust-obscured star formation. This possibility will be tested with the ALMA submm observations.

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**Contributing team(s):** CANDELS Team

## 109 – Intergalactic Medium, QSO Absorption Line Systems

### 109.01 – Understanding the physics driving the values of Lyman-alpha forest bias parameters

With the advancement of Lyman-alpha forest power spectrum measurements to larger scales and to greater precision, it is crucial that we also improve our understanding of the bias between the measured flux and the underlying matter power spectrum, especially for future percent level cosmology constraints. In order to develop an intuition for the physics driving the values of the density and velocity bias parameters of the Lyman-alpha forest, we have run a series of hydrodynamic SPH simulations to test existing approximations found in the literature. Through a series of progressively more realistic scenarios, we first introduce flux based on the Fluctuating Gunn Peterson Approximation, just using the density fields, then introduce redshift space distortions, as well as thermal broadening, and finally, analyzing the full hydrodynamic part of the simulations. We find surprising agreement between the analytical approximations developed by Seljak (2012) and the numerical methods in the limit of linear redshift space-distortions and no thermal broadening. Specifically, we find that the prediction of the analytical velocity bias expression is exact in the limit of no thermal broadening, and speculate that the measurement of this bias along with a small-scale measurement of the flux PDF, could yield a possible probe of the thermal state of the IGM. A deeper understanding of the large-scale Lyman-alpha biasing will also help us in using the large-scale clustering of the forest as a cosmological probe beyond baryon acoustic oscillations.

**Author(s):** Agnieszka M Cieplak<sup>1</sup>, Anze Slosar<sup>1</sup>

**Institution(s):** 1. Brookhaven National Laboratory

### 109.02 – Where Do Galaxies Spend Their Time? The Evolving Environment of Galaxies and Their CGM

We use a new method to study the changing environment in which galaxies and their associated circumgalactic medium evolve. We have developed a structure finding algorithm which uses the rate of change of the density gradient to self-consistently parse and follow the evolution of groups/clusters, filaments and voids in large scale simulations. We use this to map the evolution of the baryon gas phase distribution and the star formation history within the different structures. This examination yields new insights into the location of star forming regions and the gas phase distribution within the filamentary environment. Although the majority of the WHIM is associated with filaments, their multiphase nature and the fact that

star formation occurs in condensed gas regions both advise against conflating the filamentary environment with the WHIM. We track the path of star forming halos through the Cosmic Web to expose their environmental history, revealing the multiphase nature and time-dependence of the physical environment of galaxies and their associated circumgalactic medium.

**Author(s):** L. A. Phillips<sup>1</sup>, Ali Snedden<sup>1</sup>, Jared Coughlin<sup>1</sup>, Grant James Mathews<sup>1</sup>, In-Saeng Suh<sup>1</sup>

**Institution(s):** 1. *University of Notre Dame*

### 109.03D – The relationships between galaxies/AGN and the circum-/intergalactic medium at $z < 1$

The growth and evolution of galaxies is governed by gas accretion from circum-/intergalactic gas reservoirs and satellites that is regulated by feedback from stars and active galactic nuclei. To constrain the relationship between these gas reservoirs and galaxy properties, I have carried out deep and highly complete surveys of several thousand galaxies in fields with high quality absorption spectra of background quasars from the Cosmic Origins Spectrograph. The survey results imply that (1) highly ionized, heavy-element enriched gas traced by OVI absorption primarily arise in low-mass, gas-rich galaxy groups rather than the warm-hot phase of the intergalactic medium and that (2) galaxies with nearby neighbors exhibit more extended OVI absorbing gas than isolated galaxies. Together, these observations suggest that galaxy and group interactions play a role in stripping bound, heavy element enriched halo gas to enrich the intergalactic medium. In addition, I carried out the first large survey of circumgalactic gas around active galactic nuclei (AGN) and quasars. The cool, heavy-element enriched gas content of AGN and quasar host halos is strongly correlated with AGN luminosity, and the gas exhibit extreme kinematics with velocity spread inconsistent with gas bound to the AGN host. These observations provide tantalizing hints at the widespread impact of AGN feedback on the extended gas reservoirs around galaxies.

**Author(s):** Sean Johnson<sup>2</sup>, Hsiao-Wen Chen<sup>2</sup>, John S. Mulchaey<sup>1</sup>

**Institution(s):** 1. *The Observatories of the Carnegie Institution for Science*, 2. *The University of Chicago*

### 109.04 – New observations directly measuring the full continuous sizes of high redshift damped Ly $\alpha$ systems

The formation and evolution of galaxies requires large reservoirs of cold, neutral gas. The damped Lyman- $\alpha$  systems (DLAs), seen in absorption towards distant quasars and gamma ray bursts, are predicted to be the dominant reservoirs for this gas. Detailed properties of DLAs have been studied extensively for decades with great success. However, their size, fundamental in understanding their nature, has remained elusive, as quasar and gamma ray burst sightlines only probe comparatively tiny areas of the foreground DLAs. Here, we introduce a new approach to measure the full extent of DLAs in the sightlines to extended background sources. We present the discovery of  $z \sim 2$  DLAs with column densities as high as  $\log N(\text{HI}) = 21.1 \pm 0.4 \text{ cm}^{-2}$  covering 90–100% of the luminous extent of background galaxies. Estimates of the sizes of the background galaxies range from a minimum of a few kpc<sup>2</sup>, to  $\sim 100 \text{ kpc}^2$ , and demonstrate that high-column density neutral gas can span continuous areas  $10^8$ – $10^{10}$  times larger than previously explored in quasar or gamma ray burst sightlines. The DLAs are from our pilot survey that searches Lyman break and Lyman continuum galaxies at high redshift. The low luminosities, large sizes, and mass contents ( $\sim 10^6$ – $10^9 M_\odot$ ) implied by the early data suggest that DLAs contain the necessary fuel for galaxies, with many systems consistent with relatively massive, low-luminosity primeval galaxies.

**Author(s):** Jeff Cooke<sup>2</sup>, John O'Meara<sup>1</sup>

**Institution(s):** 1. *Saint Michaels College*, 2. *Swinburne University*

### 109.05 – Photon underproduction crisis and the redshift evolution of escape fraction of hydrogen ionizing photons from galaxies

In the standard picture, the only sources of cosmic UV background are the quasars and the star forming galaxies. The hydrogen ionizing

emissivity from galaxies depends on a parameter known as escape fraction ( $f_{\text{esc}}$ ). It is the ratio of the escaping hydrogen ionizing photons from galaxies to the total produced by their stellar population. Using available multi-wavelength and multi-epoch galaxy luminosity function measurements, we update the galaxy emissivity by estimating a self-consistent combination of the star formation rate density and dust attenuation. Using the recent quasar luminosity function measurements, we present an updated hydrogen ionizing emissivity from quasars which shows a factor of  $\sim 2$  increase as compared to the previous estimates at  $z < 2$ . We use these in a cosmological radiative transfer code developed by us to generate the UV background and show that the recently inferred high values of hydrogen photoionization rates at low redshifts can be easily obtained with reasonable values of  $f_{\text{esc}}$ . This resolves the problem of 'photon underproduction crisis' and shows that there is no need to invoke non-standard sources of the UV background such as decaying dark matter particles. We will present the implications of this updated quasar and galaxy emissivity on the values of  $f_{\text{esc}}$  at high redshifts and on the cosmic reionization. We will also present the effect of the updated UV background on the inferred properties of the intergalactic medium, especially on the Lyman alpha forest and the metal line absorption systems.

**Author(s):** Vikram Khairi<sup>1</sup>, Raghunathan Srianand<sup>1</sup>

**Institution(s):** 1. *Inter-University Centre for Astronomy and Astrophysics*

### 109.06 – Analyzing the Evolution of MgII and CIV Absorbers Observed in High Resolution with the Largest Optical Telescopes

We present a detailed measurement of the redshift number density of MgII and CIV absorbers as measured in archival VLT/UVES and Keck/HIRES spectra. This survey examines 432 VLT/UVES spectra from the UVES SQUAD and 170 Keck/HIRES spectra from the KODIAQ group, allowing for detections of MgII absorbers from  $0.08 < z < 2.57$  and CIV absorbers from  $0.94 < z < 5.45$ . We employ an accurate, automated approach to line detection which consistently detects absorption lines with equivalent widths  $W_r < 0.02 \text{ \AA}$  in  $S/N = 40$  spectra. We then measure the equivalent widths, apparent optical depth column densities, and velocity widths for each absorbing system. This results in a complete sample of strong ( $W_r > 0.3 \text{ \AA}$ ) and weak ( $W_r < 0.3 \text{ \AA}$ ) MgII/CIV absorbers, allowing for accurate determination of the number density of these absorbers across cosmic time. Preliminary results show power-law behavior for both the MgII and CIV equivalent width distribution functions down to small equivalent widths, implying self-similar absorbing structures. This power law is smooth and shallow at low redshifts ( $z < 1.5$ ), but has a kink at redshifts between  $1.5 < z < 2.5$  due to an excess of strong absorbers compared to weak absorbers. At high redshift ( $z > 2.5$ ), we see fewer strong CIV absorbers, truncating the distribution at the largest equivalent widths. These trends seem to follow our general idea of the history of cosmic metal enrichment, with an evolutionary transition occurring around the time of the global star formation peak of the universe.

**Author(s):** Nigel Mathes<sup>1</sup>, Christopher W. Churchill<sup>1</sup>, Michael Murphy<sup>2</sup>

**Institution(s):** 1. *New Mexico State University*, 2. *Swinburne University of Technology*

**Contributing team(s):** UVES SQUAD, KODIAQ

### 109.07 – Spectral Deception: Understanding Misleading Spectral Features Using Simulations

Quasar absorption line studies are our primary source of information for revealing the state of the intergalactic and circumgalactic media (IGM and CGM). Using quasars as bright background sources, tenuous intervening gas clouds imprint absorption features in the resulting spectra providing clues to the clouds' density, temperature, metallicity, and ionization state. Correctly interpreting these spectra is crucial to understanding the distribution of baryons in the universe.

Using the Trident code to generate synthetic spectra from high-resolution cosmological hydrodynamical simulations, we examine how spectral noise, instrument smoothing, and certain

configurations of gas can mask the true nature of gas absorbers. We demonstrate how cold gas filaments can create broad spectral features mimicking hot absorbers, and chimneys of hot gas viewed side-on appear as narrow, cold absorbers. Understanding how commonly these conditions occur is critical for correctly characterizing the physical conditions in the media galactic.

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**Institution(s):** 1. California Institute of Technology, 2. Michigan State University, 3. University of Edinburgh

### 109.08 – A Deep Search for Galaxies Associated With Very Low-redshift Metal-line Absorbers: The Circumgalactic Media of Dwarf Galaxies and Environmental Effects

I will present results from a deep survey of the galaxy environments surrounding HST/COS sightlines using SDSS and new followup ground-based observations. Our work reveals an extended, metal-enriched circumgalactic medium (CGM) that persists well beyond the virial radius of any potential host galaxy, reinforced by the depth of our galaxy data, which are complete to  $L \sim 0.02 L^*$ . Furthermore, we present evidence that environmental effects manifest in the CGM even at densities commensurate with moderately populated groups. These effects might reflect the same mechanisms behind environmental quenching that eventually transforms galaxies into red-and-dead early types.

**Author(s):** Joseph Burchett<sup>3</sup>, Todd M. Tripp<sup>3</sup>, Rongmon Bordoloi<sup>1</sup>, Christopher Willmer<sup>2</sup>

**Institution(s):** 1. MIT, 2. University of Arizona, 3. University of Massachusetts

## 110 – Variable Stars, White Dwarfs

### 110.01 – Photometric Variability of a Large Sample of Be Stars

Be stars are main sequence, rapidly rotating B-type stars with emission lines in their spectra attributed to a gaseous circumstellar disk. Variability across a wide range of timescales (from hours to decades) is observed in this class of objects, including stellar pulsations, outbursts, oscillations in the circumstellar disk, and the total disappearance (or reappearance) of the disk. Using data from the KELT survey (Kilodegree Extremely Little Telescope; a wide-field photometric survey designed to find transiting exoplanets with high precision of  $\sim 1\%$  and baselines up to 10 years for  $\sim 3$  million objects), we investigate the light curves of  $\sim 300$  known Be stars and find many systems exhibiting the aforementioned types of variability. Many of these Be stars also have existing spectra simultaneous with the KELT photometry, providing a unique look into the correlation between spectroscopic features and photometric variability, and allowing us to study how these observables relate to the underlying physical processes present in Be stars.

**Author(s):** Jonathan Labadie-Bartz<sup>1</sup>, Joshua Pepper<sup>1</sup>

**Institution(s):** 1. Lehigh University

**Contributing team(s):** the KELT Collaboration

### 110.02 – Formation and Asteroseismology of Extremely Low-mass White Dwarfs

A handful of extremely low-mass white dwarfs (ELM WD,  $M < 0.2 M_{\odot}$ ) have been discovered recently to exhibit g-mode pulsations, extending the classic DA instability strip to much smaller mass. One particular ELM WD (SDSS J111215.82+111745.0) has been observed to pulsate at periods so short that the pulsations may be p-modes, making this star unique among all WD pulsators. Since the ELM WDs are thought to be formed only through binary, and not single star evolution, the observed periods give the opportunity to constrain the interiors of these post-common-envelope or post-Roche-lobe-overflow WD through asteroseismology. I will discuss our recent efforts to construct models of these ELM WD pulsators using the MESA stellar evolution code to carry out binary evolution. The relative size of the solar-composition envelope

to helium core is expected to vary significantly with stellar mass and orbital period. This variation in structure is reflected in the oscillation mode periods for the models. Lastly, I will discuss constraints on the interior structure of J1112 from seismology.

**Author(s):** Meng Sun<sup>1</sup>, Phil Arras<sup>1</sup>

**Institution(s):** 1. University of Virginia

### 110.03D – The Long-Term Outcomes of Double White Dwarf Mergers

Binary star systems composed of two white dwarfs are a natural outcome of stellar evolution. Angular momentum losses from gravitational wave radiation cause the binary system's orbit to shrink until the two white dwarfs merge. The final outcome of the merger depends on the masses of the white dwarfs. Some potential outcomes, such as supernova explosions, may occur during or soon after the merger. Other outcomes, which I will refer to as “long-term” outcomes, occur as the merger remnant cools and its structure adjusts to the new state created during the energetic merger.

In my dissertation, I quantitatively explore the long-term outcomes of the mergers of two white dwarfs. I focus primarily on the formation of neutron stars via accretion-induced collapse and the formation of two types of unusual stars, the single sub-dwarf B stars (hot, core helium fusing stars) and the R Coronae Borealis stars (cool, carbon-rich giant stars). Beginning with the results from my previous simulations of the short-lived viscous disk initially present in these remnants, I use the state-of-the-art MESA stellar evolution code to follow their thermal evolution.

This work improves the quantitative understanding of which white dwarf binaries lead to a particular outcome and better characterizes the observational signatures of these outcomes. For systems that will undergo accretion-induced collapse, these simulations yield improved progenitor models that can then be used to explore the collapse and formation of a neutron star.

**Author(s):** Josiah Schwab<sup>1</sup>

**Institution(s):** 1. University of California

### 110.04 – On the Discovery of Massive ZZ Ceti Variables and the Peculiar Light Curve of SDSS J1529

We report the discovery of pulsations in three hydrogen atmosphere white dwarfs with masses greater than one solar mass. We identified these white dwarfs through SDSS Data Release 7 spectroscopy. All three objects show monoprotic oscillations with periods ranging from 203 s to 11 min. With follow-up observations of the confirmed ZZ Ceti stars, it should be possible to detect lower amplitude pulsation modes in order to conduct an in depth asteroseismological analysis and estimate the fraction of their core mass that is crystallized. We also present and discuss the peculiar light curve of J1529, which shows eclipse-like events every 38 min. We compare the light curve of J1529 to that of GD 394 which has similar characteristics (despite being four times hotter) which are thought to be caused by a metal-rich dark spot on the star's surface.

**Author(s):** Brandon Curd<sup>1</sup>, Mukremin Kilic<sup>1</sup>, Alex Gianninas<sup>1</sup>

**Institution(s):** 1. University of Oklahoma

### 110.05 – Study of Eclipsing Binary Systems NSVS 732240 and NSVS 5726288

We present our analysis of the photometric data collected on two  $\beta$  Lyrae type eclipsing binary systems: NSVS 732240 and NSVS 5726288. This photometry was obtained using the 16" telescope at the Ball State University Observatory as well as the 0.9-meter SARA telescope at Kitt Peak National Observatory. The analysis consisted of modeling the systems using the Wilson-Devinney code to determine the characteristics of the stellar components. The analysis indicates that NSVS 732240 is a semi-detached system wherein the primary component fills its Roche lobe while NSVS 5726288 is a detached system. There are indications that NSVS 732240 may have an accretion disk, a relatively uncommon feature in  $\beta$  Lyrae type systems that indicate that mass is being transferred between the component stars. Therefore, further study of this system may present

a unique opportunity to study mass transfer in  $\beta$  Lyrae type systems.

**Author(s):** Matthew Knotel<sup>1</sup>

**Institution(s):** 1. Florida Institute of Technology

### 110.06D – Shifting the Starspot Paradigm: Imaging Global Magnetic Structures

Stellar magnetism exists in stars across the HR diagram and fuels stellar activity (e.g. flares and starspots). This magnetism affects measurements of fundamental stellar parameters, such as radius and temperature, leading to inaccurate mass and age estimates. In order to better determine stellar parameters, we aim to understand how magnetically-suppressed convection presents as cool regions across the stellar surface. In the standard "spot paradigm" of localized starspots blemishing an otherwise featureless surface, we use precision *Kepler* data and light curve inversion to study stellar differential rotation and starspot evolution. Contrastingly, by imaging interferometric data collected with the Michigan Infrared Combiner (MIRC) at GSU's Center for High Angular Resolution Astronomy (CHARA) Array, we detect large-scale magnetic structures across the surface of  $\zeta$  Andromedae. These global regions of suppressed convection cover a large fraction of the surface, likely changing the atmospheric structure of the photosphere and impacting stellar parameter estimates. The large-scale features are at best ambiguous to interpret via established techniques that rely on rotational modulation of spots (e.g. light curve inversion and Doppler imaging). We seek to identify a class of targets where the "spot paradigm" breaks down and gives new insights into a range of phenomena such as long-term changes in flux for active stars, anomalous proper motion of spots derived from precision photometry, and the nature of the stellar dynamo of stars with large convective envelopes.

**Author(s):** Rachael M. Roettenbacher<sup>1</sup>, John D. Monnier<sup>1</sup>

**Institution(s):** 1. University of Michigan

### 110.07 – Finding Every Stellar Flare in the Kepler Light Curves

Data from the Kepler and K2 missions continue to challenge our understanding of stellar activity, from complex morphologies of flares on low-mass stars, to rates of "superflares" on stars like the Sun. I will present results from the first uniform search for stellar flares in every Kepler light curve. This is the largest sample of white-light stellar flares ever assembled. Our analysis includes long- and short-cadence data from over 200,000 stars, and will shed light on the possibility of using flares as a stellar age indicator. I will also describe the exciting prospects that K2, TESS, and LSST hold for studying stellar flares in a Galactic context.

**Author(s):** James R. A. Davenport<sup>1</sup>

**Institution(s):** 1. Western Washington University

## 111 – Dwarf and Irregular Galaxies

### 111.01 – Evidence of Cosmic Accretion in Local Tadpole Galaxies

Star formation in galaxies over cosmic time may be driven by gas accretion from the cosmic web. Spectra of local extremely metal-poor galaxies (XMPs), obtained using the Gran Telescopio Canarias, show oxygen abundances that decrease by a factor of 5 to 10 in the main star-forming regions compared with the disks in 9 of 10 observed galaxies. The results suggest that the galaxies have accreted metal-poor gas in the starburst regions. Tadpole galaxies, which have a main star-forming head and a tail, are common at high redshift but rare locally. Local tadpoles tend to be XMPs. We present multiband HST WFC3 observations of Kiso 5639, one of the tadpole XMPs in our GTC sample. There are faint extended H  $\alpha$  filaments, and dense star clusters in the midst of a powerful starburst. The clusters, with log masses of 4 to 5, are reminiscent of those found in other dwarf irregular galaxies where impacting gas streams have been suggested.

**Author(s):** Debra M. Elmegreen<sup>10</sup>, Bruce Elmegreen<sup>4</sup>, Jorge Sanchez Almeida<sup>3</sup>, Casiana Munoz-Tunon<sup>3</sup>, Marc Rafelski<sup>2</sup>, John S. Gallagher<sup>9</sup>, Jairo Mendez-Abreu<sup>8</sup>, R. Amorin<sup>5</sup>, M. Filho<sup>3</sup>, Y. Ascasibar<sup>7</sup>, P. Papaderos<sup>1</sup>, J. Vilchez<sup>6</sup>, E. Perez-Montero<sup>6</sup>

**Institution(s):** 1. Centro de Astrofisica da Universidade do Porto, 2. Goddard Space Flight Center, 3. IAC, 4. IBM T.J. Watson Research Center, 5. INAF, 6. Instituto de Astrofisica de Andalucia, 7. Universidad Autonoma de Madrid, 8. University of St. Andrews, 9. University of Wisconsin, 10. Vassar College

### 111.02 – Exploding Satellites - The Tidal Debris of the Ultra-Faint Dwarf Galaxy Hercules

The ultra-faint satellite galaxy Hercules has a strongly elongated morphology and a tentative radial velocity gradient along its extent. Recent detections of tidal features 0.25-1 deg from its center suggest that Hercules may be dissolving under the Milky Way's gravitational influence, and hence would be a tidal stream in formation. Using Bayesian inference modeling in combination with N-body simulations, I show that Hercules has to be on a very eccentric orbit within the Milky Way for such a scenario. Detailed kinematic investigation of this object will enable us to understand the dissolution of dwarf galaxies in unprecedented detail. It will also give us strong constraints on the mass of the Milky Way within 140 kpc, and, most importantly, the non-sphericity of its dark matter halo.

**Author(s):** Andreas Hans Wilhelm Kupper<sup>1</sup>, Michelle Collins<sup>4</sup>, Steffen Mieske<sup>2</sup>, Erik Jon Tollerud<sup>3</sup>

**Institution(s):** 1. Columbia University, 2. European Southern Observatory, 3. Space Telescope Science Institute, 4. University of Surrey

### 111.03D – Dwarf galaxy evolution within the environments of massive galaxies

Understanding galaxy evolution depends on connecting large-scale structure determined by the  $\Lambda$ CDM model with, at minimum, the small-scale physics of gas, star formation, and stellar feedback. Formation of galaxies within dark matter halos is sensitive to the physical phenomena occurring within and around the halo. This is especially true for dwarf galaxies, which have the smallest potential wells and are more susceptible to the effects of gas ionization and removal than larger galaxies. At dwarf galaxies scales comparisons of dark matter-only simulations with observations has unveiled various differences including the core-cusp, the missing satellites, and the too-big-to-fail problems. We have run a new suite of hydrodynamical simulations using the ART code to examine the evolution of dwarf galaxies in massive host environments. These are cosmological zoom-in simulations including deterministic star formation and stellar feedback in the form of supernovae feedback, stellar winds, radiation pressure, and photoionization pressure. We simulate galaxies with final halo masses on the order of  $10^{12} M_{\odot}$  with high resolution, allowing us to examine the satellite dwarf galaxies and local isolated dwarf galaxies around each primary galaxy. We analyzed the abundance and structure of these dwarfs specifically the velocity function, their star formation rates, core creation and the circumgalactic medium. By reproducing observations of dwarf galaxies in simulations we show how including baryons in simulations relieves tensions seen in comparing dark matter only simulations with observations.

**Author(s):** Kenza S. Arraki<sup>1</sup>, Anatoly A. Klypin<sup>1</sup>, Daniel Ceverino<sup>3</sup>, Sebastian Trujillo-Gomez<sup>1</sup>, Joel R. Primack<sup>2</sup>

**Institution(s):** 1. New Mexico State University, 2. UC Santa Cruz, 3. Universidad Autonoma de Madrid

### 111.04 – WSRT HI imaging of candidate gas-bearing dark matter halos in the Local Group

A long standing problem in cosmology is the mismatch between the number of low mass dark matter halos predicted by simulations and the number of low mass galaxies observed in the Local Group. We recently presented a set of isolated ultra-compact high velocity clouds (UCHVCs) identified within the dataset of the Arecibo Legacy Fast ALFA (ALFALFA) HI line survey that are consistent with representing low mass gas-bearing dark matter halos within the Local Group (Adams+ 2013). At distances of  $\sim 1$  Mpc, the UCHVCs

have HI masses of  $\sim 10^5$  Msun and indicative dynamical masses of  $\sim 10^7$  Msun. The HI diameters of the UCHVCs range from 4' to 20', or 1 to 6 kpc at a distance of 1 Mpc. We have selected the most compact and isolated UCHVCs with the highest average column densities as representing the best galaxy candidates. These systems have been observed with the Westerbork Synthesis Radio Telescope (WSRT) to enable higher spatial resolution studies of the HI distribution. From these data, the sources break into two clear categories. Two of the sources maintain a smooth HI morphology at higher resolution, show a velocity gradient and have the highest peak column densities of the sample, indicating they are good candidates to represent gas in dark matter halos. In fact, one of these sources, AGC 198606, has a tentative stellar counterpart detection (Janesh+ 2015). Nine of the sources break into clumps at higher angular resolution, show no ordered velocity motion, and have significantly lower peak column densities, indicating they are likely Galactic halo HI clouds. One source straddles the two categories with a relatively smooth HI morphology and some evidence for ordered velocity motion while having a lower peak column density. These observations show that higher resolution HI data is a good way to address the galaxy hypothesis for isolated HI clouds, and future HI surveys with phased-array feeds on interferometers, such as Apertif, will be able to directly detect and discriminate among these sources.

**Author(s):** Elizabeth A. Adams<sup>1</sup>, Tom Oosterloo<sup>1</sup>, John M. Cannon<sup>3</sup>, Riccardo Giovanelli<sup>2</sup>, Martha P. Haynes<sup>2</sup>

**Institution(s):** 1. *ASTRON*, 2. *Cornell University*, 3. *Macalester College*

## 111.05D – H I Structure and Kinematics in the LITTLE THINGS Dwarf Galaxies

We present a catalog and analysis of the properties of neutral hydrogen gas (H I) holes/shells in the LITTLE THINGS (Local Irregulars That Trace Luminosity Extremes, The H I Nearby Galaxy Survey) galaxies. LITTLE THINGS uses high angular resolution ( $\sim 6''$ ), high spectral resolution ( $\leq 2.6$  km s<sup>-1</sup>), and high sensitivity ( $\leq 1.1$  mJy beam<sup>-1</sup> channel<sup>-1</sup>) H I observations of 41 nearby ( $\leq 10.3$  Mpc) gas-rich dwarf galaxies. We are interested in dwarf galaxies because they are the most common types of galaxies in the local universe and they are believed to be the first galaxies to form in the universe. Here we study the interaction between star formation evolution and the interstellar medium from which stars form. In the sample, we detected 306 holes with sizes ranging from about 38 pc to 2.3 kpc, the expansion rates varying from 5 to 30 km s<sup>-1</sup>, and the estimated kinetic age varying from 1 Myr to 127 Myr. The distribution of the holes per unit area is found nearly constant both inside (51%) and outside (49%) of the V-band break radius, where the radial luminosity function changes slope. We derived surface and volume porosity and found that porosity doesn't correlate with star formation rate (SFR) for the LITTLE THINGS sample. Assuming that the holes are formed from the stellar feedback, we calculated the supernova rate (SNR) and the SFR. We did find a correlation between the SFR calculated from H $\alpha$  (a star formation tracer) and the SFR estimated from the SNR, consistent with hole formation from stellar feedback. The relation between the estimated kinetic ages of the holes with the SNR gives the indication of the star formation history.

**Author(s):** Nau Raj Pokhrel<sup>1</sup>, Caroline E. Simpson<sup>1</sup>

**Institution(s):** 1. *Florida International University*

**Contributing team(s):** LITTLE THINGS team

## 111.06 – Star Formation at Low Metallicity in Local Dwarf Irregular Galaxies

The radial profiles of star formation rates and surface mass densities for gas and stars have been compiled for 20 local dwarf irregular galaxies and converted into disk scale heights and Toomre Q values. The scale heights are relatively large compared to the galaxy sizes ( $\sim 0.6$  times the local radii) and generally increase with radius in a flare. The gaseous Q values are high,  $\sim 4$ , at most radii and even higher for the stars. Star formation proceeds even with these high Q values in a normal exponential disk as viewed in the far ultraviolet. Such normal star formation suggests that Q is not relevant to star formation in dIrrs. The star formation rate per unit area always equals approximately the gas surface density divided by the midplane

free fall time with an efficiency factor of about 1% that decreases systematically with radius in approximate proportion to the gas surface density. We view this efficiency variation as a result of a changing molecular fraction in a disk where atomic gas dominates both stars and molecules. In a related study, CO observations with ALMA of star-forming regions at the low metallicities of these dwarfs, which averages 13% solar, shows, in the case of the WLM galaxy, tiny CO clouds inside much larger molecular and atomic hydrogen envelopes. The CO cloud mass fraction within the molecular region is only one percent or so. Nevertheless, the CO clouds have properties that are similar to solar neighborhood clouds: they satisfy the size-linewidth relation observed in the LMC, SMC, and other local dwarfs where CO has been observed, and the same virial mass versus luminosity relation. This uniforming of CO cloud properties seems to be the result of a confining pressure from the weight of the overlying molecular and atomic shielding layers. Star formation at low metallicity therefore appears to be a three dimensional process independent of 2D instabilities involving Q, in highly atomic gas with relatively small CO cores, activated at a rate given by the local average midplane density.

**Author(s):** Bruce Elmegreen<sup>2</sup>, Deidre Ann Hunter<sup>4</sup>, Monica Rubio<sup>5</sup>, Elias Brinks<sup>6</sup>, Juan R Cortés<sup>3</sup>, Phil Cigan<sup>1</sup>

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## 112 – Extrasolar Planet Atmospheres: Theory I

### 112.01 – Non-grey thermal effects in irradiated planets atmospheres

The large diversity of exoplanets in terms of irradiation temperature, gravity and chemical composition discovered around stars with different properties call for the development of fast, accurate and versatile atmospheric models. We derive a new, non-grey analytical model for the thermal structure of irradiated exoplanets. Using two different opacity bands in the thermal frequency range, we highlight the dual role of thermal non-grey opacities in shaping the temperature profile of the atmosphere. Opacities dominated by lines enable the upper atmosphere to cool down significantly compared to a grey atmosphere whereas opacities dominated by bands lead both to a significant cooling of the upper atmosphere and a significant heating of the deep atmosphere.

We compare our analytical model to a grid of temperature-pressure profiles for solar composition atmospheres obtained with a state-of-the-art numerical model taking into account the full wavelength, temperature and pressure dependence of the opacities. We demonstrate the importance of thermal non-grey opacities in setting the deep temperature of irradiated giant planets atmospheres. In the particular case of highly irradiated planets we show that the presence of TiO in their atmospheres alters both the optical and the thermal opacities. The greenhouse effect – a semi-grey effect – and the “blanketing effect” – an intrinsically non-grey effect – contribute equally to set the deep temperature profile of the planet atmosphere. We conclude that non-grey thermal effects are fundamental to understand the deep temperature profile of hot Jupiters.

Our calibrated analytical model matches the numerical model within 10% over a wide range of effective temperature, internal temperature and gravities and properly predict the depth of the radiative/convective boundary, an important quantity to understand the cooling history of a giant planet. Such a fast and accurate model can be of great use when numerous temperature profiles need to be calculated, such as in atmospheric retrieval calculation, when calculating the long-term evolution of the planet or when performing population synthesis models.

**Author(s):** Vivien Parmentier<sup>3</sup>, Tristan Guillot<sup>2</sup>, Jonathan J. Fortney<sup>3</sup>, Mark S. Marley<sup>1</sup>

**Institution(s):** 1. *NASA Ames research center*, 2. *Obs. de la côte d'azur*, 3. *UCSC*

## 112.02D – Polarimetry of hot-Jupiter systems and radiative transfer models of planetary atmospheres

Thousands of exoplanets and planet candidates have been detected. The next important step in the contexts of astrobiology, planetary classification and planet formation is to characterise them. My dissertation aims to provide further characterisation to four hot Jupiter exoplanets: the relatively well-characterised HD 189733b, WASP-18b which is nearly large enough to be a brown dwarf, and two minimally characterised non-transiting hot Jupiters: HD 179949b and tau Bootis b.

For the transiting planets, this is done through two means. First, published data from previous observations of the secondary eclipse (and transit for HD 189733b) are compared to models created with the Versatile Software for the Transfer of Atmospheric Radiation (VSTAR). Second, new polarimetric observations from the High Precision Polarimetric Instrument are compared to Lambert-Rayleigh polarised light phase curves. For the non-transiting planets, only the polarimetric measurements are compared to models, but toy radiative transfer models are produced for concept. As an introduction to radiative transfer models, VSTAR is applied to the planet Uranus to measure its D/H isotope ratio. A preliminary value is derived for D/H in one part of the atmosphere.

Fitting a single atmospheric model to the transmitted, reflected, and emitted light, I confirm the presence of water on HD 189733b, and present a new temperature profile and cloud profile for the planet. For WASP-18b, I confirm the general shape of the temperature profile. No conclusions can be drawn from the polarimetric measurements for the non-transiting planets. I detect a possible variation with phase for transiting planet WASP-18b but cannot confirm it at this time. Alternative sources to the planet are discussed. For HD 189733b, I detect possible variability in the polarised light at the scale expected for the planet. However, the data are also statistically consistent with no variability and are not matched to the phase of the planet.

**Author(s):** Kimberly Bott<sup>1</sup>, Jeremy Bailey<sup>1</sup>, Lucyna Kedziora-Chudczer<sup>1</sup>, Daniel Cotton<sup>1</sup>, Jonathan Marshall<sup>1</sup>

**Institution(s):** 1. University of New South Wales

## 112.03 – Modeling of hot Jupiter H alpha transmission spectral line

The upper atmosphere of hot Jupiters is subject to the strong stellar radiation field of the host star, which can heat and ionize the gas, as well as excite atoms to higher energy levels. For planets near the parent star, a thick layer of atomic hydrogen may be present, which has now been observed through both Lyman alpha and H alpha absorption of starlight during transit. Motivated by these observations, we revisit the calculations of Christie et al to study the hydrogen level populations in detail, including radiative (de-)excitation, collisional (de-)excitation, collisional ell-mixing processes up to  $n = 6$  states, as well as radiative ionization, recombination and collisional ionization processes. Using the HD 189733b thermal and photoionization equilibrium hydrostatic balance atmosphere model of Christie et al, we find that the 2s state population is dominated by a) creation and destruction channels via np states ( $n > 2$ ), which was not considered previously, and b) 2s to 2p collisional ell-mixing process, which was treated incorrectly. I will show our modeling of H alpha transit depth observation with new level populations module.

**Author(s):** Chenliang Huang<sup>2</sup>, Phil Arras<sup>2</sup>, Duncan Christie<sup>1</sup>

**Institution(s):** 1. University of Florida, 2. University of Virginia

## 112.04D – Microphysics of Exoplanet Clouds and Hazes

Clouds and hazes are ubiquitous in the atmospheres of exoplanets. However, as most of these planets have temperatures between 600 and 2000 K, their clouds and hazes are likely composed of exotic condensates such as silicates, metals, and salts. We currently lack a satisfactory understanding of the microphysical processes that govern the distribution of these clouds and hazes, thus creating a gap between the cloud properties retrieved from observations and the

cloud composition predictions from condensation equilibrium models. In this work we present a 1D microphysical cloud model that calculates, from first principles, the rates of condensation, evaporation, coagulation, and vertical transport of chemically mixed cloud and haze particles in warm and hot exoplanet atmospheres. The model outputs the equilibrium number density of cloud particles with altitude, the particle size distribution, and the chemical makeup of the cloud particles as a function of altitude and particle mass. The model aims to (1) explain the observed variability in “cloudiness” of individual exoplanets, (2) assess whether the proposed cloud materials are capable of forming the observed particle distributions, and (3) examine the role clouds have in the transport of (cloud-forming) heavy elements in exoplanet atmospheres.

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**Institution(s):** 1. Caltech

## 112.05D – The Impact of Clouds and Hazes in Substellar Atmospheres

The formation of clouds significantly alters the spectra of cool substellar atmospheres from terrestrial planets to brown dwarfs. In cool planets like Earth and Jupiter, volatile species like water and ammonia condense to form ice clouds. In hot planets and brown dwarfs, iron and silicates instead condense, forming dusty clouds. Irradiated methane-rich planets may have substantial hydrocarbon hazes. During my thesis, I have studied the impact of clouds and hazes in a variety of substellar objects. First, I present results for cool brown dwarfs including clouds previously neglected in model atmospheres. Model spectra that include sulfide and salt clouds can match the spectra of T dwarf atmospheres; water ice clouds will alter the spectra of the newest and coldest brown dwarfs, the Y dwarfs. These sulfide/salt and ice clouds potentially drive spectroscopic variability in these cool objects, and this variability should be distinguishable from variability caused by hot spots.

Next, I present results for small, cool exoplanets between the size of Earth and Neptune, so-called super Earths. They likely have sulfide and salt clouds and also have photochemical hazes caused by stellar irradiation. Vast resources have been dedicated to characterizing the handful of super Earths accessible to current telescopes, yet of the planets smaller than Neptune studied to date, all have radii in the near-infrared consistent with being constant in wavelength, likely showing that these small planets are consistently enshrouded in thick hazes and clouds. Very thick, lofted clouds of salts or sulfides in high metallicity ( $1000\times$  solar) atmospheres create featureless transmission spectra in the near-infrared. Photochemical hazes with a range of particle sizes also create featureless transmission spectra at lower metallicities. I show that despite these challenges, there are promising avenues for understanding this class of small planets: by observing the thermal emission and reflectivity of small planets, we can break the degeneracies and better constrain the atmospheric compositions. These observations may provide rich diagnostics of molecules and clouds in small planets, in contrast to the limited success to date.

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## 113 – Instrumentation: Space and Ground

### 113.01 – Simulating PSFs for WFIRST and JWST with WebbPSF

Accurate models of a telescope's point spread function are key to predicting its performance and extracting information from observations. Developed at STScI since 2010, WebbPSF is a flexible Python-based PSF simulation tool initially developed for JWST's imaging, spectroscopy, and coronagraphic instruments. We present improvements that allow this tool to simulate PSFs for the WFIRST wide-field imaging mode, as well as additional spectroscopy modes for the NIRSpec, MIRI, and NIRISS instruments on JWST. The WFIRST wide field imaging mode is also the first WebbPSF model to

simulate PSF variation across the entire field of view. These variations are included in the Fraunhofer-domain PSF calculation as Zernike polynomial terms up to  $Z_{22}$ . As WFIRST is still early in its development, high-spatial-frequency wavefront errors (beyond  $Z_{22}$ ) are incorporated using an optical path difference map from another notable 2.4 meter space telescope. Common infrastructure to build simulated optical instruments has been made available as POPPY (Physical Optics Propagation in Python), an open-source library that has seen contributions from users in astronomy and beyond.

**Author(s):** Joseph D. Long<sup>1</sup>, Marshall D. Perrin<sup>1</sup>, Roeland P. Van Der Marel<sup>1</sup>

**Institution(s):** 1. Space Telescope Science Institute

### **113.02 – AdEPT, the Advanced Energetic Pair Telescope for Medium-Energy Gamma-Ray Polarimetry**

The Advanced Energetic Pair Telescope (AdEPT) is being developed as a future NASA/GSFC end-to-end MIDE mission to perform high-sensitivity medium-energy (5–200 MeV) astronomy and revolutionary gamma-ray polarization measurements. The enabling technology for AdEPT is the GSFC Three-Dimensional Track Imager (3-DTI), a large volume gaseous time projection chamber with 2-dimensional micro-well detector (MWD) readout. The low density and high spatial resolution of the 3-DTI allows AdEPT to achieve high angular resolution (~0.5 deg at 67.5 MeV) and, for the first time, exceptional gamma-ray polarization sensitivity. These capabilities enable a wide range of scientific discovery potential for AdEPT. We will discuss several of the key science goals of the AdEPT mission. These include: 1) Explore fundamental processes of particle acceleration in active astrophysical objects, 2) Reveal the magnetic field configuration of the most energetic accelerators in the Universe, 3) Explore the origins and acceleration of cosmic rays and the Galactic MeV diffuse emission, 4) Search for dark matter in the Galactic center, and 5) Test relativity with polarization measurements.

**Author(s):** Stanley D. Hunter<sup>1</sup>, Tonia M. Venters<sup>1</sup>, John Krizmanic<sup>1</sup>, Andrei Hanu<sup>1</sup>, Makoto Sasaki<sup>1</sup>, Andrey Timokhin<sup>1</sup>

**Institution(s):** 1. NASA/GSFC

**Contributing team(s):** The AdEPT Instrument Team

### **113.03 – It may be Possible to Use a Neutron Beam as Propulsion for Spacecraft**

It may be possible to keep Xenon 135 in a Superpositioned state with Xe-136 and Cs 135, the two decay products of Xenon 135. This may be done using a Gamma Ray or an X-ray Laser. At first glance it has the look and feel of yet another Noble Gas Laser. The difference is that it uses Neutron states within the Nucleus. The Neutrons would be emitted with a modulated Gamma or X-ray photon. In essence it may be possible to have a totally new type of Laser---This author calls them "Matter Lasers", where a lower energy photon with fewer Quantum Numbers would be used with a Noble Gas to produce a particle beam with higher energy and more Quantum Numbers. It may be possible to replace cumbersome particle accelerators with this type of Laser, to make mass from energy, via a Neutron Gas. This would be a great technological advance in Rocket Propulsion as well; low mass photon to high mass particle, such as a Higgs particle or a Top Quark. The Xenon 135, could come from a Fission Reactor within the Space Craft, as it is a reactor poison. The workings of an X-ray laser is already known and table top versions of it have been developed. Gamma Ray lasers are already in use and have been tested. A Laser would have a columnated beam with a very precise direction, unlike just a Neutron source which would go in all directions. Of course this beam could be used as a spectroscopic tool as well, in order to determine the composition of the matter that the spacecraft encounters. The spectroscopic tool could look for "Dark Matter" and other exotic types of matter that may occur in outerspace. The spacecraft could potentially reach "near speed of light velocities" in a fairly short time, since the Laser would be firing off massive particles, with great momentum. Lastly the precise Neutron beam could be used as a very powerful weapon or as a way of clearing space debris, since it could "force Nuclear Reactions" onto the object being fired upon, making it the ultimate space weapon, and Propulsion device in one package, using existing technologies,

devices and theories. With this theory, it is now just an Engineering Problem, to make it work, and a great deal of funding. The benefits would be so enormous that this should be given priority.

**Author(s):** Richard M Kriske<sup>1</sup>

**Institution(s):** 1. University of Minnesota

### **113.04D – High angular resolution observations of star-forming regions with BETTII and SOFIA**

High angular resolution observations in the far-infrared are important to understand the star formation process in embedded star clusters where extinction is large and stars form in close proximity. The material taking part in the star forming process is heated by the young stars and emits primarily in the far-IR; hence observations of the far-IR dust emission yields vital information about the gravitational potential, the mass and energy distribution, and core/star formation process. Previous observatories, such as Herschel, Spitzer and WISE lack the angular resolution required to study these dense star forming cores and are further limited by saturation in bright cores.

The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII) is pioneering the path to sub-arcsecond resolution at far-IR wavelengths. This thesis talk discusses the instrumental challenges in building BETTII, as well as results from our SOFIA survey to illustrate the potential of higher-angular resolution observations. The 8m-long two element interferometer is being tested at NASA GSFC and is scheduled for first flight in fall 2016. BETTII will provide 0.5 to 1 arcsecond spatial resolution and spectral resolving power of 10 to 100 between 30 and 90 microns, where most of the dust continuum emission peaks in local star forming regions. It will achieve spatially-resolved spectroscopy of bright, dense cores with unprecedented high definition. This talk focuses on the main challenges and solutions associated with building BETTII: thermal stability, attitude/pointing control, and path length stabilization. In each of these areas we look at the trade-off between design, control, and knowledge in order to achieve the best-possible instrumental capability and sensitivity.

As a first step towards resolving cluster cores, we surveyed 10 nearby star-forming clusters with SOFIA FORCAST at 11, 19, 31 and 37 microns. The FORCAST instrument has the highest angular resolution currently available in the far-IR. We use it to gain new insights in these important regions of stellar birth by now unambiguously matching the far-IR fluxes to their shorter wavelengths counterparts, and improve our understanding of clustered sources using SED modeling.

**Author(s):** Maxime Rizzo<sup>3</sup>, Stephen Rinehart<sup>2</sup>, Lee G. Mundy<sup>3</sup>, Dominic J. Benford<sup>2</sup>, Arnab Dhabal<sup>3</sup>, Dale J. Fixsen<sup>3</sup>, David Leisawitz<sup>2</sup>, Stephen F Maher<sup>2</sup>, Eric Mentzell<sup>2</sup>, Robert F. Silverberg<sup>2</sup>, Johannes Staguhn<sup>1</sup>, Todd Veach<sup>2</sup>

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**Contributing team(s):** Cardiff BETTII team

### **113.05 – An Accurate, All-Sky, Absolute, Low-Frequency Flux Density Scale**

The spectral flux density scale between 10 and 1000 MHz has never been accurately established. Early works from the 1960s and 1970s differ typically by 5 to 10% or more. The flux density scale proposed by Scaife and Heald (2012) is a reconciliation of these existing scales, applicable to six compact northern sources, but does not include new data, nor does it extend to any southern sources. The situation for southern sources is considerably poorer, as most of the early work was limited to northern sources.

The major causes of the discrepancies between proposed scales is in the limited resolution and imaging fidelity of the telescopes utilized. The Jansky Very Large Array has been designed for high linearity, resolution, and imaging fidelity, and is thus ideally suited for making accurate measurements of the flux density ratios between proposed calibrator sources. These ratios can then be placed on an absolute scale through knowledge of the spectrum of one of more of the sources.

We report here on the results of two recent programs using the Jansky Very Large Array:

- 1) Establishment of the absolute flux densities of eighteen sources (including seven southern sources) from 75 MHz to 48 GHz (limits vary for each source) using the absolutely-calibrated spectrum of Cygnus A (Baars et al., 1977) for frequencies lower than 1 GHz, and the proposed, absolutely-calibrated scale of Perley and Butler (2013) for frequencies above 1 GHz.
- 2) Extension of this scale to 30 compact southern sources proposed as calibrators, utilizing 3C48 (whose absolute spectrum is calibrated above) as the standard.

Polynomial expressions for the spectra, and images for all objects have been generated and will be available.

**Author(s):** Richard A. Perley<sup>1</sup>, Joseph Callingham<sup>2</sup>, Bryan J. Butler<sup>1</sup>

**Institution(s):** 1. NRAO, 2. School of Physics, University of Sydney

### 113.06 – Noise and dark performance for the FIREBall-2 EMCCD delta-doped UV optimized CCD detector

The Faint Intergalactic Redshifted Emission Balloon (FIREBall-2) is a UV multi-object spectrograph experiment designed to observe low-density emission from H I, C IV, and O VI in the circum-galactic medium (CGM) around low-redshift galaxies ( $z=0.3-1.0$ ) from a high altitude balloon. To detect this diffuse emission, we have chosen to use a high-efficiency photon-counting EMCCD as part of FIREBall-2's detector system. The flight camera system includes a custom printed circuit board, a mechanical cryo-cooler, zeolite and charcoal getters, and a NUVU controller, for fast read-out speeds and waveform shaping. Here we report on overall detector system performance. We describe our characterization of detector noise from a delta-doped, anti-reflection-coated, electron-multiplying e2v CCD201-20. We describe our use of a NUVU controller to create custom waveforms that reduce clock-induced charge (CIC). We detail the clock frequencies, waveform shapes, and well depths required to reduce parallel and serial CIC to acceptable levels for our application ( $\sim 10^{-3}$  events/pix/frame), at a range of substrate voltages. We also describe dark current measurements at several temperatures, including at our operating temperature of  $-115^{\circ}\text{C}$ , with the flight set-up.

**Author(s):** Erika T. Hamden<sup>1</sup>, Nicole Lingner<sup>1</sup>, Gillian Kyne<sup>1</sup>, Patrick Morrissey<sup>1</sup>, Christopher D. Martin<sup>1</sup>

**Institution(s):** 1. California Institute of Technology

**Contributing team(s):** FIREBall-2 Team

### 113.07 – NRES: The Network of Robotic Echelle Spectrographs

Las Cumbres Observatory Global Network (LCOGT) is building the Network of Robotic Echelle Spectrographs (NRES), which will consist of six identical, optical (390 - 860 nm) high-precision spectrographs, each fiber-fed simultaneously by up to two 1-meter telescopes and a thorium argon calibration source. We plan to install one at up to 6 observatory sites in the Northern and Southern hemispheres, creating a single, globally-distributed, autonomous spectrograph facility using up to twelve 1-m telescopes. Simulations suggest we will achieve long-term radial velocity precision of 3 m/s in less than an hour for stars brighter than  $V = 12$ . We have been funded with NSF MRI and ATI grants, and expect our first spectrograph to be deployed in early 2016, with the full network operation of 5 or 6 units beginning in 2017. We will briefly overview the NRES design, goals, robotic operation, and status. In addition, we will discuss early results from our prototype spectrograph, the laboratory and on-sky performance of our first production unit, and the ongoing software development effort to bring this resource online.

**Author(s):** Robert Siverd<sup>2</sup>, Timothy M. Brown<sup>2</sup>, John Hygelund<sup>2</sup>, Todd Henderson<sup>2</sup>, Joseph Tufts<sup>2</sup>, Jason Eastman<sup>1</sup>, Julian C. Van Eyken<sup>3</sup>, Stuart Barnes<sup>4</sup>

**Institution(s):** 1. Harvard Smithsonian Center for Astrophysics, 2. Las Cumbres Observatory Global Telescope Network, 3. NExSci, Caltech, 4. Stuart Barnes Optical Design

## 114 – HAD II: History of Astronomy: 19th and 20th Centuries

### 114.01 – The Order of the Dolphin: Origins of SETI

In 1961, the National Academy of Sciences organized a meeting on the search for extraterrestrial intelligence (SETI) at the National Radio Astronomy Observatory in Green Bank, West Virginia. The ten scientists who attended, including future SETI icons such as Frank Drake and Carl Sagan, represented a variety of scientific fields. At the conclusion of the meeting, the attendees adopted the moniker “The Order of the Dolphin,” in honor of participant John Lilly’s work on interspecies communication. Since this seminal meeting, researchers in each of the attendees’ fields have contributed in some way to the search for intelligent life. This study investigates the circumstances that led to each attendee’s invitation to Green Bank and explores SETI as the legacy of this meeting. We will focus in this talk on the SETI connections of two attendees, astronomer Otto Struve and physicist Philip Morrison, both in regards to their personal contributions to SETI and the influence of their work on subsequent SETI research. Specifically, we will examine proposals by Otto Struve for exoplanet discovery methods, and Philip Morrison for radio searches that laid the groundwork for modern SETI.

**Author(s):** Maria Temming<sup>1</sup>, Anthony Crider<sup>1</sup>

**Institution(s):** 1. Elon University

### 114.02 – The Golden Years of Radio Astronomy

The 1960s were the Golden Years of Radio Astronomy. During this decade a new generation of young scientists discovered quasars, pulsars, the cosmic microwave background, cosmic masers, giant molecular clouds, radio source variability, superluminal motion, radio recombination lines, the rotation of Mercury and Venus, the Venus Greenhouse effect, Jupiter’s radiation belts, and opened up the high redshift Universe. On the technical side, the 1960s saw the completion of the NRAO 140-ft and 300-ft radio telescopes, the Haystack, Arecibo and Parkes antennas, the Owens Valley Interferometer, the first practical demonstrations of aperture synthesis, VLBI, and CLEAN, the Cambridge 1-mile radio telescope, the most precise tests of GR light bending, and the introduction of the 4th test of GR. Following sessions at the recent IAU 29th General Assembly on the “Golden Years of Radio Astronomy,” we will discuss the circumstances surrounding these transformational discoveries which changed the course of modern astronomy.

**Author(s):** Kenneth I. Kellermann<sup>1</sup>

**Institution(s):** 1. NRAO

### 114.03 – Max Wolf’s Discovery of Near-Earth Asteroid 887 Alinda

Max Wolf, director of the Heidelberg Observatory (Landessternwarte Königstuhl), was the most prodigious discoverer of asteroids in the early twentieth century. He is now best known for the discovery of the Trojan asteroids associated with Jupiter in 1906, but was a pioneer in the application of photographic techniques to astronomy, particularly for conducting asteroid surveys. His attention to detail and perseverance also led to the discovery of the near-Earth asteroid 887 Alinda, which is the eponym of an orbital class in 3:1 resonance with Jupiter. Alinda class contains several potentially hazardous asteroids, and has been particularly instructive in development of theories of eccentricity increase for resonant asteroids. Alinda was discovered on January 3, 1918, on the very edge of one of two plates taken with the 40 cm aperture Bruce double astrograph. The inability to reduce a long trail going off the plate meant that only one month later could the object again be found with the Bruce telescope, and later observed with the follow-up instrument, the 72 cm aperture Waltz reflector. In what Wolf referred to as “the greatest

embarrassment of my life”, reflector observations had him conclude that Alinda had a satellite. At a time when plates had to be exposed for several hours, laboriously developed and analyzed, and in the case of high eccentricity objects like Alinda, predicted with inadequate theories, Wolf’s persistence allowed it never to be lost. Despite this, its essential resonant nature was not determined until 1969, despite the pioneering work by Brown (1911) on resonance in the asteroid belt and the knowledge dating to the late nineteenth century work of Kirkwood that commensurabilities were important in its structure. The majority of Wolf’s plates are available as online scans through the Heidelberg Digitized Astronomical Plates project of the German Astrophysical Virtual Observatory, but the Alinda discovery plate, which was broken, was scanned specially.

**Author(s):** Martin Connors<sup>1</sup>, Holger Mandel<sup>2</sup>, Markus Demleitner<sup>3</sup>

**Institution(s):** 1. Athabasca University, 2. Landesternwarte Heidelberg, 3. University of Heidelberg

**Contributing team(s):** Heidelberg Digitized Astronomical Plates Project

#### 114.04 – Lowell Observatory’s 24-inch Clark Refractor: Its History and Renovation

In 1895, Percival Lowell hired eminent telescope maker Alvan G. Clark to build a 24-inch refractor. Lowell intended the telescope initially for observing Mars in support of his controversial theories about life on that planet. Clark finished the telescope within a year and at a cost of \$20,000. Lowell and his staff of assistants and astronomers began observing through it on July 23, 1896, setting off a long and productive career for the telescope.

While Lowell’s Mars studies dominated early work with the Clark, V.M. Slipher by the 1910s was using it to observe planetary rotations and atmospheric compositions. He soon revolutionized spectroscopic studies, gathering excruciatingly long spectra – some in excess of 40 hours – of the so-called white nebula and determining startling radial velocities, evidence of an expanding universe. In the 1960s, scientists and artists teamed up on the Clark and created detailed lunar maps in support of the Apollo program.

In recent decades, the Clark has played a central role in the education programs at Lowell, with general public audiences, students, and private groups all taking advantage of this unique resource.

With this nearly 120 years of constant use, the Clark had been wearing down in recent years. The telescope was becoming more difficult to move, old electrical wiring in the dome was a fire hazard, and many of the telescope’s parts needed to be repaired or replaced.

In 2013, Lowell Observatory began a fundraising campaign, collecting \$291,000 to cover the cost of dome and telescope renovation. Workers removed the entire telescope mount and tube assembly from the dome, examining every part from tube sections to individual screws. They also stabilized the dome, adding a water vapor barrier and new outer wall while reinforcing the upper dome. The project lasted from January, 2014 through August, 2015. The facility reopened for daytime tours in September, 2015 and evening viewing the following month.

**Author(s):** Kevin Schindler<sup>1</sup>, Ralph Nye<sup>1</sup>, Peter Rosenthal<sup>1</sup>  
**Institution(s):** 1. Lowell Observatory

#### 114.05 – Who Really Discovered The First Asteroid, Ceres?

Giuseppe Piazzi has been credited as the sole discoverer of the first asteroid, Ceres, ever since it was found on January 1, 1801. However, a mid-nineteenth century book about Cicero has been found to contain an interview that reveals the full story of the discovery, not the sanitized version presented by Piazzi in his two monographs about Ceres. In addition, research has uncovered the only interview ever given by Piazzi, which offers a unique insight into his views on English and French astronomy from the perspective of 1808.

**Author(s):** Clifford J. Cunningham<sup>1</sup>

**Institution(s):** 1. National Astronomical Research Institute of Thailand

#### 114.06 – Lost in the Dark: A proto-history of dark matter

The Greeks were probably not the first to think of everything, but they were quite often the first to write about it. Thus the first dark matter candidate was the counter-earth of Philolaus (c. 460 BCE), with its illuminated face forever turned away from us. The eclipsing binary interpretation of Algol brought forward the idea (Pigott & Goodricke 1780s) of stars not yet lit up, while the incorporation of thermodynamics into the astronomical tool kit suggested dark, dead stars. Jeans reported a number for these about three times the number of illuminated stars in 1922, the same year that Kapteyn set a comparable limit to what he called dark matter. The phrase appears as an index item in Russell et al.’s 1927 *Astronomy* and cannot, therefore, have been invented any later. The first extragalactic investigation seems to have been that by Knut Lundmark, writing in German in the *Meddelande of the Lund Observatory* in 1930. One of the columns of his *Tabelle 4* is headed: (Leuchtende + dunkle Materie)/(Leuchtende Materie) and lists values from six up to 100 for six galaxies, e.g. Messier 51 (10), Andromedanebel (20), and NGC 4594 (30). Binary galaxies came from Holmberg (1937), Virgo from Sinclair Smith (1936), and flat rotation curves from Babcock (1939, Andromeda) and Oort (1940, NGC 3115), the latter writing cautiously that the distribution of mass seemed to be very different from that of the light. Then there was a war, but by the time of a 1961 symposium in Santa Barbara focused on the large velocity dispersions in clusters of galaxies, the votes for dark matter slightly outnumbered those for unbound clusters and other alternatives. The idea of a constant of gravity increasing with distance came a smidge later from Arigo Finzi in 1963. The tipping point was arguably 1974 with a pair of short papers summarizing M/L ratios vs. distance scale (which could, of course, have been plotted before WWII). I mention only the slightly earlier and much less often cited one by Einasto, Kaasik, and Saar (published in *Nature*, in case you are thinking of more *Meddelande*). I feel enormous respect and affection for Vera Rubin and Fritz Zwicky, but the published papers as are they are.

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**Institution(s):** 1. UC, Irvine

**Contributing team(s):** History 1

#### 114.07 – Joseph Henry and Astronomy

Joseph Henry (1797-1878) is best known for his work in electromagnetism and as the first secretary of the Smithsonian Institution. But he was also a pioneer solar physicist, an early advocate of US participation in astrophysics, and a facilitator of international cooperation in astronomy. This paper will briefly trace his role in the development of the US astronomical community from the time he taught astronomy at Princeton in the 1830s through his death, focusing on failed efforts to persuade US astronomers and patrons of astronomy that the best path for US astronomy should be astrophysics. He thought that the US could make a more significant contribution to astronomy science by striking out on a less travelled path rather than competing with the established European observatories.

**Author(s):** Marc Rothenberg<sup>1</sup>

**Institution(s):** 1. Smithsonian Institution

### 118 – Galaxies in the Nearby Universe

#### 118.01 – The HI Content of Groups as Measured by ALFALFA

We present the HI content of galaxies in nearby groups and clusters as measured by the 70% complete Arecibo Legacy Fast-ALFA (ALFALFA) survey, including constraints from ALFALFA detection limits. Our sample includes 22 groups at distances between 70-160 Mpc over the mass range  $12.5 < \log M/M_{\odot} < 15.0$ , for a total of 1986 late-type galaxies out to a projected group-centric distance of 4.0 Mpc. We find that late-type galaxies in the centers of groups lack HI

at fixed stellar mass relative to the regions surrounding them. Larger groups show evidence of a stronger gradient in HI properties, despite a similar gradient in stellar mass, and in color at fixed stellar mass, over the same range in  $r/R_{200}$ . We compare several environment variables to determine which is the best predictor of galaxy properties; group-centric distance  $r$  and  $r/R_{200}$  are similarly effective predictors, while local density is slightly more effective and group size and halo mass are slightly less effective. Finally, we see evidence that HI is deficient for blue cloud galaxies in denser environments even when both stellar mass and color are fixed. This is consistent with a picture where HI is removed or destroyed, followed by reddening within the blue cloud. Overall, our results support the existence of pre-processing in isolated groups, along with an additional rapid mechanism for gas removal within larger groups and clusters, perhaps by ram-pressure stripping. This work has been supported by NSF grants AST-0724918/0902211, AST-075267/0903394, AST-0725380, and AST-1211005.

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**Contributing team(s):** ALFALFA Team

### 118.02 – The Arecibo Pisces-Perseus Survey: An Undergraduate ALFALFA Team Project

The Milky Way's position in an outer filament of Laniakea affords us a striking view of the Pisces-Perseus Supercluster (PPS) arcing roughly from  $22^h$  to  $4^h$  and  $0^\circ$  to  $+50^\circ$  concentrated between  $cz = 4,000$  km/s and  $cz = 8,000$  km/s as a "wall" parallel to the plane of the sky. It is bounded by voids both between Laniakea and PPS and beyond PPS. Within this box, the 70% ALFALFA survey has detected 4,800 galaxies within  $cz = 8,000$  km/s. Of these, 80% have masses greater than  $10^8 M_\odot$ . At the distance of the PPS, galaxies with  $M_{HI} \leq 10^8 M_\odot$  are below the ALFALFA detection limit. Thus to further explore this rich diversity of galaxy environments and the adjoining voids, the Undergraduate ALFALFA Team is in the process of using the L-band Wide receiver at Arecibo Observatory for the Arecibo Pisces-Perseus Supercluster Survey (APPSS). We will observe galaxies with  $10^8 M_\odot \leq M_{HI} \leq 10^9 M_\odot$  chosen from the SDSS DR12 and GALEX catalogs. We are limiting our observations to the PPS ridge in  $21^h 30^m$  to  $3^h 15^m$  and  $23^\circ$  to  $35^\circ$ . Since this region lacks SDSS spectroscopy, targets have been selected using photometric criteria derived from SDSS and GALEX observations for galaxies detected by ALFALFA. The results of these observations will allow us to constrain the HI mass function along the PPS ridge. Application of the Tully-Fisher relation will allow a robust measure of the infall velocities of galaxies into the filament. This work has been supported by NSF grant AST-1211005.

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**Contributing team(s):** Undergraduate ALFALFA Team

### 118.03D – The HI mass function in ALFALFA 70% and the role of confusion in future HI surveys

The HI mass function represents a fundamental component of our understanding of the gas content of galaxies. How its form varies throughout the local Universe and as a function of redshift, is key to developing a complete picture of galaxy evolution.

We use the ALFALFA 70% catalog, the largest uniform catalog of extragalactic HI sources to date, to explore the environmental dependence of the HI mass function based on the projected neighbour densities in both SDSS and 2MRS. The Schechter function 'knee' mass is found to increase by approximately 0.2 dex from the lowest to highest density quartiles. However, this dependence is seen only when environment is defined by SDSS neighbours, and not with 2MRS. We interpret this as an indication of local, rather than large scale, environmental dependence. In addition, we find no evidence for

any change in the faint-end slope; which is a source of tension with HI surveys of galaxy groups, and DM halo simulations.

As HI surveys push deeper in an attempt to assess the HI content of the Universe towards a redshift of order unity, only the integral of the HI mass function will be measurable through stacking. We present an analytic, and thus computationally cheap, method to estimate the contribution of HI confusion noise to these stacks and explore the design implications for upcoming SKA-precursor surveys.

The ALFALFA team at Cornell is supported by NSF grants AST-0607007 and AST-1107390 to RG and MPH and by grants from the Brinson Foundation.

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**Contributing team(s):** ALFALFA Team

### 118.04 – NGC 5195 in M51: Feedback 'Burps' after a Massive Meal?

We describe a double-arc-like X-ray structure lying  $\sim 15\text{--}30''$  ( $\sim 0.8\text{--}1.7$  kpc) south of the NGC 5195 nucleus visible in the merged exposures of long *Chandra* pointings of M51. The curvature and orientation of the arcs argues for a nuclear origin. We interpret the arcs as episodic outbursts from the central super-massive black hole (SMBH). The arcs are radially spaced by  $\sim 15''$  ( $\sim 1$  kpc), but are rotated relative to each other by  $\sim 30^\circ$ , requiring episodic activity. We also find a slender H $\alpha$ -emitting region just outside the outer edge of the outer X-ray arc, suggesting that the X-ray-emitting gas plowed up and displaced the H $\alpha$ -emitting material from the galaxy core. Star formation may have commenced in that arc. H $\alpha$  emission is present at the inner arc, but appears more complex in structure. In contrast to an explosion expected to be azimuthally symmetric, the X-ray arcs suggest a focused outflow. We conclude that NGC 5195 represents the nearest galaxy exhibiting on-going, large-scale outflows of gas, in particular, two episodes of a focused outburst of the SMBH. The observation has implications for SMBH feedback and the subsequent galaxy evolution.

**Author(s):** Eric M. Schlegel<sup>4</sup>, Christine Jones<sup>2</sup>, Marie E. Machacek<sup>3</sup>, Laura D. Vega<sup>1</sup>

**Institution(s):** 1. Fisk University/Vanderbilt University, 2. Harvard-Smithsonian Center for Astrophysics, 3. Smithsonian Astrophysical Observatory, 4. Univ. of Texas, San Antonio

### 118.06 – The Extended Disk of NGC 404

I will discuss recent work on the star forming, HI-dominated extended ultraviolet (XUV) disk of the early-type galaxy NGC 404. This galaxy is one of the nearest, most striking XUV disks, and with deep, wide-field mapping, we aim to study star formation in the atomic-dominated outer disks of galaxies. With our new observations, we reveal the full extent of the distribution of HI, including a very extended and previously undetected coherent feature that measures  $\sim 100$  kpc in size. I will discuss the star formation in this region in the context of the resolved properties of the gas as well as the diffuse reservoir of atomic hydrogen available to fuel (or not) the central galaxy.

**Author(s):** Jennifer Donovan Meyer<sup>2</sup>, Paul Martini<sup>3</sup>, Adam Leroy<sup>3</sup>, Daniel J. Pisano<sup>4</sup>, David A. Thilker<sup>1</sup>

**Institution(s):** 1. Johns Hopkins, 2. NRAO, 3. Ohio State University, 4. West Virginia University

### 118.07 – A Tale of Two Tails: Exploring Stellar Populations in the Tidal Tails of NGC 3256

Galaxy interactions can inject material into the intergalactic medium via violent gravitational dynamics, often visualized in tidal tails. The composition of these tails has remained a mystery, as previous studies have focused on detecting tidal features, rather than the composite material itself. We have developed an observing program using deep, multiband imaging to probe the chaotic regions of tidal

tails in search for an underlying stellar population. NGC 3256's twin tidal tails serve as a case study for this new technique. Our results show color values of  $u - g = 1.15$  and  $r - i = 0.08$  for the Western tail, and  $u - g = 1.33$  and  $r - i = 0.22$  for the Eastern tail, corresponding to discrepant ages between the tails of approximately 320 Myr and 785 Myr, respectively. With the interaction age of the system measured at 400 Myr, we find the stellar light in Western tail to be dominated by disrupted star clusters formed during and after the interaction, whereas the light from the Eastern tail is dominated by a 10 Gyr population originating from the host galaxies. We fit the Eastern tail color to a Mixed Stellar Population (MSP) model comprised 94% by mass of a 10 Gyr stellar population, and 6% of a 309 Myr population. We find 52% of the bolometric flux originating from this 10 Gyr population. We also detect a blue to red color gradient in each tail, running from galactic center to tail tip. In addition to tidal tail light, we detect 29 star cluster candidates (SCCs) in the Western tail and 19 in the Eastern, with mean ages of 282 Myr and 98 Myr respectively. Interestingly, we find an excess of very blue SCCs in the Eastern tail as compared to the Western tail, marking a recent, small episode of star formation.

**Author(s):** Michael Rodruck<sup>2</sup>, Jane C. Charlton<sup>2</sup>, Iraklis Konstantopoulos<sup>1</sup>  
**Institution(s):** 1. Australian Astronomical Observatory, 2. Penn State University

### 118.08 – A New Coadded Spectroscopy Technique: Kinematics of NGC 4449's Tidal Stream

We present a new coadded spectroscopy technique to study the kinematics of low surface brightness stellar streams located as far as 4 Mpc away. We target blends of stars that populate the super-TRGB region of the color-magnitude diagram. These spectra are then coadded to boost S/N ratio. We show results based on the application of this technique to a stellar tidal stream near the low-luminosity galaxy NGC 4449 located 3.5 Mpc away.

**Author(s):** Puragra Guhathakurta<sup>3</sup>, Elisa Toloba<sup>2</sup>, Aaron J. Romanowsky<sup>1</sup>, Jean P. Brodie<sup>3</sup>  
**Institution(s):** 1. SJSU, 2. Texas Tech U, 3. UC, Santa Cruz  
**Contributing team(s):** NSF, NASA

## 119 – AGN, Black Holes and Host Galaxies

### 119.01 – Relations Between Black Hole Mass and Total Galaxy Stellar Mass in the Local Universe

Scaling relations between central black hole (BH) mass and host galaxy properties are of fundamental importance to studies of BH and galaxy evolution throughout cosmic time. Reines & Volonteri (2015) investigate the relationship between BH mass and host galaxy total stellar mass using a sample of 262 broad-line AGNs in the nearby Universe ( $z < 0.055$ ), as well as 79 galaxies with dynamical BH masses. We find a clear correlation between BH mass and total stellar mass for the AGN host galaxies with BH mass proportional to stellar mass, similar to that of early-type galaxies with dynamically-detected BHs. However, the relation defined by the AGNs has a normalization that is lower by more than an order of magnitude, with a BH-to-total stellar mass fraction of only  $\sim 0.025\%$ . This result has significant implications for studies at high redshift and cosmological simulations in which stellar bulges cannot be resolved.

**Author(s):** Amy E. Reines<sup>2</sup>, Marta Volonteri<sup>1</sup>  
**Institution(s):** 1. IAP, 2. NOAO

### 119.02D – A Near-Infrared Spectroscopic Investigation of Ionization Mechanisms and AGN Activity in Luminous Infrared Galaxies

I present an analysis of ionization mechanisms in a sample of 65 luminous infrared galaxies as traced by their near-infrared line emission. These galaxies are hotbeds of extreme merger-driven star formation and are sometimes observed to contain luminous AGN - both phenomena are obscured by dust within the galaxies, necessitating the need for long-wavelength observations to assess the nature of their activity. The near-infrared TRIPLESPEC spectra are

characterized by strong line emission from hydrogen recombination lines, [Fe II] emission, and ro-vibrational lines of molecular hydrogen. The emission line ratios overwhelmingly favor ionization via radiative shocks over photoionization by the starburst. In addition, no evidence of embedded AGN (as traced via broad line regions or emission from the [Si VI] coronal line) in narrow-line LIRGs with HII region-like or LINER spectra were found. Finally, the average temperatures and nuclear masses of warm molecular hydrogen are estimated. This study is part of the Great Observatories All-Sky LIRG Survey (GOALS).

**Author(s):** H. Jacob Borish<sup>1</sup>  
**Institution(s):** 1. University of Virginia  
**Contributing team(s):** GOALS

### 119.03 – Merger-Triggered AGN Activity as Traced by Dual and Offset AGN

Dual AGN and offset AGN are  $<10$  kpc separation supermassive black hole pairs that are created during galaxy mergers, where both or one of the black holes are AGN, respectively. Although few dual and offset AGN have been discovered to date, they are ideal probes of the link between galaxy mergers and AGN activity. Using Chandra and HST observations, we have discovered six galaxies that host either dual AGN or offset AGN. These galaxies have two stellar bulges visible in the HST images, and the Chandra observations reveal which bulges host AGN. We find that most of the dual and offset AGN are created in major mergers of galaxies, and that these AGN are 10 times more luminous than single AGN that are not in mergers. This is observational support of the theoretical prediction that the most luminous AGN are triggered in major mergers. We also find that the AGN in the less massive stellar bulge accretes at a higher Eddington ratio than the AGN in the more massive stellar bulge, which is an effect reproduced by simulations of AGN triggering during galaxy mergers.

**Author(s):** Julia M. Comerford<sup>1</sup>  
**Institution(s):** 1. University of Colorado, Boulder

### 119.04D – Quenching histories of galaxies and the role of AGN feedback

Two open issues in modern astrophysics are: (i) how do galaxies fully quench their star formation and (ii) how is this affected - or not - by AGN feedback? I present the results of a new Bayesian-MCMC analysis of the star formation histories of over 126,000 galaxies across the colour magnitude diagram showing that diverse quenching mechanisms are instrumental in the formation of the present day red sequence. Using classifications from Galaxy Zoo we show that the rate at which quenching can occur is morphologically dependent in each of the blue cloud, green valley and red sequence. We discuss the nature of these possible quenching mechanisms, considering the influence of secular evolution, galaxy interactions and mergers, both with and without black hole activity. We focus particularly on the relationship between these quenched star formation histories and the presence of an AGN by using this new Bayesian method to show a population of type 2 AGN host galaxies have recently (within 2 Gyr) undergone a rapid ( $\tau < 1$  Gyr) drop in their star formation rate. With this result we therefore present the first statistically supported observational evidence that AGN feedback is an important mechanism for the cessation of star formation in this population of galaxies. The diversity of this new method also highlights that such rapid quenching histories cannot account fully for all the quenching across the current AGN host population. We demonstrate that slower ( $\tau > 2$  Gyr) quenching rates dominate for high stellar mass ( $\log_{10}[M^*/M_{\odot}] > 10.75$ ) hosts of AGN with both early- and late-type morphology. We discuss how these results show that both merger-driven and non-merger processes are contributing to the co-evolution of galaxies and supermassive black holes across the entirety of the colour magnitude diagram.

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**Institution(s):** 1. University of Oxford  
**Contributing team(s):** Galaxy Zoo Team

## 119.05 – Black holes a-wandering in Abell 2261

The brightest cluster galaxy in Abell 2261 (BCG2261) has an exceptionally large, flat, and asymmetric core, thought to have been shaped by a binary supermassive black hole inspiral and subsequent gravitational recoil. BCG2261 should contain a  $10^{10}$  Msun black hole, but it lacks the central cusp that should mark such a massive black hole. Based on the presence of central radio emission, we have explored the core of this galaxy with HST and the VLA to identify the presence and location of the active nucleus in this galaxy's core. We present our exploration of whether this system in fact contains direct evidence of a recoiling binary supermassive black hole. A recoiling core in this system would represent a pointed observational test of three preeminent theoretical predictions: that scouring forms cores, that SMBHs may recoil after coalescence, and that recoil can strongly influence core formation and morphology.

**Author(s):** Sarah Spolaor<sup>5</sup>, Holland Ford<sup>3</sup>, Kayhan Gultekin<sup>7</sup>, Tod R. Lauer<sup>4</sup>, T. Joseph W. Lazio<sup>2</sup>, Abraham Loeb<sup>1</sup>, Leonidas A. Moustakas<sup>2</sup>, Marc Postman<sup>6</sup>, Joanna M. Taylor<sup>6</sup>

**Institution(s):** 1. Harvard/CfA, 2. Jet Propulsion Laboratory, 3. JHU, 4. NOAO, 5. NRAO, 6. STScI, 7. U Michigan

## 119.07 – Variability Statistics for Galaxies Observed by Kepler

The Kepler / K2 telescope combines high photometric precision with near-continuous observing cadence, permitting a unique perspective on the optical / near-IR variability of galactic systems. In particular, Kepler / K2 data can be exploited to quantify the amplitude of AGN signals in galaxy cores, to directly address this question - What fraction of galactic nuclei are active at any given time? Alternatively stated, this question becomes - What is the duty cycle for supermassive black hole accretion of sufficient strength to produce a detectable optical signal? Additionally, the quasi-continuous cadence provides the capability to detect low-level episodic variations from the central AGN, highly luminous stars and other compact objects.

Previously we reported on analysis of a subset of the complete galaxy dataset observed during the Kepler prime mission: ~1200 individual light curves of ~150 targeted galaxies observed during Quarters 3-10 and ~1000 light curves of galaxies observed serendipitously by the exoplanet program from Q2 through Q16. Based on an average of 8 quarters of data for ~300 systems and excluding systems specifically targeted as AGNs, we found that the observed occurrence rate of nuclear variability in galaxies with amplitude > 1 millimag is ~2-3%, a value which is ~2-3 times smaller than previous estimates from ground-based monitoring.

Here we provide an update on galactic nuclear variability statistics using an expanded dataset from the Kepler Prime mission. We combine the previous data with 1200 light curves for ~200 targeted systems from Q11-16 and ~800 additional light curves found in the exoplanet program. These data are the longest continuous time series for galaxies ever obtained - some systems were observed for the entire mission (Q2-16). Our previous result is confirmed using this expanded dataset; only a few percent of galaxies show variability above 0.5 millimag. Several systems exhibiting activity in other bands, or via their optical spectra, show no measurable variations in the Kepler band. We also provide some preliminary variability estimates from K2 data.

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**Institution(s):** 1. NASA Ames Research Center, 2. SETI

## 120 – Supernovae: Spectroscopy and Classification

### 120.01 – Late-Time Spectral Observations of Type IIP Supernovae

Type II-Plateau supernovae (SNe IIP) are H-rich explosions that come from red supergiant (RSG) progenitors. Despite the fact that

they are the most common subtype of SN, little work has been done on late-time observations of SNe IIP owing to their relative faintness at these epochs. We analyze 91 late-time (older than about 100 days past explosion) optical spectra of 38 SNe IIP, making this the largest sample of SN IIP nebular spectra ever studied. Quantitative criteria from the spectra themselves are employed to determine if an observation is truly nebular, and thus should be included in the study. We measure the fluxes, shapes, and velocities of various emission lines and investigate their temporal evolution. These values are also compared to photometric data in order to search for correlations that may allow us to gain insight into the RSG progenitors of SNe IIP and learn more about the details of the explosion itself.

**Author(s):** Jeffrey M. Silverman<sup>2</sup>, Stephanie Pickett<sup>2</sup>, J. Craig Wheeler<sup>2</sup>, Alexei Filippenko<sup>1</sup>

**Institution(s):** 1. University of California - Berkeley, 2. University of Texas at Austin

### 120.02D – Type Ia Supernovae: UV, Optical, NIR Spectral Series and the Integrated Bolometric Lightcurves

Using photometry and spectra from the Carnegie Supernova Project and Swift UVOT we construct UV, optical, and NIR spectral series of several Type Ia supernovae near maximum light and calculate integrated bolometric lightcurves. Our sample consists of normal SNe Ia with decline rates  $0.8 < \Delta m_{15}(B) < 1.6$  mag. The spectra sample is useful for computing K-corrections which are sensitive to the decline rate and for comparison to the opacities of theoretical models, particularly in the ultraviolet. The integrated bolometric lightcurves are used to compute bolometric corrections and are compared to theoretical models.

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**Institution(s):** 1. Texas A&M University

**Contributing team(s):** Carnegie Supernova Project

### 120.03 – Type Ibn Supernovae: Not a Single Class

Type Ibn supernovae are a small yet diverse class of explosions whose spectra are characterized by low-velocity helium emission lines. The prevailing theory has been that these are the core-collapse explosions of very massive stars embedded in helium-rich circumstellar material. However, unlike the more common Type IIn supernovae, whose interaction with hydrogen-rich circumstellar material has been shown to generate a wide variety of light curve shapes, we find that light curves of Type Ibn supernovae are more homogeneous and faster evolving. Spectroscopically, we find that Type Ibn supernovae divide cleanly into two classes, only one of which resembles the archetypal Type Ibn SN 2006jc. We explore various photometric and spectroscopic parameter spaces in order to characterize these two classes. We consider the possibility that not all objects classified as Type Ibn have the same physical origin.

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**Institution(s):** 1. Las Cumbres Observatory Global Telescope Network, 2. University of California, Davis

### 120.04 – UV Observations of Type Iax Supernovae

Type Iax (aka SN 2002cx-like) supernovae (SNe) are fainter and have lower ejecta velocities than normal type Ia SNe, but have otherwise similar optical spectra near maximum light. It is not clear how SNe Iax are physically related to SNe Ia which are used for cosmology. A hint may come from the UV which is sensitive to the progenitor system and explosion mechanism for thermonuclear SNe. We will present SWIFT and HST UV observations of SN 2013dh, a low luminosity and low velocity SN Iax. While the broad band UV colors of SN 2013dh are bluer than the normal Ia SN 2011fe, the UV spectral features of both objects are remarkably similar (though SN 2013dh has a much lower ejecta velocity). These data, along with the detection of the progenitor system of the Iax, SN 2012Z, in pre-explosion HST images are helping us understand the physical diversity of these stellar explosions.

**Author(s):** Curtis McCully<sup>1</sup>, Dale Andrew Howell<sup>1</sup>, Saurabh Jha<sup>2</sup>, Ryan Foley<sup>3</sup>, Steven Downing<sup>3</sup>, Stefano Valenti<sup>1</sup>

**Institution(s):** 1. Las Cumbres Observatory Global Telescope Network, Inc., 2. Rutgers, The State University of New Jersey, 3. University of Illinois

## 120.05 – Near-infrared spectroscopy of Type Ia supernovae

Improving the cosmological experiments with Type Ia supernovae (SNe Ia) is now not simply a question of observing more supernovae, since any survey, no matter how large, will ultimately be limited by the systematic errors. It has been clearly demonstrated in a number of studies that SNe Ia are better distance indicators in the near-infrared compared to the optical. As exciting as these new results are, SNe Ia in the NIR are expected to be even better than these studies indicate. A key ingredient for improving SN Ia in the NIR as distance indicators is to obtain NIR spectroscopy to determine precise k-corrections, which account for the effect of cosmological expansion upon the measured magnitudes. Better knowledge of the NIR spectroscopic behaviors, akin to that in the optical, is necessary to reach the distance precision required to identify viable models for dark energy. Carnegie Supernova Project II has built a definitive data set, much improved from previous samples, both in size and quality. With this previously unavailable window, we are also beginning to gain new insight on the physics of these events.

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**Institution(s):** 1. Aarhus University, 2. Carnegie Observatories, 3. Florida State University, 4. Harvard-Smithsonian, CfA, 5. Las Campanas Observatory, 6. Texas Tech University, 7. University of Texas at Austin

**Contributing team(s):** Carnegie Supernova Project

## 120.07D – A New Empirical Model for Type Ia Supernovae Using Spectrophotometry from the Nearby Supernova Factory

Type Ia supernovae are currently limited in their use for cosmology by dispersion in standardized magnitudes. A large part of this dispersion is due to the fact that the current lightcurve fitters do not describe the full range of Type Ia supernova diversity. I will present an empirical model of Type Ia supernovae that captures a wider range of supernova behavior and can improve magnitude standardization. This model is constructed using over 2000 spectrophotometric observations of Type Ia supernovae from the Nearby Supernova Factory. The true spectral time series for each supernova is modeled using Gaussian Processes. The supernova model predictions are used to calculate the principal components of the full set of supernova spectral time series. K-fold cross-validation is used to determine how many components correlate to absolute magnitude. Future work will test this method on independent photometric data sets.

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**Institution(s):** 1. Lawrence Berkeley National Laboratory

**Contributing team(s):** The Nearby Supernova Factory

## 120.08 – An Integral Condition for Core-Collapse Supernova Explosions

We derive an integral condition for core-collapse supernova explosions and use it to construct a new diagnostic of explodability. The fundamental challenge in core-collapse supernova theory is to explain how a stalled accretion shock revives to explode a star. In this manuscript, we assume that shock revival is initiated by the delayed-neutrino mechanism and derive an integral condition for shock expansion,  $v_s > 0$ . Assuming that  $v_s > 0$  corresponds to explosion, we recast this integral condition as a dimensionless condition for explosion,  $\Psi > 0$ . Using 1D simulations, we confirm that  $\Psi = 0$  during the stalled phase and  $\Psi > 0$  during explosion. Having validated the integral condition, we use it to derive a useful explosion diagnostic. First, for a given set of parameters, we find the family of

solutions to the steady-state equations, parameterized by shock radius  $R_s$ , yielding  $\Psi(R_s)$ . For any particular solution,  $\Psi(R_s)$  may be negative, zero, or positive, and, since  $\Psi \propto v_s$ , this corresponds to a solution with a receding, stationary, or expanding shock, respectively. Within this family, there is always a solution with a minimum  $\Psi$ ,  $\Psi_{\min}$ . When  $\Psi_{\min} < 0$ , there always exists a stalled accretion shock solution, but when  $\Psi_{\min} > 0$ , all solutions have  $v_s > 0$ . Therefore,  $\Psi_{\min} = 0$  defines a critical hypersurface for explosion, and we show that the critical neutrino luminosity curve proposed by Burrows & Goshy 1993 is a projection of this more general critical condition. Finally, we propose and verify with 1D simulations that  $\Psi_{\min}$  is a reliable and accurate explosion diagnostic.

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## 121 – Stars II: Red Dwarfs and Brown Dwarfs

### 121.01 – Measuring the Ultraviolet Variability of M Dwarfs with GALEX

The likelihood of finding an Earth-like planet in the habitable zone of an M dwarf in the near future is very high. In order to characterize such a planet's habitability, we need to understand how much ultraviolet (UV) radiation the planet is receiving from its host star. UV light from the host star influences a planet's atmospheric photochemistry and will affect our interpretations of measured exoplanetary atmospheric compositions from future missions like JWST and the extremely large ground-based telescopes. Time resolved UV data for a large number of stars can provide more detailed boundary conditions for atmospheric modeling and information on the activity behavior of low-mass stars. The Galaxy Evolution Explorer (GALEX) provides time resolved data in the near-ultraviolet (NUV) band (1771 – 2831 Å). On average, there are 4 UV observations per M dwarf in our population of 436 M dwarfs within 25 pc of Earth. The GALEX mission has multiple surveys, which covered different sized areas of the sky. At the final data release, the All Sky Survey (AIS) covered 2/3 of the sky and accounts for 58% of our 2595 measurements. The Deep Imaging Survey (DIS), Medium Imaging Survey (MIS), Guest Investigator Survey (GII), and Nearby Galaxy Survey (NGS) contribute the remaining data. From the NUV GALEX data we find an increase in variability among later M dwarfs within the Mo – M4 range. Mo stars vary on average by 9% around their mean flux, while M4 stars vary by 31% around their mean flux.

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**Institution(s):** 1. Arizona State University, 2. UCLA

### 121.02 – Identifying Bright Carbon-Enhanced Metal-Poor Stars in the RAVE Catalog

Bright metal-poor stars are of great importance for high-resolution spectroscopic follow-up, since their brightness allows for detailed studies of the chemical compositions of their atmospheres, obtainable with short integration times on 4m-8m class telescopes. We have carried out a medium-resolution spectroscopic follow-up survey of very metal-poor ( $[Fe/H] < -2.0$ ) stars selected from the RAVE catalog.

Over the course of four semesters we observed over 1,200 stars with the Gemini North, Gemini South, SOAR, KPNO/Mayall, and ESO/NTT telescopes. These spectra are used to confirm the estimated atmospheric parameters from RAVE, as well as to determine  $[C/Fe]$ , using our spectroscopic analysis pipeline. This information has already enabled the identification of many new carbon-enhanced metal-poor (CEMP) stars, including representatives of the inner- and outer-halo populations of the Milky Way, for which high-resolution spectroscopy is in progress from the ground with the Magellan/Clay Telescope and with the South African Large Telescope (SALT). The most interesting stars from the high-resolution follow-up will be observed from space with HST/STIS or COS. In this talk I will present the results of the medium-resolution follow-up, and preliminary results from the high-resolution effort.

We acknowledge partial support from the grant PHY 14-30152; Physics Frontier Center/JINA Center for the Evolution of the Elements (JINA-CEE), awarded by the US National Science Foundation.

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**Institution(s):** 1. University of Notre Dame

### 121.03 – Examining the ages of M7-L8 dwarfs with the BOSS Ultracool Dwarf sample

We present the latest results from the BOSS Ultracool Dwarfs (BUD) sample of 12998 M7-L8 dwarfs, identified from a combination of photometry and spectroscopy from the Sloan Digital Sky Survey (SDSS). Using a cross-match of the BUD sample to the Two Micron All-Sky Survey (2MASS) and the Wide-field Infrared Survey Explorer (WISE) catalogs, we measure both colors and proper motions for the majority of the sample. The proper motions, combined with radial velocities from SDSS spectra and updated distance estimates based on i-Ks colors, yield three-dimensional velocities for 9121 ultracool dwarfs. We use these velocities as statistical proxies for age to identify and test other potential age indicators, including H $\alpha$  emission, atomic line strengths, molecular band depths, and broad-band colors.

**Author(s):** Sarah J. Schmidt<sup>2</sup>, Suzanne L. Hawley<sup>4</sup>, Andrew A. West<sup>1</sup>, John J. Bochanski<sup>3</sup>

**Institution(s):** 1. Boston University, 2. Leibniz-Institute for Astrophysics Potsdam (AIP), 3. Rider University, 4. University of Washington

### 121.04 – The Age of Planet Host $\kappa$ Andromedae Based on Interferometric Observations

We present CHARA Array interferometric observations, obtained with the PAVO beam combiner in the optical ( $\sim 750$  nm), of  $\kappa$  Andromedae. This nearby (51.6 pc) B9/AoV star hosts a directly-imaged low mass companion. Observations made at multiple orientations show the star to be oblate ( $\sim 15\%$ ), consistent with its large projected rotational velocity ( $v \sin i = 161.6 \pm 22.2$  km s<sup>-1</sup>). The interferometric observations, combined with photometry and the  $v \sin i$  are used to constrain an oblate star model of  $\kappa$  And, enabling us to determine its fundamental properties (e.g., average radius, bolometric luminosity, and equatorial velocity). These stellar properties are compared to the predictions of MESA evolution models to determine an age and mass for the star. The best fit model favors a young age for the system ( $< 100$  Myr), which implies that  $\kappa$  And b has a mass around the limit separating planets and brown dwarfs.

**Author(s):** Jeremy Jones<sup>2</sup>, Russel J. White<sup>2</sup>, Samuel N. Quinn<sup>2</sup>, Ellyn K. Baines<sup>3</sup>, Tabetha S. Boyajian<sup>4</sup>, Michael Ireland<sup>1</sup>

**Institution(s):** 1. Australian National University, 2. Georgia State University, 3. Naval Research Laboratory, 4. Yale University  
**Contributing team(s):** The CHARA Team

### 121.05 – The MUSCLES Treasury Survey: Intrinsic Ly $\alpha$ Profile Reconstructions and UV, X-ray, and Optical Correlations of Low-mass Exoplanet Host Stars

UV stellar radiation can significantly impact planetary atmospheres through heating and photochemistry, even regulating production of potential biomarkers. Cool stars emit the majority of their UV radiation in the form of emission lines, and the incident UV radiation on close-in habitable-zone planets is significant. Ly $\alpha$  (1215.67 Å) dominates the 912 – 3200 Å spectrum of cool stars, but strong absorption from the interstellar medium (ISM) makes direct observations of the intrinsic Ly $\alpha$  emission of even nearby stars challenging. The MUSCLES *Hubble Space Telescope* Treasury Survey (Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanetary Systems) has completed observations of 7 M and 4 K stars hosting exoplanets ( $d < 22$  pc) with simultaneous X-ray and ground-based optical spectroscopy for many of the targets. We have reconstructed the intrinsic Ly $\alpha$  profiles using an MCMC technique and used the results to estimate the extreme ultraviolet (100 – 911 Å) spectrum. We also present empirical relations between

chromospheric UV and optical lines, e.g., Ly $\alpha$ , Mg II, Ca II H & K, and H $\alpha$ , for use when direct UV observations of low-mass exoplanet host stars are not possible. The spectra presented here will be made publicly available through MAST to support exoplanet atmosphere modeling.

**Author(s):** Allison Youngblood<sup>1</sup>, Kevin France<sup>1</sup>, R. O. Parke Loyd<sup>1</sup>

**Institution(s):** 1. University of Colorado at Boulder

### 121.06 – An Empirically-derived non-LTE XUV-Visible Spectral Synthesis Model of the M1 V Exoplanet Host Star GJ832

GJ832 (HD 204961) is a nearby M1 V host star with two exoplanets: a Jovian mass planet and a super-Earth. We have obtained near-UV and far-UV spectra of GJ832 with the STIS and COS instruments on HST as part of the Cycle 19 MUSCLES pilot program (France et al. 2013). Our objective is to obtain the first accurate physical model for a representative M-dwarf host star in order to understand the stellar radiative emission at all wavelengths and to infer the radiation environment of their exoplanets that drives their atmospheric photochemistry.

We have calculated a full non-LTE model for GJ 832 including the photosphere, chromosphere, transition region, and corona to fit the observed emission lines formed over a wide range of temperatures and the X-ray flux. Our one-dimensional semi-empirical model uses the Solar-Stellar Physical Modelling tools that are an offspring of the tools used by Fontenla and collaborators for computing solar models. For this model of GJ832, we calculate the populations of 52 atoms and ions and 20 molecules with 2 million spectral lines. We find excellent agreement with the observed H $\alpha$ , CaII, MgII, CII, SiIV, CIV, and NV lines. Our model for GJ832 has a temperature minimum in the lower chromosphere much cooler than the Sun and then a steep temperature rise different from the Sun. The different thermal structure of GJ832 compared to the Sun results in the formation regions of the emission lines being different for the two stars. We also compute the radiative cooling rates as a function of height and temperature in the atmosphere of GJ832.

This work is supported by grants from STScI to the University of Colorado.

**Author(s):** Jeffrey Linsky<sup>2</sup>, Juan Fontenla<sup>1</sup>, Jesse Witbrod<sup>2</sup>, Kevin France<sup>2</sup>

**Institution(s):** 1. NorthWest Research Associates, 2. Univ. of Colorado

### 121.07 – The MUSCLES Treasury Survey: Temporally- and Spectrally-Resolved Irradiance from Low-mass Exoplanet Host Stars

The spectral and temporal behavior of exoplanet host stars is a critical input to models of the chemistry and evolution of planetary atmospheres. High-energy photons (X-ray to near-UV; 5 – 3200 Å) from these stars regulate the atmospheric temperature profiles and photochemistry on orbiting planets, influencing the production of potential “biomarker” gases. It has been shown that the atmospheric signatures of potentially habitable planets around low-mass stars may be significantly different from planets orbiting Sun-like stars owing to the different UV spectral energy distribution. I will present results from a panchromatic survey (Hubble/Chandra/XMM/optical) of M and K dwarf exoplanet hosts, the MUSCLES Treasury Survey (Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanetary Systems). We reconstruct the Lyman-alpha and extreme-UV (100-900 Å) radiation lost to interstellar attenuation and create 5 Ångstrom to 5 micron stellar irradiance spectra; these data will be publicly available as a High-Level Science Product on MAST. We find that all low-mass exoplanet host stars exhibit significant chromospheric/transition region/coronal emission -- no “UV inactive” M dwarfs are observed. The F(far-UV)/F(near-UV) flux ratio, a driver for possible abiotic production of the suggested biomarkers O<sub>2</sub> and O<sub>3</sub>, increases by  $\sim 3$  orders of magnitude as the habitable zone moves inward from 1 to

0.1 AU, while the incident far-UV (912 – 1700 Ang) and XUV (5 – 900 Ang) radiation field strengths decrease by factors of a few across this range. Far-UV flare activity is common in ‘optically inactive’ M dwarfs; statistics from the entire sample indicate that large UV flares ( $E(300 - 1700 \text{ Ang}) \geq 10^{31} \text{ erg}$ ) occur several times per day on typical M dwarf exoplanet hosts.

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**Institution(s):** 1. *University of Colorado*

**Contributing team(s):** The MUSCLES Treasury Survey Team

## 121.08D – Priming the Solar Neighborhood M dwarfs for Future Planet Searches

The nearby low-mass stars are the best candidate hosts for searching for transiting exoplanets to enable atmospheric characterization. Unfortunately, our understanding of exoplanets is most often limited by our ability to characterize the host star. My thesis has focused on this stellar characterization problem. MEarth consists of 2 arrays of 8 telescopes each, one located at Mt. Hopkins, Arizona, and the other at Cerro Tololo, Chile. First, I used data from the Northern array to measure the trigonometric parallax of 1500 northern M dwarfs with a precision of 3 mas. With these distances we better characterized the MEarth M dwarfs and selected a volume-limited sample from which to search for planets. Second, I calibrated the MEarth photometric system using observations of Landolt standard fields. We measured the red-optical MEarth magnitude for 1800 M dwarfs with 1.5% precision. Combined with trigonometric parallaxes and spectroscopic metallicity estimates, I created a color-magnitude-metallicity relation for the mid-to-late M dwarfs capable of reproducing spectral metallicities with 0.1 dex precision. With these metallicities, we plan to measure any potential planet-metallicity correlation at the low-mass end of the stellar sequence once future missions uncover the planets orbiting these stars. Third, I present MEarth-South’s discovery of a low mass eclipsing binary system. The system has an orbital period of 4.7 days, possesses zero eccentricity but is non-synchronously rotating. We obtained high precision radial velocity measurements from the TRES spectrograph, allowing us to measure the mass of each component with 1% precision. Both components are slightly inflated compared to the most recent stellar models, in keeping with previous precise mass-radius determinations for low mass stars. Fourth, I am currently gathering sloan photometry for M dwarfs to calibrate a color-color metallicity relation in the sloan bandpass. My thesis has focused on characterizing the nearby M dwarfs, whose size and proximity make them the ideal planetary hosts for current and future exoplanet studies.

MEarth gratefully acknowledges funding from the NSF, the David and Lucile Packard Foundation, and the John Templeton Foundation.

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**Institution(s):** 1. *Harvard Smithsonian, CfA*

## 122 – Extrasolar Planet Detection: Results from Kepler and K2

### 122.01 – Determining the Mass of Kepler-78b with Nonparametric Gaussian Process Estimation

Kepler-78b is a transiting planet that is 1.2 times the radius of Earth and orbits a young, active K dwarf every 8 hr. The mass of Kepler-78b has been independently reported by two teams based on radial velocity (RV) measurements using the HIRES and HARPS-N spectrographs. Due to the active nature of the host star, a stellar activity model is required to distinguish and isolate the planetary signal in RV data. Whereas previous studies tested parametric stellar activity models, we modeled this system using nonparametric Gaussian process (GP) regression. We produced a GP regression of relevant Kepler photometry. We then use the posterior parameter distribution for our photometric fit as a prior for our simultaneous GP + Keplerian orbit models of the RV data sets. We tested three simple kernel functions for our GP regressions. Based on a Bayesian

likelihood analysis, we selected a quasi-periodic kernel model with GP hyperparameters coupled between the two RV data sets, giving a Doppler amplitude of  $1.86 \pm 0.25 \text{ m s}^{-1}$  and supporting our belief that the correlated noise we are modeling is astrophysical. The corresponding mass of  $1.87_{-0.26}^{+0.27} \text{ M}_{\oplus}$  is consistent with that measured in previous studies, and more robust due to our nonparametric signal estimation. Based on our mass and the radius measurement from transit photometry, Kepler-78b has a bulk density of  $6.0_{-1.4}^{+1.9} \text{ g cm}^{-3}$ . We estimate that Kepler-78b is  $32\% \pm 26\%$  iron using a two-component rock-iron model. This is consistent with an Earth-like composition, with uncertainty spanning Moon-like to Mercury-like compositions.

**Author(s):** Samuel Kai Grunblatt<sup>1</sup>, Andrew Howard<sup>1</sup>, Raphaëlle Haywood<sup>2</sup>

**Institution(s):** 1. *University of Hawaii Institute for Astronomy*, 2. *University of St Andrews*

### 122.02 – Where Are All The Earth Twins Hiding? Measuring the Detection Efficiency of the Kepler Pipeline

We present the results of the first measurement of the Kepler pipeline detection efficiency that explores the full Kepler observation baseline, the full field of view, and uses the same code as that used to generate the planet candidate catalogue. The full table of nearly 160,000 injections, including their parameters and recovery status, is publicly available at the NASA Exoplanet Archive; we demonstrate a worked example starting from the table to illustrate use cases. We find that there are significant differences in detection efficiency across transit period (lower efficiency at longer periods than expected from pure signal-to-noise estimates) and across stellar type (lower efficiency for giant stars than expected). The former highlights the difficulty in detecting Earth-like planets in the Kepler data; the latter the importance of starting from a well-characterised stellar sample.

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**Institution(s):** 1. *NASA Ames Research Center*, 2. *NASA Exoplanet Science Institute*, 3. *SETI Institute*

### 122.03 – Visual Analysis and Comparison of Kepler Transit Timing Variations

NASA’s Kepler Space Telescope is designed to find extrasolar planets by watching a section of the sky and observing if an object transits in front its parent star. By noticing the dimming and brightening of the star as a prospective transit occurs, Kepler records the times when the planet moves in front of its star. If other planets are gravitationally influencing the transiting planet, the planet might transit late or early; these deviations from a perfectly periodic set of transits are called “transit timing variations (TTVs). Therefore, Kepler TTVs are useful in determining exoplanet masses which are hard to measure in other ways.

We decided to visually analyze the TTV data of all ~6000 Kepler objects of interest (KOIs) to determine whether interesting TTV signals would be missed by purely statistical analyses. Using data from Rowe et al. 2014 and Holczer et al. 2015, submitted, we created combined TTV plots, periodograms, and folded quadratic+sinusoid fits. The raw TTV data and ancillary plots were visually inspected for each of the ~6000 KOIs. To find the most likely KOIs containing visible TTVs and to organize the over 6000 KOIs analyzed, a rating system was developed based on numerous visual factors. These rating factors include the amount of outliers, if there is a clear sinusoidal period within the folded plots, and if there is a clear peak in the periodogram. By sorting KOIs as such, we were able to compare our findings of the strongest candidates with the same KOIs statistically analyzed by Holczer et al. 2015 (submitted, see also Mazeh et al. 2013).

It was found that the majority of our findings matched those of Holczer et al. 2015, with only small discrepancies that were understandable based on our different methodologies. Our visual inspection of the full list of KOIs contributed multiple systems that were not included in the initial list of KOIs with significant TTVs

identified statistically.

**Author(s):** Mackenzie Kane<sup>1</sup>, Darin Ragozzine<sup>1</sup>, Tomer Holczer<sup>3</sup>, Tsevi Mazeh<sup>3</sup>, Jason Rowe<sup>2</sup>  
**Institution(s):** 1. Florida Institute of Technology, 2. NASA Ames Research Center, 3. Tel Aviv University

#### 122.04 – Investigation of bias in the mass-radius relationship from Radial Velocity and Transit Timing Variation measurements

The planetary mass radius relationship is an important piece of information to understand the formation and properties of exoplanets. This relationship can best be probed using mass measurements of transiting exoplanets—which allow for robust estimates of planet size relative to the host star. Radial Velocity (RV) and Transit Timing Variations (TTVs) are the two primary means to measure planetary masses. However, early comparisons of these two methods show a difference in their respective populations of measured planet densities. Using analytic modeling and Monte Carlo simulations I show how much, if not all, of the difference can be attributed to how the signal-to-noise depends upon planet size, mass, and orbital period. I find that for the smallest-sized planets, TTVs are likely to provide a more accurate mass radius relationship as an increasing number of planetary systems are studied.

**Author(s):** Jason H. Steffen<sup>1</sup>  
**Institution(s):** 1. University of Nevada, Las Vegas

#### 122.05 – Planetary Candidates from the First Year of the K2 Mission

Due to a mechanical failure, Kepler ceased its original mission of searching for earth-like exoplanets in one part of the sky, and is now is now searching for short period planets transiting stars across the ecliptic plane. Data from this new K2 mission exhibit large systematic effects, but can be calibrated to produce photometry precise enough to detect small planets. We present a catalog of planet candidates from the first year of this survey, that is from K2 Fields 0, 1, 2, and 3. Many of these candidates are likely small planets around bright stars, amenable to follow-up observations. We conducted initial reconnaissance observations of many of the brighter candidate host stars and release our results and data to the community.

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**Institution(s):** 1. Harvard-Smithsonian Center for Astrophysics

#### 122.06 – Latest Results From the K2 Exoplanet Survey

For the past year, the K2 mission has used the repurposed Kepler spacecraft to obtain precise time-series photometry in a succession of fields for 80 days each. Our team is using K2 to identify new transiting extrasolar planets in order to: find targets for atmospheric characterization via transmission and eclipse spectroscopy with HST and JWST; find RV targets to measure the exoplanetary mass/radius relationship and constrain bulk compositions; and measure planet occurrence frequencies as a function of stellar environment, age, metallicity, and spectral type. To date we are finding roughly 50 planet candidates per K2 field including numerous multi-planet systems. In this talk I will describe our program methodology and present updated results from our transit search, validation efforts, and followup characterization of these exciting new planetary systems.

**Author(s):** Ian Crossfield<sup>7</sup>, Erik Petigura<sup>1</sup>, Joshua E. Schlieder<sup>4</sup>, Andrew Howard<sup>10</sup>, Evan Sinukoff<sup>10</sup>, Kimberly Mei Aller<sup>10</sup>, Charles A. Beichman<sup>1</sup>, David R. Ciardi<sup>1</sup>, Justin R. Crepp<sup>5</sup>, Courtney D. Dressing<sup>1</sup>, Bradley M. Hansen<sup>9</sup>, Thomas Henning<sup>3</sup>, Howard T. Isaacson<sup>8</sup>, Sebastien Lepine<sup>2</sup>, Michael C. Liu<sup>10</sup>, Arturo Omar Martinez<sup>6</sup>, Christian Obermeier<sup>3</sup>, Michael W. Werner<sup>1</sup>  
**Institution(s):** 1. Caltech, 2. Georgia State University, 3. MPIA, 4. NASA/Ames, 5. Notre Dame, 6. SDSU, 7. UA/LPL, 8. UC Berkeley, 9. UCLA, 10. UH/IfA

#### 122.07 – Constraining the Properties of Small Stars and Small Planets Observed by K2

We are using the results of the NASA K2 mission (the second career of the *Kepler* spacecraft) to study how the frequency and architectures of planetary systems orbiting M dwarfs throughout the ecliptic plane compare to those of the early M dwarf planetary systems observed by *Kepler*. In a previous analysis of the *Kepler* data set, we found that planets orbiting early M dwarfs are common: we measured a cumulative planet occurrence rate of  $2.45 \pm 0.22$  planets per M dwarf with periods of 0.5-200 days and planet radii of 1-4 Earth radii. Within a conservative habitable zone based on the moist greenhouse inner limit and maximum greenhouse outer limit, we estimated an occurrence rate of 0.15 ( $+0.18/-0.06$ ) Earth-size planets and 0.09 ( $+0.10/-0.04$ ) super-Earths per M dwarf HZ. Applying these occurrence rates to the population of nearby stars and assuming that mid- and late-M dwarfs host planets at the same rate as early M dwarfs, we predicted that the nearest potentially habitable Earth-size planet likely orbits an M dwarf a mere  $2.6 \pm 0.4$  pc away. We are now testing the assumption of equal planet occurrence rates for M dwarfs of all types by inspecting the population of planets detected by K2 and conducting follow-up observations of planet candidate host stars to identify false positives and better constrain system parameters. I will present the results of recent observing runs with SpeX on the IRTF to obtain near-infrared spectra of low-mass stars targeted by K2 and determine the radii, temperatures, and metallicities of our target stars using empirical relations. We gratefully acknowledge funding from the NASA XRP Program, the John Templeton Foundation, and the NASA Sagan Fellowship Program.

**Author(s):** Courtney D. Dressing<sup>1</sup>, Elisabeth R. Newton<sup>2</sup>, David Charbonneau<sup>2</sup>, Josh Schlieder<sup>3</sup>  
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**Contributing team(s):** Hawaii/California/Arizona/Indiana K2 Follow-up Consortium, HARPS-N Consortium

#### 122.08 – Follow-Up of K2 Planetary Candidates from Campaigns 0, 1, and 2

As part of our efforts to understand how uniform the results of Kepler are across the Galaxy, we have combined programs from various groups to form a uniform search for exoplanets around FGK and M stars. We have obtained spectra and high resolution imaging of hundreds of candidates and have generated a catalog of planetary candidate properties. We discuss the overall results of the follow-up observations and the resulting properties of the catalog.

**Author(s):** David R. Ciardi<sup>1</sup>  
**Institution(s):** 1. Caltech

#### 122.09 – Using K2 to Find Free-floating Planets

In 2011, Sumi et al. announced the discovery of an excess of short-timescale microlensing events, which they inferred to be caused by a population of unbound planetary-mass objects. Their result implies that these free-floating planet candidates may constitute an overwhelming fraction of the mass budget for planet formation. K2's Campaign 9 (K2C9) will conduct a  $\sim 4$  square-degree microlensing survey toward the Galactic bulge and is our first and potentially *only* opportunity to perform a synoptic survey to measure the masses of a substantial number of short-timescale events. The  $\sim 0.5$  AU baseline between K2 and the Earth during C9 will facilitate satellite parallax measurements for short-timescale events, with durations of  $\sim 1$  day, which will identify that the cause of the event is in fact a very low-mass object, i.e., a free-floating planet candidate. By taking near-infrared (NIR) photometry during the event and comparing to high-resolution NIR photometry after the event is over, we can then distinguish between a planet that is widely separated from but gravitationally bound to a host star and one that is truly free-floating. Here we overview this procedure, describe the resources available to accomplish it, and detail the expected yields.

**Author(s):** Calen B. Henderson<sup>1</sup>  
**Institution(s):** 1. Jet Propulsion Laboratory

## 124 – Dust and Star Formation in High Redshift Galaxies

### 124.01 – Galaxy Structure as a Driver of the Star Formation Sequence Slope and Scatter

It is well established that (1) star-forming galaxies follow a relation between their star formation rate (SFR) and stellar mass ( $M^*$ ), the “star formation sequence,” and (2) the SFRs of galaxies correlate with their structure, where star-forming galaxies are less concentrated than quiescent galaxies at fixed mass. In this talk, we consider whether the scatter and slope of the star formation sequence is correlated with systematic variations in the Sérsic indices,  $n$ , of galaxies across the SFR- $M^*$  plane. Using a mass-complete sample of 23,848 galaxies at  $0.5 < z < 2.5$  selected from the 3D-HST photometric catalogs, we find that the scatter of the star formation sequence is related in part to galaxy structure; the scatter due to variations in  $n$  at fixed mass for star-forming galaxies ranges from  $0.14 \pm 0.02$  dex at  $z \sim 2$  to  $0.30 \pm 0.04$  dex at  $z < 1$ . While the slope of the  $\log(\text{SFR})-\log(M^*)$  relation is of order unity for disk-like galaxies, galaxies with  $n > 2$  (implying more dominant bulges) have significantly lower SFR/ $M^*$  than the main ridgeline of the star formation sequence. These results suggest that bulges in massive  $z \sim 2$  galaxies are actively building up, where the stars in the central concentration are relatively young. At  $z < 1$ , the presence of older bulges within star-forming galaxies lowers global SFR/ $M^*$ , decreasing the slope and contributing significantly to the scatter of the star formation sequence.

**Author(s):** Katherine E. Whitaker<sup>1</sup>

**Institution(s):** 1. UMass Amherst

**Contributing team(s):** 3D-HST collaboration

### 124.02D – Star formation histories of $z \sim 2$ galaxies and their intrinsic characteristics on the SFR- $M^*$ plane

Using CANDELS in the GOODS-North and South field, we investigate how galaxies quench their star formations and evolve on the SFR- $M^*$  plane at  $1 < z < 3$ . With an improved SED fitting technique, we are able to obtain more accurate stellar mass and SFR by testing various star formation histories (SFH) for each galaxy, not just commonly used tau model. We show that galaxies are apparently separated in four different populations: starbursts which lie above the main sequence of star formation (MS), normal star-forming galaxies on the tight MS, galaxies below the MS with a little star-forming activity, and quiescent galaxies with different time evolutions of SFR. We constrain the slope and the scatter on the MS better at  $1 < z < 3$ . MS slope cannot be explained by a single power-law and becomes flatter at  $\log(M^*) > 10.5$ , indicating that star formation efficiency decreases at high masses. We study morphologies of galaxies using non-parametric (Sersic Index) and parametric measures as well as a projected mass surface density. We find that the average morphologies of SB galaxies are disk-like and generally have much more diffuse optical light profile than massive compact early-type galaxies (ETGs). The sizes of the SB galaxies are clearly larger than those of the MS galaxies on average. Using a projected mass surface density, more distinct morphological differences are shown among different galaxy populations. As star formation activities decrease, galaxies become more compact at all explored redshifts. The morphologies of galaxies below the MS are similar to those of quiescent galaxies, which are compact and mostly have steep optical light profiles. The existence of compact star-forming galaxies (SFGs) supports the idea that galaxies quench their star formations as they increase the core-growth in SFGs. Very compact SB galaxies are rather rare. Our morphological analysis is not consistent with the dissipative mechanism that gas-rich merging is the key driver to assemble very compact, massive early-type galaxies observed at  $z \sim 2$ .

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**Institution(s):** 1. University of Massachusetts at Amherst

**Contributing team(s):** CANDELS

### 124.03 – Evolution of Intrinsic Scatter in the SFR-Stellar Mass Correlation at 0.5

We present observations of intrinsic scatter in the Star Formation Rate (SFR) - Stellar Mass ( $M^*$ ) correlation in the redshift range  $0.5 < z < 3.0$  and in the mass range  $10^7 < M^* < 10^{11}$  Msun. We utilize photometry from the Hubble Ultra Deep Field from the UDF12 and UVUDF campaigns and CANDELS/GOODS-S. By utilizing the exceptionally deep UDF photometry (e.g. F160W 29.9 AB, 5 sigma depth) and fitting the corresponding SEDs, we extend the SFR- $M^*$  correlation by a factor of 10-100X lower in  $M^*$ . We detect galaxies down to  $M^*$  approx  $10^7$  Msun, comparable to dwarf galaxies in the local universe. We find that the intrinsic scatter is relatively constant across the mass range, and in conflict with theoretical predictions, we do not find evidence for markedly increased scatter at low mass. We find a moderate increase in total and intrinsic scatter with time across the epoch of peak cosmic star formation. These findings are consistent with gradual assembly of stellar mass in galaxies as low as  $10^7$  Msun and star formation that is increasingly stochastic with cosmic time.

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NASA Goddard Space Flight Center, 4. Rutgers University

**Contributing team(s):** UVUDF Team, CANDELS Team

### 124.04 – Explaining the Three-decade Correlation between Star Formation Rate and Stellar Mass in Galaxies at $z \sim 1$

In star-forming galaxies across cosmic time, a correlation has been found between the mass of stars already assembled and its time derivative, the star formation rate. This surprising correlation was not predicted by theory, but it can be reproduced within cosmological hydrodynamics simulations and semi-analytical models of galaxy formation. Here we use SpeedyMC, a Markov Chain Monte Carlo code for Spectral Energy Distribution fitting, to measure the star formation rates and stellar masses of 800 galaxies from the Ultraviolet Ultra Deep Field (UVUDF) and CANDELS/GOODS-S field at redshift  $1 < z < 1.5$ . This galaxy sample leverages the deepest images taken with the Hubble Space Telescope to extend the SFR- $M^*$  correlation a factor of 10-100X lower in  $M^*$  than previous studies, down to values of  $10^7 M_{\text{sun}}$  comparable to present-day dwarf galaxies. Accounting for each galaxy's parameter uncertainties, including their covariances, yields a power-law correlation across three decades with intrinsic scatter of 0.2 dex. Having assumed realistic star formation histories that can rise and fall with time, we are able to measure star formation rates on timescales varying from instantaneous to the "lifetime" average for each galaxy. As the timescale over which star formation rate is averaged increases, the power-law exponent of the correlation with stellar mass increases to unity, and the scatter decreases to 0.05 dex. We conclude that the observed correlation between star formation rate and stellar mass results from a tight correlation between recent and lifetime-average star formation rates and a narrow spread of galaxy ages at a given star formation rate. The resulting correlation provides crucial evidence that galaxy formation proceeds through self-regulated star formation.

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### 124.05D – Probing the Peak Epoch of Cosmic Star Formation (1

Obtaining a complete census of cosmic star formation requires an understanding of faint star-forming galaxies that are far below the detection limits of current surveys.

To search for the faint galaxies, we use the power of strong gravitational lensing from foreground galaxy clusters to boost the detection limits of HST to much fainter luminosities. Using the WFC3/UVIS on board the HST, we obtain deep UV images of 4 lensing clusters with existing deep optical and near-infrared data (three from Frontier Fields survey). Building multiband photometric catalogs and applying a photometric redshift selection, we uncover a large population of dwarf galaxies ( $-18.5 < M_{UV} < -12.5$ ) with small stellar masses ( $M^* < 10^9$ ) at the peak epoch of cosmic star formation ( $1 < z < 3$ ). Running a Monte Carlo simulation to correct for sample incompleteness and then using a Bayesian maximum likelihood technique, we demonstrate that the number density (LF) of star-forming galaxies keeps increasing steeply toward very faint magnitudes ( $M_{UV} = -12.5$ ). As an important implication of a steep faint-end slope LF, we show that the faint galaxies ( $-18.5 < M_{UV} < -12.5$ ) produce a large fraction of UV background ( $> 50\%$ ) at these redshifts. We use this unique sample to investigate further the various properties of dwarf galaxies as it is claimed to deviate from the trends seen for the more massive galaxies. Recent hydrodynamical simulations and observations of local dwarfs show that these galaxies have episodic bursts of star formation on short time scales ( $< 10$  Myr). We find that the bursty star formation histories (SFHs) cause a large intrinsic scatter in UV colors ( $\beta$ ) at  $M_{UV} > -16$ , comparing a sample of low mass galaxies from simulations with bursty SFHs with our comprehensive measurements of the observed  $\beta$  values. As this scatter can also be due to the dust extinction, we distinguish these two effects by measuring the dust attenuation using Balmer decrement ( $H\alpha/H\beta$ ) ratios from our MOSFIRE/Keck spectroscopy.

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#### 124.06D – Using Bayesian Evidence to Deduce the Dust-Attenuation Law at High Redshift

Although the nature of dust attenuation affects nearly all aspects of galaxy evolution, very little is known about the form of the dust-attenuation law in the distant Universe. Dust enshrouds and obscures UV star formation, convoluting our understanding of galaxy evolution at high redshift. Recent literature has recognized how the inferred physical properties of distant galaxies can be influenced by the non-universality of their attenuation curve shape. In this talk, I will present a Bayesian method to quantitatively constrain the dust-attenuation curve in high-redshift star-forming galaxies. This method is tested on galaxies at  $z \sim 2$  where we have CANDELS UV-to-optical photometry and Spitzer/Herschel IR luminosities. We find that the dust law implied from using only UV/optical data to calculate the full posterior probability densities supports the observed IR luminosities as predicted by that dust law. This method shows promise to deduce the shape of the attenuation curve at higher redshifts ( $z > 4$ ), as supported by our experiments using mock data from a semi-analytic model with qualities like those of the CANDELS GOODS fields.

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## 125 – The Sun and Solar System

### 125.01 – The Effects of Magnetic Field Morphology on the Determination of Oxygen and Iron Abundances in the Solar Photosphere

The solar chemical abundance (or a scaled version of it) is implemented in numerous astrophysical analyses. Thus, an accurate and precise estimation of the solar elemental abundance is crucial in astrophysics.

We have explored the impact of magnetic fields on the determination of the solar photospheric oxygen and iron abundances using 3D radiation-magnetohydrodynamic (MHD) simulations of convection. Specifically, we examined differences in abundance deduced from three classes of atmospheres simulated with the MURaM code: a pure hydrodynamic (HD) simulation, an MHD simulation with a local dynamo magnetic field that has saturated with an unsigned vertical field strength of 80 G at the optical depth unity surface, and an MHD simulation with an initially imposed vertical mean field of 80 G. We use differential equivalent width analysis for diagnosing abundances derived from five oxygen and four iron spectral lines of differing wavelength, oscillator strength, excitation potential, and Lande  $g$ -factor, and find that the morphology of the magnetic field is important to the outcome of abundance determinations. The largest deduced abundance differences are found in the vertical mean field simulations and small scale unresolved field resulting from the local dynamo has a smaller impact on abundance determinations.

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### 125.02 – Structure, Dynamics, and Spectra of the Solar Corona at the 2013 and 2015 Total Eclipses and Plans for 2017's American Totality

We observed the total solar eclipses of 3 November 2013 from Gabon and of 20 March 2015 from Svalbard in clear skies with cameras to image the solar corona at high resolution and with spectrographs for coronal emission lines. We report on the composite images showing coronal structure and (in comparison with other sites' images) dynamics, as well as the relation of our inner- and middle-corona composite images with surface EUV images from SDO and SWAP and with the outer-corona images from the coronagraphs on SOHO/LASCO. Our spectra show not only the common forbidden lines of Fe XIV (green line) and Fe X (red line) but also rarer species such as Ca XV. Finally, we describe our planned suite of observations for the 21 August 2017 solar eclipse, whose path of totality will cross the United States from Pacific to Atlantic, with more-favorable cloudiness statistics for western sites.

Our Gabon and Svalbard expeditions were supported by grants from the Committee for Research and Exploration of the National Geographic Society.

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### 125.03 – Low-coronal Sources of Stealth CMEs

Coronal mass ejections (CMEs) are eruptions in the solar atmosphere which expand and propagate into space. They are generally associated with eruptive phenomena in the lower corona such as solar flares, filament eruptions, EUV waves or jets, known as low-coronal signatures (LCS). Recent studies have observed CMEs without a LCS which have been referred to as stealth CMEs. Through new image processing applied to EUV images we find clear evidence of LCS leading to stealth CMEs. In this work, the new processing methods are applied to some of the data identified to contain stealth CMEs in previous studies to investigate the possible existence of observable LCS. The LCS of stealth CMEs are fairly sizeable yet faint eruptions with structure consistent with a rising flux tube, possibly formed higher in the corona in regions of weaker magnetic field. We believe these flux tubes are formed mostly in polar regions due to the larger shear resulting from the slowly-rotating lower atmosphere below the more rapidly rotating corona. This would allow the formation of large flux tubes in weaker field regions, leading to low-energy and low-density flux tube eruptions.

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#### 125.04D – Magnetic Influences on the Solar Wind

The Sun is our closest star, and even with the ability to resolve fine structure, there are several large mysteries that remain unsolved. One of these unanswered questions is how the supersonic outflow from the Sun, the solar wind, is generated and accelerated. In this dissertation, I have investigated the role of Alfvén waves in heating the corona and accelerating the wind. I focus on modeling of flux tubes that are open to the heliosphere, i.e. bundles of magnetic field that stretch beyond a few solar radii into the heliosphere. In these flux tubes, Alfvén waves are launched by the shaking of the footpoints from the convective motions of granulation on the solar photosphere. I present results of modeling efforts in one dimension that investigate how this process changes for a variety of different magnetic field structures over a solar cycle and three-dimensional modeling of time-dependent processes that unlock a connection between pico- and nanoflare-scale events and the turbulent heating generated by counter-propagating Alfvén waves. In addition to computational modeling, I also present efforts to find magnetic thresholds in observations of small-scale network jets seen with the Interface Region Imaging Spectrograph (IRIS). These jets were first discovered by IRIS due to their short lifetimes (10s of seconds) and small size (widths of 100s of kilometers). The findings for this project suggest that the modeled Alfvén-wave-driven turbulence is consistent with these network jets.

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#### 125.05 – Fermi-LAT observations of the gamma-ray emission from the quiescent sun - first 6 years in orbit

The quiescent sun is a steady source of high energy gamma-ray emission due to the interactions of cosmic ray (CR) protons and electrons with matter and photons in the solar environment. Such interactions lead to two components of the emission with distinctly different spatial distributions and spectra: a point-like emission from the solar disk due to the CR cascades in the solar atmosphere, and the extended emission from the inverse Compton (IC) scattering of CR electrons off solar photons that is coming from the whole heliosphere. The Fermi-LAT Collaboration has reported the detection of the gamma-ray emission from the quiescent sun in a previous publication, based on the first 18 months of observations. In this paper we present the results of the first 6 years of observations. The new Pass 8 event-level analysis was applied to the data set. Significantly larger photon statistics and better instrument performance allow us to explore both components of the emission in greater details and let us better comparisons of data with current models of the IC component. Moreover, the longer period of observations allows us to study the variations of the emission over the solar cycle.

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#### 125.06 – Resolving Volcanism on Io with Aperture Mask Interferometry

James Webb Space Telescope (JWST) is due to launch in October 2018. However, much preparatory work is needed to ensure JWST's effective use once it is launched. One major issue is to ensure that data taken by JWST can be properly analyzed. This summer, I worked on developing methods for data analysis of simulated images of Io, Jupiter's closest moon. These images will come from JWST's instrument, the Near InfraRed Imager and Slitless Spectrograph (NIRISS). Io is the most volcanically active body in the solar system, shining brightly in the infrared during its volcanic outbursts. Currently, we observe Io with ground based telescopes, but because of atmospheric turbulence we can't resolve volcanism on Io. This is why using JWST to observe Io's volcanos would be extremely

beneficial. The most relevant parameters are the position of volcanic eruptions, the flux of those eruptions, and the surface brightness of Io itself. Simultaneously, finding both the positional parameters of Io's volcanoes and the flux parameters of Io's volcanoes was inefficient. Instead, I found it best to acquire the positions of the volcanoes first, then fixing these positions to fit for the flux of the volcanoes and the brightness of Io. In addition, I found that with just an assumption of Poisson noise affecting the image, the correct fluxes and brightness could be measured within 3% error. The remaining work includes fine tuning our forward modeling procedures to reduce the error on measured parameters and accounting for other types of noise in the simulation.

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#### 125.07 – Preparations for VLBA Astrometry of Juno at Jupiter

The Juno mission will provide a unique opportunity to improve our knowledge of the orbit of Jupiter. The Juno spacecraft has been on its way to Jupiter since August 2011, and will enter Jupiter orbit in July 2016. It will orbit the planet more than 30 times during following 1.5 years. This will allow us to improve the orbit of Jupiter in the planetary ephemeris by using the NRAO Very Long Baseline Array (VLBA) to measure precise sky positions of Juno during the orbital phase of its mission. These positions can be combined with orbit solutions for Juno about Jupiter from Deep Space Network tracking to determine positions for the Jupiter system barycenter. This is the same technique that we have used to improve the Saturn ephemeris with VLBA astrometry of Cassini during the past decade. Test observations of Juno with the VLBA have shown that it will provide position accuracies at least as good as Cassini, 0.2-0.4 milliarcseconds (1-2 nrad). This corresponds to errors of approximately 0.8-1.6 km at the average distance of Jupiter from Earth. All previous missions to Jupiter have been single-epoch flybys except for Galileo, whose high gain antenna failed to deploy. Consequently Juno will be our first opportunity to obtain routine sub-milliarcsecond positions for Jupiter during an extended period of time. As was the case for Saturn, we expect a factor of several improvement in Jupiter's orbit as a result of the planned VLBA astrometry of Juno.

We gratefully acknowledge support of this project from NASA's Planetary Astronomy division through grant NNX15AJ11G to the Space Science Institute. Part of this research has been carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. The VLBA is part of the National Radio Astronomy Observatory, a facility of the National Science Foundation operated under a cooperative agreement with Associated Universities, Inc. This work made use of the Swinburne University of Technology software correlator, developed as part of the Australian Major National Research Facilities Program and operated under license.

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#### 125.08 – From Dust Grains to Planetesimals: The Importance of the Streaming Instability in Protoplanetary Disks

Planetesimals are the precursors to planets, and understanding their formation is an essential step towards developing a complete theory of planet formation. For small solid particles (e.g., dust grains) to coagulate into planetesimals, however, requires that these particles grow beyond centimeter sizes; with traditional coagulation physics, this is very difficult. The streaming instability, which is a clumping process akin to the pile-up of cars in a traffic jam, generates sufficiently high solid densities that the mutual gravity between the clumped particles eventually causes their collapse towards planetesimal mass and size scales. Exploring this transition from

dust grains to planetesimals is still in its infancy but is extremely important if we want to understand the basics of planet formation. Here, I present a series of high resolution, first principles numerical simulations of protoplanetary disk gas and dust to study the clumping of particles via the streaming instability and the subsequent collapse towards planetesimals. These simulations have been employed to characterize the planetesimal population as a function of radius in protoplanetary disks. The results of these simulations will be crucial for planet formation models to correctly explain the formation and configuration of solar systems.

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## 126 – Elliptical and Spiral Galaxies I

### 126.01 – The Extended Distribution of Hot Baryons Around Isolated Galaxies

X-ray surface brightness studies find that for isolated galaxies of luminosity  $L^*$  and greater, hot halos are detected to 50-100 kpc, where typically,  $M(< 50 \text{ kpc}) \sim 5E9 \text{ Msun}$  and with a density declining as  $r^{-3/2}$ . When extrapolated to the virial radius, the gas mass is an order of magnitude larger, making it comparable to the stellar mass, but is still does not account for the missing baryons. The missing baryons could be accounted for if this density distribution extends to about three virial radii. While there is no a priori reason for this very extended gas to be hot, a high temperature is suggested from the Sunyaev-Zeldovich signal of stacked galaxies, although there may be issues with this interpretation. These hot halos show significant enrichment. The Galactic halo metallicity has a mean value of at least 0.3 solar for lines of sight out to the LMC, and studies of dust extinction around other galaxies show comparable metal content out to and beyond the virial radii.

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### 126.02D – Baryonic Distributions in Galaxy Dark Matter Halos

Understanding the role and significance of dark matter in the evolution of baryonic components (i.e., conversion of the gaseous disk into stars) is a critical aspect for realistic models of galaxy evolution. In an effort to address fundamental questions regarding the growth and distribution of stellar disks in dark matter halos in a statistical manner, we have undertaken a project correlating structural properties and star formation activity with the dark matter properties of the host galaxy. The project uses a statistical sample of 45 nearby galaxies which are optimally suited for rotation curve decomposition analysis. The dataset includes deep Spitzer 3.6  $\mu\text{m}$  images to trace the stellar distribution, neutral and ionized gas rotation curves to trace the total mass distribution, and optical images to examine the dominant stellar populations. Using a sub-set of galaxies from the full sample, we find that the distribution of the baryonic mass relative to the total mass is roughly self-similar in more massive galaxies when normalized by the average stellar disk scale length measured at 3.6  $\mu\text{m}$ . We additionally observe an emerging trend between total baryonic mass and the radius at which the total mass distribution transitions from baryon-dominated to dark matter-dominated. However, we find no significant correlation between the distribution of dark matter and structural properties of the stellar disk, such as changes in color or star formation activity.

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### 126.03 – The Longest Stellar Stream in M31's Halo

We present updated data and dynamical modeling of several tidal features in the M31 halo. We focus on the NW Stream, a nearly radial feature extending outwards from M31. Using new distance estimates from evolved stars and embedded globular clusters, we find this stream

extends to a greater distance from its host than any other known tidal stream. We update the stream velocity profile with new measures from resolved stars and globular clusters. We use Bayesian dynamical modeling to discover the stream's implications for M31's halo mass and the life history of its progenitor galaxy.

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**Contributing team(s):** PAndAS Collaboration

### 126.04 – A New Deep, Hard X-ray Survey of M31: Monitoring Black Hole and Neutron Star Accretion States in the X-ray Binary Population of Our Nearest Neighbor

X-ray binaries (XRBs) trace old and new stellar populations in galaxies, and thus star formation history and star formation rate. X-ray emission from XRBs may be responsible for significant amounts of heating of the early Intergalactic Medium at Cosmic Dawn and may also play a significant role in reionization. Until recently, the hard emission from these populations could only be studied for XRBs in our own galaxy, where it is often difficult to measure accurate distances and thus luminosities. The launch of *NuSTAR*, the first focusing hard X-ray observatory, has allowed us to resolve the brightest XRBs (down to  $L_X \sim \text{few times } 10^{38} \text{ erg/s}$ ) in galaxies like NGC 253, M83, and M82 up to 4 Mpc away. To reach much lower X-ray luminosities that are more typical of XRBs in the Milky Way ( $L_X < 10^{37} \text{ erg/s}$ ), we have observed M31 in 3 *NuSTAR* fields, up to 5 visits apiece for more than 1 Ms total exposure, mostly within the footprint of the Panchromatic Hubble Andromeda Treasury (PHAT) Survey. Our monitoring campaign reveals over 40 accreting black holes and neutron stars -- distinguished from each other by their spectral shape in the hard band -- some of which undergo state changes over the month-long timescales captured by our legacy survey to date. We also discuss implications for this updated understanding of XRB populations on early-Universe measurements in, e.g., the 7 Ms Chandra Deep Field survey.

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### 126.05 – The ALMA and HST Views of the Molecular Gas and Star Formation in the Prototypical Barred Spiral Galaxy NGC 1097

We mapped the entire inner disk of NGC 1097 (the circumnuclear ring, bar ends, the bar and inner spiral arms) using ALMA in the CO J=1-0 line at resolution of 1" ( $\sim 65 \text{ pc}$ ). We also mapped the northern half of the bar in every other common molecular gas tracer at 3mm (HCN, HCO+, C18O, 13CO, C34S). Together these data provide the most detailed and highest resolution map of the molecular gas distribution and kinematics in a nearby barred spiral, rivaling the incredible maps seen for galaxies like M51 in the northern hemisphere. The data show the impact of the different environments in the galaxy as well as evidence for a multi-phased molecular medium. The data also evidence how the shear induced by the bar shock completely inhibits the star formation activity in the inner ends of the bar (clearly showing an anti-correlation between the strength of the CO line emission and H $\alpha$  emission). We will also present multiwavelength HST observations of the galaxy which are used to identify and map star clusters across the inner disk of the galaxy. We use these data to understand how star formation proceeds from one environment to the next across the galaxy.

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## 126.06 – Making the Near-Far Connection in Disk Galaxy Formation

Modern, high-resolution, cosmological galaxy formation simulations reveal that disks can grow “upside-down” in the sense that progressively younger stellar populations are born with increasingly smaller vertical velocity dispersion, tracing the kinematics of the collapsing gas disk from which they form. We find that the upside-down model matches the most stringent observational constraints here in the MW, including the steep stellar age-velocity relationship measured in the solar neighborhood. Tracing the temporal evolution of our simulated galaxies, we find that the vertical velocity dispersion of young stars is highest at early times and decreases towards the present-day, matching the “disk settling” results found in disk galaxies from  $z \sim 2$  to now. Our findings suggest that the upside-down model is currently the only self-consistent disk formation mechanism to connect the multi-scale kinematics of galaxies in both the near and far field.

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**Contributing team(s):** UW N-Body Shop

## 126.07 – The role of interactions in triggering bars, spiral arms and AGN in disk galaxies

The role of secular structures like bars, rings and spiral arms in triggering star formation and AGN activity in disk galaxies are not well understood. In addition, the mechanisms which create and destroy these structures are not well characterized. Mergers are considered to be one of the main mechanisms which can trigger bars in massive disk galaxies. Using a sample of  $\sim 8000$  close pair galaxies at  $0.02 < z < 0.06$  from the Sloan Digital Sky Survey, I will present results illustrating the role of mergers in triggering bars, rings, spiral arms and AGN as a function of close pair separation and merger ratios as well as their dependence on morphology and other physical properties of the galaxies. Time permitting, I will show how resolved IFU observations from SDSS MaNGA will help to place stronger constraints on the role of these structures in triggering star formation and AGN.

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## 126.08 – Demographics of galactic bulges in the local universe through optical windows

We present our results of two-dimensional bulge-disk decompositions for 14,659 galaxies drawn from SDSS DR12 in order to examine properties of bulges residing in the local universe ( $0.005 < z < 0.05$ ). We performed the decompositions in g and r-bands by utilizing GALFIT software. We have derived the color of bulges and found that bulge color is redder than galaxy color and most of bulges ( $B/T > 0.2$ ) show almost constant (g-r) colors regardless of their size. We also investigated the scaling relations (Kormendy and Faber-Jackson relations), which ellipticals are generally known to follow, for all of our sample bulges. Specifically, we have found that low B/T ( $0.1 < B/T < 0.3$ ) bulges show the largest difference in the slope of the Kormendy relation from that of ellipticals. The differences become gradually smaller as bulges are larger. The Faber-Jackson relation on our bulges shows that low B/T bulges seem to have lower slopes than high B/T bulges do, approximately by a factor of 1.5, by being located below the well-known relation (i.e., the exponent of 4). Bulges on the Fundamental Plane basically appear to lie on the same plane while the noticeable tilt of the plane has been found for low B/T bulges. We have examined the effect of young stellar population on the tilt with H $\beta$  absorption line strengths and found that a significant tilt (at least more than  $\sim 30\%$  of the tilt) mainly arises from the effect of young stellar population in bulges. This implies that bulges are basically virialized systems irrespective of their size and thus the scatters

about the scaling relations are a result of the presence of young stellar population preferentially in low B/T bulges. Drawn from our results, bulges seem very similar to ellipticals, although they are thought to be formed through the different formation mechanisms.

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## 128 – Extrasolar Planet Atmospheres: Theory II

### 128.01 – Stellar activity effects on high energy exoplanet transits

High energy (X-ray / UV) observations of transiting exoplanets have revealed the presence of extended atmospheres around a number of systems. At such high energies, stellar radiation is absorbed high up in the planetary atmosphere, making X-ray and UV observations a potential tool for investigating the upper atmospheres of exoplanets. At these high energies, stellar activity can dramatically impact the observations. At short wavelengths the stellar disk appears limb-brightened, and active regions appear as extended bright features that evolve on a much shorter timescale than in the optical making it difficult. These features impact both the transit depth and shape, affecting our ability to measure the true planet-to-star radius ratio.

I will show results of simulated exoplanet transit light curves using Solar data obtained in the soft X-ray and UV by NASA’s Solar Dynamics Observatory to investigate the impact of stellar activity at these wavelengths. By using a limb-brightened transit model coupled with disk resolved Solar images in the X-ray, extreme- and far-UV I will show how both occulted and unocculted active regions can mimic an inflated planetary atmosphere by changing the depth and shape of the transit profile. I will also show how the disk integrated Lyman-alpha Solar irradiance varies on both short and long timescales and how this variability can impact our ability to recover the true radius ratio of a transiting exoplanet.

Finally, I will present techniques on how to overcome these effects to determine the true planet-to-star radius in X-ray and UV observations.

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### 128.02 – Exploring Chemical Equilibrium in Hot Jovians

It has been established that equilibrium chemistry is usually achieved deep in the atmosphere of hot Jovians where timescales are short (Line and Yung 2013). Thus, equilibrium chemistry has been used as a starting point (setting initial conditions) for evaluating disequilibrium processes. We explore parameters of setting these initial conditions including departures from solar metallicity, the number of species allowed in a system, the types of species allowed in a system, and different thermodynamic libraries in an attempt to create a standard for evaluating equilibrium chemistry. NASA’s open source code Chemical Equilibrium and Applications (CEA) is used to calculate model planet abundances by varying the metallicity, in the pressure regime 0.1 to 1 bar. These results are compared to a variety of exoplanets (T<sub>eq</sub> between 600 and 2100K) qualitatively by color maps of the dayside with different temperature redistributions. Additionally, CEA (with an up-dated thermodynamic library) is compared with the thermochemical model presented in Venot et al. (2012) for HD 209458b and HD 189733b. This same analysis is then applied to the cooler planet HD 97658b. Spectra are generated and we compare both models’ outputs using the open source code transit (<https://github.com/exosports/transit>) using the opacities of 15 molecules. We make the updated CEA thermodynamic library and supporting Python scripts to do the CEA analyses available open source. This

work was supported by NASA Planetary Atmospheres grant NNX12AI69G.

**Author(s): Sarah Blumenthal<sup>3</sup>, Joseph Harrington<sup>3</sup>, Avi Mandell<sup>2</sup>, Eric Hébrard<sup>2</sup>, Olivia Venot<sup>1</sup>, Patricio Cubillos<sup>3</sup>, Jasmina Blecic<sup>3</sup>, Ryan Challener<sup>3</sup>**

**Institution(s):** 1. *Instituut voor Sterrenkunde, Katholieke Universiteit Leuven*, 2. *NASA Goddard Space Flight Center*, 3. *University of Central Florida*

### 128.03 – Simulations of Hot Jupiter-Stellar Wind Hydrodynamic Interaction

Hot Jupiters and Neptunes are subjected to large UV and stellar wind fluxes due to their proximities to their host stars. We have investigated the hydrodynamic interaction between the stellar wind and the planetary atmosphere and how the stellar wind can potentially limit the formation of a supersonic planetary outflow. We also discuss the ability of charge exchange in creating a potentially observable population of hot, neutral hydrogen, and how the flow geometry is reflected in the Lyman alpha transit signal with the signal from the hot population being concentrated at impact parameters. The influence of radiation pressure from stellar Lyman-alpha photons will also be discussed.

**Author(s): Duncan Christie<sup>1</sup>, Phil Arras<sup>2</sup>, Zhi-Yun Li<sup>2</sup>**

**Institution(s):** 1. *University of Florida*, 2. *University of Virginia*

### 128.04D – Forward Models of Exoplanets for Atmosphere Retrievals with JWST

We present models of extrasolar planets incorporating self-consistent treatment of internal structures, radiative cooling and XUV-driven mass loss over time, and over a range of masses. We also present new atmosphere models with 1-D radiative transfer and a range of compositions and cloud structures, with both theoretical transit and secondary eclipse spectra. These complimentary model sets are designed for performing retrievals of atmosphere parameters with data from the upcoming JWST mission. Finally, we present preliminary results with new theoretical spectra fit to well-observed transiting exoplanets.

**Author(s): Alex Howe<sup>1</sup>, Adam Seth Burrows<sup>1</sup>**

**Institution(s):** 1. *Princeton University*

### 128.05 – Spectral Signatures of WFIRST-AFTA Exoplanet Coronagraphy Targets

A key component of the WFIRST-AFTA mission is high contrast imaging of planets and debris disks around nearby stars. It is expected that the WFIRST-AFTA mission will be able to characterize around a dozen exoplanets, many of which are already known to exist from current radial velocity surveys. These planets will possess a broad range of atmospheric properties, including a number of possible cloud species and atmospheric compositions. In preparation for the WFIRST-AFTA mission, our team is constructing a library of relevant theoretical spectra and performing spectral retrieval analyses to assess the robustness with which WFIRST-AFTA will be able to characterize exoplanet atmospheres. Here we present our initial findings for a subset of the known exoplanet population that will likely be prime targets for the WFIRST-AFTA mission.

**Author(s): Nikole K. Lewis<sup>5</sup>, Mark S. Marley<sup>3</sup>, Roxana E. Lupu<sup>4</sup>, Jonathan J. Fortney<sup>6</sup>, Caroline Morley<sup>6</sup>, Thomas P. Greene<sup>3</sup>, Tyler D Robinson<sup>6</sup>, Channon Visscher<sup>1</sup>, Richard Freedman<sup>3</sup>, Michael R. Line<sup>3</sup>, Wesley A. Traub<sup>2</sup>**

**Institution(s):** 1. *Dordt*, 2. *JPL*, 3. *NASA Ames*, 4. *SETI*, 5. *STScI*, 6. *UCSC*

## 129 – Stellar Winds and Magnetospheres

### 129.01 – $\theta$ Car: X-ray Emission from Low Density Radiation-Driven Winds

We present *Chandra* X-ray grating spectroscopy (and *IUE* spectroscopy) of the B0.2 V star,  $\theta$  Carina.  $\theta$  Car is in a critical transition region between the earliest B stars and the latest O stars,

where the density of the wind is observed to decrease more than theoretically expected. In general, X-ray emission in this low-density wind regime should be less prominent, but observations have shown that there is a higher than expected production of X-ray emission from the winds of these stars; this severely challenges predictions of radiatively driven wind theory. We measure the  $f/i$  ratio, widths, and velocities of several Helium-like lines in the X-ray spectrum. The  $f/i$  ratio is a diagnostic of the radial location of the X-ray emitting plasma, which is sensitive to the specific transition of each He-like ion. We use  $\theta$  Car to study the radiatively-driven mass-loss of early B-type stars.

**Author(s): Trisha Doyle (Mizusawa)<sup>2</sup>, Veronique Petit<sup>2</sup>, David Held Cohen<sup>6</sup>, Alexander W. Fullerton<sup>5</sup>, Marc Gagne<sup>8</sup>, Maurice A. Leutenegger<sup>3</sup>, Zequn Li<sup>6</sup>, Stanley P. Owocki<sup>7</sup>, Jon Sundqvist<sup>1</sup>, Gregg Wade<sup>4</sup>**

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### 129.02 – Spectropolarimetric Analysis of the Giant Magnetosphere of O-type Star NGC1624-2

The Of?p star, NGC1624-2, has the largest magnetic field ever found for an O-type star. Like many magnetic O-type stars NGC1624-2 has a slow rotation with a period of  $\sim 158$  days but its strong magnetic field strength of 20 kG (Wade et al. 2012) is an order of magnitude larger than those of other O-type stars. This study aims to model the geometry of the longitudinal magnetic field and to determine the surface field modulus using spectropolarimetry data from the ESPaDOnS instrument at the Canada-French-Hawaii Telescope. Our preliminary results found a longitudinal field strength,  $\langle B_z \rangle$ , of  $5.27 \pm 0.7$  kG, which agrees with the original results from Wade et al. (2012) who found a  $\langle B_z \rangle$  of  $5.35 \pm 0.5$  kG. Zeeman splitting as never seen before observed in an O-type star spectra. However, we observe it in the spectra for this star, which allows us to put unprecedented constraints on the field topology compared to other magnetic O-type stars. This model will help with the interpretation of observations of NGC1624-2's giant magnetosphere obtained with Chandra and HST.

**Author(s): Rebecca MacInnis<sup>1</sup>, Veronique Petit<sup>1</sup>, Gregg Wade<sup>2</sup>**

**Institution(s):** 1. *Florida Institute of Technology*, 2. *Royal Military College of Canada*

### 129.03 – Massive-Star Magnetospheres in the Near-Infrared

Magnetospheres of massive stars are known to exhibit variable emission signatures in the Hydrogen recombination lines in spectroscopy in optical wavelengths (i.e. the Balmer series). These features have been used to study both the mass content and the structure of the magnetosphere. This work aims to broaden our knowledge of these circumstellar environments into the near-infrared (JHK bands). We explore the line profiles produced in the Brackett series, and search for variability. Infrared is fast becoming the next frontier, and this study represents a first step in utilizing the benefits of longer wavelengths over UV and optical.

**Author(s): Mary E. Oksala<sup>1</sup>**

**Institution(s):** 1. *Observatoire de Paris-Meudon*

### 129.04 – An X-ray Comparison of Centrifugal Magnetospheres in Five B-type Stars

Massive stars lose a large amount of their main sequence mass through their strong stellar winds. However, the stellar wind properties and distribution are affected by the strong ( $\sim$ kG) dipolar magnetic fields being detected in a growing population of massive stars by the MiMeS project. In these magnetic stars the stellar wind is channeled along the closed magnetic field loops toward the magnetic equator. The wind flows from opposite hemispheres collide producing X-rays via radiative cooling. Rapidly rotating massive stars have an added centrifugal support allowing for the build up of additional material and the production of energetic X-rays. However, surveys indicate that some stars deviate from these predictions. To better understand this phenomenon, XMM Newton-EPIC and

Chandra-ACIS observations were used to characterize various rapidly rotating magnetic B-type stars. The X-ray fluxes provide a comparison to the slow rotating magnetic stars, which will provide strong constraints the underlying physics of magnetospheres in massive stars.

**Author(s):** Corinne Fletcher<sup>1</sup>, Veronique Petit<sup>1</sup>, Y. Naze<sup>6</sup>, Asif Ud-Doula<sup>2</sup>, Gregg Wade<sup>4</sup>, Matt Shultz<sup>3</sup>, David Held Cohen<sup>5</sup>  
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### 129.05D – Steady-State Models of X-ray Emission from Massive-Star Magnetospheres

In the subset of OB stars with large-scale, organized magnetic fields, the stellar wind is forced to flow along magnetic field lines and is trapped within a magnetosphere corotating with its host star. As the wind turns on itself, shocks heat the plasma to millions of degrees and produce X-ray emission. Such magnetospheres are typically classified with the “wind magnetic confinement parameter”, a simplified ratio between the magnetic energy density and the wind kinetic energy density. This parameter is often used to estimate magnetosphere properties, such as size, mass-loss rate, and spin-down time. Unfortunately, the strong magnetic fields in magnetospheres (polar strength: 100 G - 10 kG) and resulting Alfvén velocities make magnetohydrodynamics simulations computationally difficult due to very small timesteps. To get around this issue, we approximate a massive-star magnetosphere as a series of one-dimensional flows along magnetic dipole field lines and develop a steady-state model from the resulting hydrodynamic equations. With this model, we derive scaling relations for the stellar mass-loss rate as a function of surface colatitude and find agreement with previous scaling results derived from simulations. These relations are further extended to include the effects of rigid-body rotation within the magnetosphere. Additionally, we develop an X-ray emission model from this steady-state analysis and compare it against both the “XADM” model for X-ray emission from massive star magnetospheres and observations of massive magnetic stars. Finally, we discuss improvements to the traditional wind magnetic confinement parameter to take into account the effect of a magnetic field on the wind kinetic energy density.

**Author(s):** Christopher Bard<sup>1</sup>, Richard D. Townsend<sup>1</sup>  
**Institution(s):** 1. University of Wisconsin

### 129.06 – Charge Exchange of Ne<sup>9+</sup> for X-ray Emission

Using the molecular-orbital close-coupling (MOCC) method, single electron capture (SEC) cross sections were computed for Ne<sup>9+</sup> colliding with H. Potential energies and nonadiabatic couplings were calculated and used to obtain the MOCC cross sections which are final-quantum-state-resolved including a separation of singlet and triplet states. Atomic-orbital close-coupling, classical trajectory Monte Carlo, and multichannel Landau-Zener (MCLZ) calculations are also performed. Cross sections for more complicated targets including He, H<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>O, CO, and CO<sub>2</sub>, were obtained with the MCLZ method. The SEC results are compared with experimental and other theoretical data, where available. The SEC cross sections are being used in cascade models to predict X-ray emission spectra relevant to solar system and astrophysical environments.

D. Lyons, R. S. Cumbee, P. D. Mullen, P. C. Stancil (UGA), D. R. Schultz (UNT), P. Liebermann (Wuppertal Univ.), R. Buenker (NCSU).  
This work was partially supported by NASA grant NNX09AC46G.

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## 130 – HAD III: History of Astronomy: History, Archaeoastronomy, Philosophy, and

## Education

### 130.02 – Kilohoku Ho`okele Wa`a--- Na `Ohana Hoku `Eha (The Astronomy of the Hawaiian Navigators--- The Four Star Families)

This paper documents the complete modern Hawaiian navigational full-sky. Over eight years of field notes, observations, and interviews with cultural leaders, historians, and ho`okele wa`a (navigators) were used to construct and validate Kilohoku Ho`okele Wa`a, the Astronomy of the Hawaiian Navigators. In contrast to the various historical sky maps designed by different practitioners and local groups in pre-colonial times, this sky-map depicts the four whole-sky constellations used by present day wayfinders. Designed by a loosely bound group of cultural leaders and navigators as a tool to use in modern non-instrumental navigation, Kilohoku Ho`okele Wa`a is a pragmatic fusion of ancient Hawaiian tradition, traditions of greater Polynesia, and modern-day Indigenous cultural forces. Like a very small number of cultures who use the sky for non-instrumental navigation, the ho`okele wa`a conceive of each season's visible sky as a whole image, using a single constellation that stretches from the northern to the southern horizon as a tool that facilitates direction finding in skies that are often very cloudy, and that chunks the sky into sections that decrease the cognitive load placed on the navigator. Moving through the seasons, beginning in Winter, Na `Ohana Hoku `Eha (The Four Star Families) are Kekaomakali `I (The Bailer), Kaiwikuamo`o (The Backbone), Manaiaikalani (The Fishhook), and Kalupekawelo (The Kite). The whole-sky character of each of the four “star families,” combines with that star family's mo`olelo (purposeful story) to further facilitate navigation, employing the emotional component of moral and familial associations to enhance memorization and to provide wayfinders with encouragement on their long journeys.

**Author(s):** Stephanie Slater<sup>1</sup>, Timothy F. Slater<sup>3</sup>, Kalepa C. Baybayan<sup>2</sup>  
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### 130.03 – Profiling Some of the Lesser-Known Historical Women Astronomers

Although some historical women astronomers such as Henrietta Swan Leavitt and Cecilia Payne Gaposchkin have recently become somewhat well known among the astronomical community, many others--especially those from non-Western cultures--remain a mystery even to those of us who are actively aware of and interested in the role of early women in astronomy. As part of a project to educate myself on some of these women, I started a blog series (<http://ashpags.tumblr.com/tagged/lady-astronomers>) to share this newfound knowledge with a population that is on average relatively young, extremely tech savvy, and generally would not consider themselves to be science-inclined. I will discuss some of the more interesting women I have profiled, as well as my observations on the efficacy of this method of history education.

**Author(s):** Ashley Pagnotta<sup>1</sup>  
**Institution(s):** 1. American Museum of Natural History

### 130.04 – Teaching the History of Astronomy On Site in London

In the autumn of 2014, the author had the opportunity to teach a class on the history of astronomy in England as part of a study abroad experience for students at Illinois Wesleyan University. The philosophy of the program is to use the rich cultural environment of London as a setting for active learning. In the classroom, students read and discussed selected works by Ptolemy, Copernicus, Kepler, Galileo, and Herschel. We visited Stonehenge, the Royal Greenwich Observatory, the London Science Museum, the London Monument, and the library of the Royal Astronomical Society. Lessons learned from the experience will be shared.

**Author(s):** Linda M. French<sup>1</sup>  
**Institution(s):** 1. Illinois Wesleyan Univ.

### 130.05 – The Astronomy Genealogy Project: A

## Progress Report

Although it is not yet visible, much progress has been made on the Astronomy Genealogy Project (AstroGen) since it was accepted as a project of the Historical Astronomy Division (HAD) three years ago. AstroGen will list the world's astronomers with information about their highest degrees and advisors. (In academic genealogy, your thesis advisor is your parent.) A small group (the AstroGen Team) has compiled a database of approximately 12,000 individuals who have earned doctorates with theses (dissertations) on topics in astronomy, astrophysics, cosmology, or planetary science. These include nearly all those submitted in Australia, Canada, the Netherlands, and New Zealand, and most of those in the United States (all through 2014 for most universities and all through 1990 for all). We are compiling more information than is maintained by the Mathematics Genealogy Project (MGP). In addition to name, degree, university, year of degree, and thesis advisor(s), all provided by MGP as well, we are including years of birth and death when available, mentors in addition to advisors, and links to the thesis when it is online and to the person's web page or obituary, when we can find it. We are still struggling with some questions, such as the boundaries of inclusion and whether or not to include subfields of astronomy. We believe that AstroGen will be a valuable resource for historians of science as well as a source of entertainment for those who like to look up their academic family trees. A dedicated researcher following links from AstroGen will be able to learn quite a lot about the careers of astronomy graduates of a particular university, country, or era. We are still seeking volunteers to enter the graduates of one or more universities.

**Author(s): Joseph S. Tenn<sup>1</sup>**

**Institution(s):** 1. *Sonoma State Univ.*

### 130.06 – Critical Issues in the Philosophy of Astronomy and Cosmology

Although the philosophy of science and of specific sciences such as physics, chemistry, and biology are well-developed fields with their own books and journals, the philosophy of astronomy and cosmology have received little systematic attention. At least six categories of problems may be identified in the astronomical context: 1) the nature of reasoning, including the roles of observation, theory, simulation, and analogy, as well as the limits of reasoning, starkly evident in the anthropic principle, fine-tuning, and multiverse controversies; 2) the often problematic nature of evidence and inference, especially since the objects of astronomical interest are for the most part beyond experiment and experience; 3) the influence of metaphysical preconceptions and non-scientific worldviews on astronomy, evidenced, for example in the work of Arthur S. Eddington and many other astronomers; 4) the epistemological status of astronomy and its central concepts, including the process of discovery, the problems of classification, and the pitfalls of definition (as in planets); 5) the role of technology in shaping the discipline of astronomy and our view of the universe; and 6) the mutual interactions of astronomy and cosmology with society over time. Discussion of these issues should draw heavily on the history of astronomy as well as current research, and may reveal an evolution in approaches, techniques, and goals, perhaps with policy relevance. This endeavor should also utilize and synergize approaches and results from philosophy of science and of related sciences such as physics (e.g. discussions on the nature of space and time). Philosophers, historians and scientists should join this new endeavor. A Journal of the Philosophy of Astronomy and Cosmology (JPAC) could help focus attention on their studies.

**Author(s): Steven J. Dick<sup>1</sup>**

**Institution(s):** 1. *NASA*

### 130.07 – General relativity, Islamic cosmology, at odds or not?

The cosmology of the Islamic Qur'an is interesting, both historically and currently. Our universe is described as a cyclical, repeating creation (Ch. #27, Vs. #64), existing within multiple layers or boundaries (Ch. #67, Vs. #3). In modern terms, Islamic cosmology is comparable to Lemaitre's 1927 dynamic equilibrium theory (Lemaitre 1927a), only recently reintroduced (Steer 2013, 2014,

2015). Could the old idea of a cyclical universe, found in the Qur'an and suggested by Lemaitre, yet prove revolutionary to today's theory that expansion had only one beginning, proceeds in only one direction, and arose from only nothing?

**Author(s): Ian Steer<sup>1</sup>**

**Institution(s):** 1. *NED*

## 134 – HAD IV: History of Astronomy Poster Session

### 134.01 – Stonehenge's Greater Cursus

Archaeological investigations have emphasized relationships between solar and lunar phenomena and architectural features of prehistoric sites located on the Stonehenge ritual landscape. However, no over-riding landscape design has been identified to explain the purpose of placing hundreds of Neolithic through Iron Age burial sites upon the landscape. Our research and analysis shows the mid-4<sup>th</sup> millennium BC (mid-Neolithic) landscape represents an 'above, so below' cosmo-geographical relationship. Type, shape, size and orientation of specific elements (such as long barrows, henges, cursus and topography) created a hierotopy representing the Winter Hexagon asterism, Milky Way, ecliptic and other stellar features. The resulting pattern of ritual sites represents translocation of the astronomical Otherworld – the Spirit World – onto the plain. Results of the analysis create a new paradigm of purpose for the built landscape circa 3500 BC, and identifies the reason why Stonehenge is located where it is with respect to other contemporary monuments.

**Author(s): Paul Burley<sup>1</sup>, Howard D Mooers<sup>1</sup>**

**Institution(s):** 1. *University of Minnesota Duluth*

### 134.02 – Urania in the Marketplace: The Selling of Mt. Palomar

The 200-inch Hale telescope atop Mt. Palomar is one of the most iconic scientific facilities ever constructed. The world's largest optical telescope for over a quarter-century, it served as a symbol of hope for America during the Great Depression and in the post-war years. In 2016 we celebrate the eightieth anniversaries of the completion of the mirror blank, the start of construction of the dome and mounting, and the beginning of astronomical research at Palomar Observatory by Fritz Zwicky (with the 18-inch Schmidt camera).

During its construction, and for many years after "first light" in 1949, the Hale telescope was prominently featured in numerous magazine advertisements. Most of these represented companies directly involved in its construction, notably Corning Glass Works, which was justly proud of its magnificent accomplishment. But companies only vaguely linked to the project, or not at all, also co-opted the mystique of "the World's Largest Eye" to promote their goods or services. Surprisingly, in light of the fact that it bore responsibility for fabricating the complex and innovative mounting, the Westinghouse Electric & Manufacturing Company appears to have run only a single advertisement (in *The National Geographic Magazine*) touting its contribution to the project.

Examples of magazine advertisements spanning the period 1936 to 1959 are presented.

*This work was supported by a faculty scholarship grant from Valdosta State University.*

**Author(s): Kenneth S. Rumstay<sup>1</sup>**

**Institution(s):** 1. *Valdosta State University*

### 134.03 – Preserving the History of Wesleyan University's Van Vleck Observatory

Since its opening in 1916, the Van Vleck Observatory at Wesleyan University has been dedicated to the joint mission of astronomical education and research. In celebration of the Observatory's centennial year, we are undertaking a number of projects to preserve and chronicle its history. The centerpiece of these efforts has been the renovation of the 20-inch Alvan Clark refracting telescope.

Through careful compromise of historical restoration and modernization, we have ensured the future of one of the nation's last large, long-focus refractors well into the 21st century. In addition, we are producing an historical exhibition in the Observatory and online that will open to the public in the spring of 2016. Our exhibition explores the place-based nature of astronomical research, the scientific instruments, labor, and individuals that have connected places around the world in networks of observation, and the broader history of how observational astronomy has linked local people, amateur observers, professional astronomers, and the tools and objects that have facilitated their work under Connecticut's skies over the past 100 years. We are also collecting memories from the community to enrich our exhibition. If you have a story about the Van Vleck Observatory you would like to share with our researchers, please contact one of the authors.

**Author(s):** Roy E. Kilgard<sup>1</sup>, Paul Erickson<sup>1</sup>, William Herbst<sup>1</sup>, Seth Redfield<sup>1</sup>, Amrys Williams<sup>1</sup>  
**Institution(s):** 1. *Wesleyan Univ.*

## 135 – Elliptical and Spiral Galaxies Poster Session

### 135.01 – Formaldehyde in Absorption: Tracing Molecular Gas in Early-Type Galaxies

Early-Type Galaxies (ETGs) have been long-classified as the red, ellipsoidal branch of the classic Hubble tuning fork diagram of galactic structure. In part with this classification, ETGs are thought to be molecular and atomic gas-poor with little to no recent star formation. However, recent efforts have questioned this ingrained classification. Most notably, the ATLAS3D survey of 260 ETGs within ~40 Mpc found 22% contain CO, a common tracer for molecular gas. The presence of cold molecular gas also implies the possibility for current star formation within these galaxies. Simulations do not accurately predict the recent observations and further studies are necessary to understand the mechanisms of ETGs.

CO traces molecular gas starting at densities of  $\sim 10^2 \text{ cm}^{-3}$ , which makes it a good tracer of bulk molecular gas, but does little to constrain the possible locations of star formation within the cores of dense molecular gas clouds. Formaldehyde ( $\text{H}_2\text{CO}$ ) traces molecular gas on the order of  $\sim 10^4 \text{ cm}^{-3}$ , providing a further constraint on the location of star-forming gas, while being simple enough to possibly be abundant in gas-poor ETGs. In cold molecular clouds at or above  $\sim 10^4 \text{ cm}^{-3}$  densities, the structure of formaldehyde enables a phenomenon in which rotational transitions have excitation temperatures driven below the temperature of the cosmic microwave background (CMB),  $\sim 2.7 \text{ K}$ . Because the CMB radiates isotropically, formaldehyde can be observed in absorption, independent of distance, as a tracer of moderately-dense molecular clouds and star formation.

This novel observation technique of formaldehyde was incorporated for observations of twelve CO-detected ETGs from the ATLAS3D sample, including NGC 4710 and PGC 8815, to investigate the presence of cold molecular gas, and possible star formation, in ETGs. We present images from the Very Large Array, used in its C-array configuration, of the  $J = 1_{1,0} - 1_{1,1}$  transition of formaldehyde towards these sources. We report our preliminary results here.

Niklaus M. Dollhopf gratefully acknowledges the support of the National Radio Astronomy Observatory Summer Student REU Program sponsored by the National Science Foundation.

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### 135.02 – Stellar Populations of Shell Galaxies

We present a study of the inner (out to  $\sim 1$  effective radius) stellar populations in a sample of 9 shell galaxies. We derive stellar population parameters from long slit spectra by both analyzing the

Lick indices of the galaxies and by fitting high resolution SSP model spectra to the full galaxy spectra. The results from the two methods agree reasonably well. We find the presence of young stellar populations in several of the galaxies, implying recent star formation and allowing us to speculate on the age of the shells. Analyzing the metallicity gradients in our sample, we find an average metallicity gradient of  $-0.16 \pm 0.10 \text{ dex/decade}$  in radius. Finally, we compare this with galaxy evolution models to try to constrain the merging history of shell galaxies. We argue that our galaxies likely have undergone major mergers in their past but it is unclear whether the shells formed from these events or from separate minor mergers.

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**Institution(s):** 1. *NOAO-South*, 2. *Rice University*

### 135.03 – An HI Survey of Extremely Isolated Early-type Galaxies

We present preliminary results from an HI survey of extremely isolated early-type galaxies (IEGs) conducted using the NRAO Robert C. Byrd Green Bank Telescope (GBT). The IEGs in our study are isolated to within 2.5 Mpc from other galaxies with luminosities brighter than  $M_V = -16.5$ . The IEGs presented here are a subset of targets previously studied at shorter wavelengths. A large fraction of the IEGs shows evidence of recent or ongoing star formation, in contrast to their counterparts in higher density environments. The survey described here represents the first comprehensive assessment of neutral gas content within and around such systems. Preliminary findings from our HI survey indicate at least a quarter of the observed galaxies have detectable HI gas.

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**Institution(s):** 1. *NASA Ames Research Center*

### 135.04 – The Dynamical Relationship Between the Bar and Spiral Patterns of NGC 1365

Theories describing the dynamical relationship between bar and spiral patterns in galaxy disks make different predictions about the radial profile of the pattern speed. The purpose of this poster is to test these predictions for the bar and spiral patterns of NGC 1365. The pattern speed is measured by fitting different forms of the Tremaine-Weinberg equations to H-alpha intensity and velocity maps. The results are the most consistent with the currently observed bar and spiral patterns being dynamically distinct features. They show compelling evidence for the bar rotating faster than the spiral pattern, inconsistent with a global wave mode or a manifold. The evidence for mode coupling of the bar and spiral patterns is weak due to inconsistencies in the results for different solution methods. The bar pattern speed is approximately constant between the inner Lindblad and corotation resonances, demonstrating that the solutions can detect large-scale, rigid patterns. Beyond the bar, the results resemble what is expected for coupled spiral modes and tidal interactions.

**Author(s):** Jason Speights<sup>1</sup>  
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### 135.05 – Measuring the Dark Matter Content of Galaxies with SALT

In order to test the predictions of galaxy formation models, we seek to measure the detailed dark matter distributions of spiral galaxies. The best way to accomplish this is through measurements of the Doppler shift of the H $\alpha$  line, through which we can produce detailed velocity maps and rotational models of a galaxy. Since the gas flows in rough centrifugal balance, we can use the rotational models to estimate the central gravitational attraction and therefore the mass distribution. As an example, we present a rotational velocity model fitted to an H $\alpha$  velocity map of the spiral galaxy NGC 908, and find that the fitted systemic velocity gives good agreement with previous measurements in the literature. In the future, this method can be used to determine the rotation curves of the nineteen nearby galaxies for which we have or plan to collect interferometric data; we are currently working to produce similar results for the galaxy NGC 7606.

This research has been supported by NSF grant PHY-1263280.

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**Institution(s):** 1. Rutgers, The State University of New Jersey, 2. University of Virginia

### 135.06 – Spectral Observations of Superthin Galaxies

We study the properties of a large sample of edge-on galaxies with high radial-to-vertical scale ratio in their stellar disks, which we call superthin galaxies. Several dozens of such galaxies were selected from EGIS catalog (edge-on galaxies selected from the Sloan Digital Sky Survey). Here we present spectral observations ( $R \sim 5000$ ) of more than 20 superthin galaxies performed with the DIS spectrograph at the Apache Point Observatory 3.5m telescope. The superthin galaxies are found to be similar to low surface brightness disk galaxies. We use the structural parameters of edge-on stellar disks to constrain modeling of ionized gas rotation curves of the galaxies. We discuss some properties of the dark halos in superthin galaxies that can be responsible for the formation and evolution of this rare type of objects.

**Author(s):** Dmitry Bizyaev<sup>1</sup>, Stefan J. Kautsch<sup>2</sup>, Natalia Ya Sotnikova<sup>3</sup>, Aleksander Mosenkov<sup>4</sup>, Vladimir P Reshetnikov<sup>3</sup>

**Institution(s):** 1. NMSU/APO, 2. Nova Southeastern University, 3. St. Petersburg State University, 4. Universiteit Gent

### 135.07 – Searching for Non-Circular Motions in H $\alpha$ Velocity Fields

We present H $\alpha$  velocity fields for four spiral galaxies: NGC 2654, NGC 2841, NGC 5746 and NGC 6674. These velocity fields were constructed from SparsePak IFU data taken on the WIYN telescope at KPNO. We use the DiskFit code to model the kinematics of these galaxies and to determine a rotation curve for each object. We find that two of these galaxies, NGC 2654 and NGC 5746, are nearly edge-on and display both photometric and kinematic evidence of a bar. NGC 6674 is closer to face-on and shows the signatures of a bar and ring. The velocity field of NGC 2841 does not show evidence for significant non-circular motions in the disk.

**Author(s):** Wesley Peters<sup>1</sup>, Rachel Kuzio de Naray<sup>1</sup>

**Institution(s):** 1. Georgia State University

### 135.08 – High-Resolution H $\alpha$ Velocity Fields of Nearby Spiral Galaxies with the Southern African Large Telescope

In an effort to test  $\Lambda$ CDM predictions of galaxy mass distributions, we have obtained spectrophotometric observations of several nearby spiral galaxies with the Southern African Large Telescope (SALT) Fabry-Pérot (FP) interferometer as part of the RSS Imaging spectroscopy Nearby Galaxy Survey. Utilizing the SALT FP's 8 arcmin field of view and 2 arcsec angular resolution, we have derived 2D velocity fields of the H $\alpha$  emission line to high spatial resolution at large radii. We have modeled these velocity fields with the *DiskFit* software package and found them to be in good agreement with lower-resolution velocity fields of the HI 21 cm line for the same galaxies. Here we present our H $\alpha$  kinematic map of the barred spiral galaxy NGC 578. At the distance to this galaxy (22 Mpc), our kinematic data has a spatial resolution of 185 pc and extends to galactocentric radii of 13 kpc. The high spatial resolution of this data allows us to resolve the inner rising part of the rotation curves, which is compromised by beam smearing in lower-resolution observations. We are using these H $\alpha$  kinematic data, combined with HI 21 cm kinematics and broadband photometric observations, to place constraints on NGC 578's mass distribution.

**Author(s):** Carl Mitchell<sup>3</sup>, Ted Williams<sup>4</sup>, Kristine Spekkens<sup>2</sup>, Karen Lee-Waddell<sup>2</sup>, Rachel Kuzio de Naray<sup>1</sup>, Jerry Sellwood<sup>3</sup>

**Institution(s):** 1. Georgia State University, 2. Royal Military College of Canada, 3. Rutgers, the State University of New Jersey, 4. South African Astronomical Observatory

### 135.09 – The RINGS Survey: Optical Broadband

### Photometry

We have targeted a sample of 19 nearby spiral galaxies, the RSS Imaging and Spectroscopy Nearby Galaxy Survey (RINGS), for detailed study of their mass distributions. We have obtained Fabry-Perot H $\alpha$  velocity fields using the Southern African Large Telescope (SALT), 21-cm HI observations using the Very Large Array (VLA), and optical broadband BVRI photometry using the CTIO 0.9m and KPNO 2.1m telescopes. We present the results of the photometric component of the survey including multicolor images, surface brightness profiles, and DiskFit structural models.

**Author(s):** Rachel Kuzio de Naray<sup>1</sup>, Carl Mitchell<sup>3</sup>, Kristine Spekkens<sup>2</sup>, Jerry Sellwood<sup>3</sup>, Ted Williams<sup>4</sup>

**Institution(s):** 1. Georgia State University, 2. Royal Military College of Canada, 3. Rutgers University, 4. South African Astronomical Observatory

### 135.10 – The Influence of Companion Morphology on Dust Properties and Star Formation in Galaxy Pairs

We present an analysis of dust properties of a sample of close major-merger galaxy pairs selected by Ks magnitude and redshift. The pairs represent the two populations of spiral-spiral (S+S) and mixed morphology spiral-elliptical (S+E). The CIGALE (Code Investigating GALaxy Emission) is used to fit dust models to the 2MASS, WISE and Herschel flux measurements and derive the parameters describing the PAH contribution, interstellar radiation field (ISRF) and photo-dissociation regions (PDRs). Model fits verify our previous Spitzer Space Telescope analysis that S+S and S+E pairs do not have the same level of enhancement of star formation and differ in dust composition. The spirals of mixed morphology galaxy pairs do not exhibit the enhancements in interstellar radiation field and therefore dust temperature for spirals in S+S pairs in contrast to what would be expected according to standard models of gas redistribution due to encounter torques. This suggests the importance of the companion environment/morphology in determining the dust properties of a spiral galaxy in a close major-merger pair.

**Author(s):** Donovan L. Domingue<sup>1</sup>, Chen Cao<sup>3</sup>, C. Kevin Xu<sup>2</sup>, Tom Jarrett<sup>5</sup>, Joseph Ronca<sup>1</sup>, Emily Hill<sup>4</sup>

**Institution(s):** 1. Georgia College and State Univ., 2. IPAC, 3. School of Space Science and Physics, Shandong University, 4. Specialty Analytical, 5. University of Cape Town

### 135.11 – Searching for Tidal Features in Galaxy Pair ARP 142

We present the beginning of an ongoing research project to detect tidal features in galaxy pairs with the test case of ARP 142 (NGC 2936 & NGC 2937). Using the 0.6 meter telescope at the Pohl Observatory of Georgia College and State University, a series of sixty, fifteen second luminance exposures, were taken using an SBIG 9XE CCD. In order to reduce the background sky brightness, images were calibrated using standard techniques, as well as using additional flats created from nearby sections of the sky.

**Author(s):** Joseph Ronca<sup>1</sup>, Donovan L. Domingue<sup>1</sup>

**Institution(s):** 1. Georgia College and State University

### 135.12 – Scattered UV light in the interarm regions of M101

We present images from the Solar Blind Channel on the Hubble Space Telescope that resolve hundreds of far-ultraviolet (FUV) emitting stars in two 1 kpc<sup>2</sup> interarm regions of the grand-design spiral M101. The luminosity functions of these stars are compared with predicted distributions from simple star formation histories, and are best reproduced when the star formation rate has recently declined (past 10–50 Myr). In both interarm regions studied, significant amounts of FUV light remain after the detected stellar sources, clusters, and background galaxies are removed. The flux remaining is consistent with predictions of scattered light from radiative transfer models. In Pointing 1, which is immediately adjacent to a spiral arm, we find that scattered light from the arm must contribute significantly to the total FUV in that field ( $\sim 60\%$ ). Meanwhile, Pointing 2, which is further from any spiral arm or

bright star-forming knots, has an upper bound of 16% scattered light. Thus the FUV emission in interarm regions in M101 is partly due to individual FUV-bright stars and partly due to light scattered from the spiral arms. The latter contribution is only significant immediately adjacent to spiral arms.

**Author(s):** Alison Faye Crocker<sup>2</sup>, Rupali Chandar<sup>7</sup>, Daniela Calzetti<sup>6</sup>, Benne Holwerda<sup>5</sup>, Claus Leitherer<sup>3</sup>, Cristina Popescu<sup>4</sup>, Richard Tuffs<sup>1</sup>

**Institution(s):** 1. Max Planck Institut für Kernphysik, Saupfercheckweg, 2. Reed College, 3. STSCI, 4. University of Central Lancashire, 5. University of Leiden, 6. University of Massachusetts, 7. University of Toledo

### 135.13 – Turbulence and Star Formation in a Sample of Spiral Galaxies

We investigate turbulent gas motions in spiral galaxies and their importance to star formation in far outer disks, where the column density is typically far below the critical value for spontaneous gravitational collapse. Following the methods of Burkhart et al. (2010) as applied to the Small Magellanic Cloud, we use the third and fourth statistical moments, skewness and kurtosis, which are indicators of structures caused by turbulence, to examine the integrated neutral hydrogen (H<sub>I</sub>) column density of a sample of spiral galaxies selected from The H<sub>I</sub> Nearby Galaxy Survey (THINGS, Walter et al. 2008). We examine the kurtosis and skewness values of each galaxy as a whole, as well as their variation as a function of radius and in discrete sub-regions defined by a square, moving 'kernel,' essentially splitting each galaxy into a grid. We then create individual grid maps of kurtosis and skewness for each galaxy. To investigate the relation between these moments and star formation, we compare these maps with maps of each galaxy's far-ultraviolet (FUV) image, taken by the *Galaxy Evolution Explorer* (GALEX) satellite. We find that the moments are largely uniform across the galaxies: the variation does not appear to trace any star forming regions. This may, however, be due to the spatial resolution of our analysis, which could potentially limit the scale of turbulent motions to at most ~700 pc. From our analysis of the comparison between the two moments themselves, we find that the gas motions in our sample galaxies are largely supersonic. This analysis shows that Burkhart et al. (2010)'s methods may be applied not just to dwarf galaxies but normal spiral galaxies as well. We acknowledge the NSF for their funding of this work through their Research Experience for Undergraduates (REU) program (Grant No. AST-1461200).

**Author(s):** Erin R Maier<sup>3</sup>, Deidre Ann Hunter<sup>1</sup>, Li-Hsin Chien<sup>2</sup>

**Institution(s):** 1. Lowell Observatory, 2. Northern Arizona University, 3. University of Iowa

### 135.14 – Star formation rates of spiral galaxies in the Cosmic Web

We look for shifts in stellar mass and star formation rate along filaments in the cosmic web by examining the stellar masses and UV-derived star formation rates of 1,799 ungrouped and unpaired spiral galaxies from the Galaxy And Mass Assembly (GAMA) survey that reside in filaments. We devise multiple distance metrics to characterise the complex geometry of filaments, and find that galaxies closer to the orthogonal core of a filament have higher stellar masses than their counterparts near the periphery of filaments, on the edges of voids. We also find that these peripheral galaxies have higher specific star formations at a given mass. Our results suggest a model in which gas accretion from voids onto filaments is primarily in an orthogonal direction. While the star formation rates of spiral galaxies in filaments are susceptible to their locations, we find that the global star formation rates of galaxies in different large scale environments are similar to each other. The primary discriminant in star formation rates is therefore the stellar mass of each spiral galaxy, as opposed to its large scale environment.

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**Institution(s):** 1. NASA Ames Research Centre

**Contributing team(s):** Galaxy And Mass Assembly (GAMA)

## 136 – Dwarf and Irregular Galaxies Poster Session

### 136.01 – SHIELD: The Star Formation Law in Extremely Low-mass Galaxies

The "Survey of HI in Extremely Low-mass Dwarfs" (SHIELD) is a multiwavelength, legacy-class observational study of 12 low-mass dwarf galaxies discovered in Arecibo Legacy Fast ALFA (ALFALFA) survey data products. Here we analyze the relationships between HI and star formation in these systems using multi-configuration, high spatial (~300 pc) and spectral (0.82 - 2.46 km s<sup>-1</sup> ch<sup>-1</sup>) resolution HI observations from the Karl G. Jansky Very Large Array, Ha imaging from the WIYN 3.5m telescope, and archival GALEX far-ultraviolet imaging. We compare the locations and intensities of star formation with the properties of the neutral ISM. We quantify the degree of local co-spatiality between star forming regions and regions of high HI column densities using the Kennicutt-Schmidt (K-S) relation. The values of the K-S index  $N$  vary considerably from system to system; because no single galaxy is representative of the sample, we instead focus on the narratives of the individual galaxies and their complex distribution of gaseous and stellar components. At the extremely faint end of the HI mass function, these systems are dominated by stochastic fluctuations in their interstellar media, which governs whether or not they show signs of recent star formation.

Support for this work was provided by NSF grant AST-1211683 to JMC at Macalester College.

**Author(s):** Yaron Teich<sup>1</sup>, Andrew McNichols<sup>1</sup>, John M. Cannon<sup>1</sup>

**Institution(s):** 1. Macalester College

**Contributing team(s):** SHIELD Team

### 136.02 – SHIELD: Neutral Gas Kinematics and Dynamics

The "Survey of HI in Extremely Low-mass Dwarfs" (SHIELD) is a multiwavelength, legacy-class observational study of 12 low-mass dwarf galaxies discovered in Arecibo Legacy Fast ALFA (ALFALFA) survey data products. Here we present new results of detailed kinematic analyses of these systems using multi-configuration, high spatial (~300 pc) and spectral (0.82 - 2.46 km s<sup>-1</sup> ch<sup>-1</sup>) resolution HI observations from the Karl G. Jansky Very Large Array. For each source, we produce velocity fields and dispersion maps using different spatial and spectral resolution representations of the data in order to attempt derivation of an inclination-corrected rotation curve. While both two- and three-dimensional fitting techniques are employed, the comparable magnitudes of velocity dispersion and projected rotation result in degeneracies that prohibit unambiguous circular velocity solutions. We thus make multiple position-velocity cuts across each galaxy to determine the maximum circular rotation velocity ( $\leq 30$  km s<sup>-1</sup> for the survey population). Baryonic masses are calculated using single-dish H I fluxes from Arecibo and stellar masses derived from HST and Spitzer imaging. Comparison is made with total dynamical masses estimated from the position-velocity analysis. The SHIELD galaxies are contextualized on the baryonic Tully-Fisher relation.

Support for this work was provided by NSF grant AST-1211683 to JMC at Macalester College.

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**Institution(s):** 1. Macalester College

**Contributing team(s):** SHIELD Team

### 136.03 – SHIELD II: TRGB Distance Measurements from HST Imaging

The "Survey of HI in Extremely Low-mass Dwarfs II" ("SHIELD II") is a multiwavelength, legacy-class observational campaign that is facilitating the study of both internal and global evolutionary processes in low-mass dwarf galaxies discovered by the Arecibo Legacy Fast ALFA (ALFALFA) survey. The observations and science expand on the results from detailed studies of 12 similarly low-mass dwarf galaxies from the original SHIELD campaign. New HST

observations of 18 SHIELD II galaxies have allowed us to determine their TRGB distances, thus anchoring the physical scales on which our ongoing analysis is based. Combined with the HST observations of the original 12 SHIELD galaxies presented in McQuinn et al. (2014, 2015), these HST optical images enable a holistic study of the fundamental parameters and characteristics of a statistically robust sample of 30 extremely low-mass galaxies. Additional science goals include an accurate census of the dark matter contents of these galaxies, a spatial and temporal study of star formation within them, and a characterization of the fundamental parameters that change as galaxy masses range from "mini-halo" to star-forming dwarf.

Support for this work was provided by NSF grant AST-1211683 to JMC at Macalester College, and by NASA through grant GO-13750 from the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS5-26555.

**Author(s):** John M. Cannon<sup>1</sup>, Kristen B. McQuinn<sup>2</sup>, Evan D. Skillman<sup>2</sup>

**Institution(s):** 1. Macalester College, 2. University of Minnesota  
**Contributing team(s):** SHIELD Team

### 136.04 – SHIELD II: WSRT HI Spectral Line Observations

The "Survey of HI in Extremely Low-mass Dwarfs II" ("SHIELD II") is a multiwavelength, legacy-class observational campaign that is facilitating the study of both internal and global evolutionary processes in low-mass dwarf galaxies discovered by the Arecibo Legacy Fast ALFA (ALFALFA) survey. We present new results from WSRT HI spectral line observations of 22 galaxies in the SHIELD II sample. We explore the morphology and kinematics by comparing images of the HI surface densities and the intensity weighted velocity fields with optical images from HST, SDSS, and WIYN. In most cases the HI and stellar populations are cospatial; projected rotation velocities range from less than 10 km/s to roughly 30 km/s.

Support for this work was provided by NSF grant AST-1211683 to JMC at Macalester College, and by NASA through grant GO-13750 from the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS5-26555.

**Author(s):** Alex Jonah Robert Gordon<sup>2</sup>, John M. Cannon<sup>2</sup>, Elizabeth A. Adams<sup>1</sup>

**Institution(s):** 1. *ASTRON*, 2. Macalester College  
**Contributing team(s):** SHIELD II Team

### 136.05 – SHIELD II: AGC 198507 - An Extremely Rare Low-Mass Galaxy Interaction?

The "Survey of HI in Extremely Low-mass Dwarfs II" ("SHIELD II") is a multiwavelength, legacy-class observational campaign that is facilitating the study of both internal and global evolutionary processes in low-mass dwarf galaxies discovered by the Arecibo Legacy Fast ALFA (ALFALFA) survey. New HST imaging of one of these sample galaxies, AGC 198507, has revealed it to be a very rare interacting system; to our knowledge this is one of only a few known interactions in this extreme mass range. WSRT imaging indicates that the bulk of the HI is associated with the more luminous AGC 198507, while low surface brightness gas extends toward and coincides with the less luminous companion, which is separated by roughly 1.5 kpc from AGC 198507. Here we present new VLA B configuration HI imaging that allows us to localize the HI gas, to examine the rotational dynamics of AGC 198507, and to study the nature of star formation in this unique low-mass interacting system.

Support for this work was provided by NSF grant AST-1211683 to JMC at Macalester College, and by NASA through grant GO-13750 from the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS5-26555.

**Author(s):** Karin Nikolina Borg Stevens<sup>1</sup>, John M. Cannon<sup>1</sup>, Andrew McNichols<sup>1</sup>, Kristen B. McQuinn<sup>2</sup>, Yaron Teich<sup>1</sup>

**Institution(s):** 1. Macalester College, 2. University of Minnesota  
**Contributing team(s):** SHIELD II Team

### 136.06 – The Extremely Metal-Poor Dwarf Galaxy

### AGC 198691

We present spectroscopic observations of the nearby dwarf irregular galaxy AGC 198691. This object is part of the Survey of HI in Extremely Low-Mass Dwarfs (SHIELD) sample, which consists of ultra-low HI mass galaxies discovered by the Arecibo Legacy Fast-Acting ALFA (ALFALFA) survey. SHIELD is a multi-configuration Expanded Very Large Array (EVLA) study of the neutral gas content and dynamics of galaxies with HI masses in the range of  $10^6$ – $10^7 M_\odot$ . Our spectral data were obtained using the new high-throughput KPNO Ohio State Multi-Object Spectrograph (KOSMOS) on the Mayall 4-m telescope as part of a systematic study of the nebular abundances in the SHIELD galaxy sample. These observations enable measurement of the temperature sensitive [OIII] $\lambda$ 4363 line and hence the determination of a "direct" oxygen abundance for AGC 198691. We find this system to be an extremely metal-deficient (XMD) galaxy with an oxygen abundance comparable to such objects as I Zw 18, SBS 0335-052W, Leo P, and DDO 68 – the lowest metallicity star-forming systems known. It is worth noting that two of the five lowest-abundance galaxies currently recognized were discovered via the ALFALFA blind HI survey. These XMD galaxies are potential analogues to the first star-forming systems, which through hierarchical accretion processes built up the large galaxies we observe today in the local Universe. Detailed analysis of such XMD systems offers observational constraint to models of galactic evolution and star formation histories to allow a better understanding of the processes that govern the chemical evolution of low-mass galaxies.

**Author(s):** Alec S. Hirschauer<sup>1</sup>, John Joseph Salzer<sup>1</sup>, John M. Cannon<sup>2</sup>, Evan D. Skillman<sup>3</sup>

**Institution(s):** 1. Indiana University, 2. Macalester College, 3. University of Minnesota

**Contributing team(s):** The SHIELD II Team

### 136.07 – SHIELD II: VLA HI Spectral Line Observations

The "Survey of HI in Extremely Low-mass Dwarfs II" ("SHIELD II") is a multiwavelength, legacy-class observational campaign that is facilitating the study of both internal and global evolutionary processes in low-mass dwarf galaxies discovered by the Arecibo Legacy Fast ALFA (ALFALFA) survey. We present new results from low-resolution D-configuration VLA HI spectral line observations of 6 galaxies in the SHIELD II sample. We explore the morphology and kinematics by comparing images of the HI surface densities and the intensity weighted velocity fields with optical images from SDSS and WIYN. These data allow us to localize the HI gas and to study the bulk neutral gas kinematics.

Support for this work was provided by NSF grant AST-1211683 to JMC at Macalester College.

**Author(s):** Eojin Lee<sup>1</sup>, John M. Cannon<sup>1</sup>, Andrew McNichols<sup>1</sup>, Yaron Teich<sup>1</sup>

**Institution(s):** 1. Macalester College

**Contributing team(s):** SHIELD II Team

### 136.08 – Star Formation in Extreme Environments: The Case of the Prototypical Blue Compact Dwarf Galaxy II Zw 40

With their high star formation rate surface densities and low metallicities, blue compact dwarf galaxies represent one of the most extreme environments for star formation in the local universe: one more akin to that found in high redshift galaxies than in local spirals. Until the advent of ALMA, however, the molecular gas fueling the prodigious star formation in blue compact dwarfs was difficult to observe because these galaxies generally have weak CO emission. In this talk, I present the first detailed study of the dust and molecular gas content (as traced by CO) in the prototypical nearby blue compact dwarf galaxy II Zw 40. Using the extraordinary resolution and sensitivity of our ALMA Cycle 1 observations, we have separated the molecular gas emission into discrete GMC-sized clumps and measured their properties. The clouds within II Zw 40 have high linewidths for their size, reflecting the greater turbulence within II Zw 40. However, despite their large linewidths, these clouds are

largely still in virial equilibrium. Comparing the virial masses of the clouds to their CO luminosities, we find that the CO to molecular gas conversion factor within this galaxy is at least 5 times that of the Milky Way and possibly as high as 35 times. Even with the maximum CO-to-molecular gas conversion factor for this galaxy, we find that the star formation efficiency is still at least a factor of 3 higher than solar metallicity systems.

**Author(s):** Amanda A. Kepley<sup>2</sup>, Adam Leroy<sup>3</sup>, Kelsey E. Johnson<sup>5</sup>, Karin Sandstrom<sup>4</sup>, C.-H. Rosie Chen<sup>1</sup>

**Institution(s):** 1. *Max Planck Institute for Radio Astronomy*, 2. *National Radio Astronomy Observatory*, 3. *The Ohio State University*, 4. *University of California, San Diego*, 5. *University of Virginia*

### 136.09 – The Star Formation Properties of Void Dwarf Galaxies

We measure the star formation properties of two large samples of galaxies from the SDSS in large-scale cosmic voids on time scales of 10 Myr and 100 Myr, using H $\alpha$  emission line strengths and GALEX FUV fluxes, respectively. The first sample consists of 109,818 optically selected galaxies. We find that void galaxies in this sample have higher specific star formation rates (SSFRs; star formation rates per unit stellar mass) than similar stellar mass galaxies in denser regions. The second sample is a subset of the optically selected sample containing 8070 galaxies with reliable S/N HI detections from ALFALFA. For the HI detected sample, SSFRs are similar regardless of large-scale environment. Investigating only the HI detected dwarf galaxies reveals a trend towards higher SSFRs in voids. Furthermore, we estimate the star formation rate per unit HI mass, known as the star formation efficiency (SFE) of a galaxy, as a function of environment. For the overall HI detected population, we notice no environmental dependence. Limiting the sample to dwarf galaxies again reveals a trend towards higher SFEs in voids. These results suggest that void environments provide a nurturing environment for dwarf galaxy evolution.

**Author(s):** Crystal Moorman<sup>1</sup>, Michael S. Vogeley<sup>1</sup>

**Institution(s):** 1. *Drexel University*

### 136.10 – Gas Flowing out of the Large Magellanic Cloud Galaxy due to Numerous Supernovae Explosions

The Large Magellanic Cloud (LMC) galaxy is currently losing gas due to the numerous supernovae explosions that are spread across its disk. We detected H $\alpha$  emission from this wide-spread galactic wind using the Wisconsin H $\alpha$  Mapper (WHAM) telescope and present mapped observations of the LMC and its intermediate and high velocity clouds between  $+125 \leq v_{\text{LSR}} \leq +400$  km/s. Previous absorption studies found that these clouds contain a few  $10^7$  solar masses of gas (Lehner et al. 2009 and Barger et al. 2015). However, these studies were only sensitive to the region in front of the LMC. From this study, we conclude that the gas cloud extends much further off the LMC and that it is much more massive than previous studies predict.

**Author(s):** Madeline Horn<sup>1</sup>, Kathleen Barger<sup>2</sup>, Nicolas Lehner<sup>3</sup>, J. Christopher Howk<sup>3</sup>, L. Matthew Haffner<sup>4</sup>

**Institution(s):** 1. *Smith College*, 2. *Texas Christian University*, 3. *University of Notre Dame*, 4. *University of Wisconsin-Madison*

### 136.11 – Cannibalization of Dwarf Galaxies by the Milky Way: Distance to the Leading Arm of the Magellanic Clouds

Tidal interactions between two dwarf galaxies near the Milky Way, the Large and Small Magellanic Clouds, have caused large quantities of gas to be flung into the halo of the Milky Way. Much of this tidal debris, known as the Magellanic System, is currently headed towards the disk of the Milky Way, spearheaded by the Leading Arm, with the Bridge connecting the two dwarf galaxies, and the trailing Magellanic Stream at the end. Estimates for the amount of gas that the Magellanic System contains are in the range of  $(2 - 4) \times 10^9 M_{\odot}$  and this could supply our Galaxy with  $(3.7 - 6.7) M_{\odot} \text{ yr}^{-1}$  (Fox et al. 2014). Although this is higher than the present star-formation rate of

the Galaxy, the position of the tidal debris predisposes it to ionizing radiation from the extragalactic background and Galactic disk, as well as ram-pressure stripping from the halo, hindering gas accretion. Some parts of the Leading Arm, however, appear to have already survived the trip to the disk as their morphology is indicative of interaction with the interstellar medium of the Galaxy. The exact amount of gas that this structure contains is uncertain because of weak constraints in its distance. In this study, we made seven pointed H $\alpha$  observations using the Wisconsin H $\alpha$  Mapper Telescope and then compared the H $\alpha$  intensity we obtained to models of the anticipated ionizing flux from the Milky Way and extragalactic background. From this, we calculated the distance from the Sun to the Leading Arm of the Magellanic System at the locations of our observations.

**Author(s):** Jacqueline Antwi-Danso<sup>1</sup>, Kathleen Barger<sup>1</sup>, L. Matthew Haffner<sup>2</sup>

**Institution(s):** 1. *Texas Christian University*, 2. *University of Wisconsin-Madison*

### 136.12 – Investigating the Diffuse Ionized Gas in the Magellanic Stream with Mapped WHAM Observations

We present early stages of an H $\alpha$  survey of the Magellanic Stream using the Wisconsin H-Alpha Mapper (WHAM). While the neutral component of the Stream may extend  $200^\circ$  across the sky (Nidever et al. 2010), its ionized gas has not yet been studied in detail. Fox et al. 2014 find that the tidal debris in the Magellanic System contains twice as much ionized gas as neutral and may extend  $30^\circ$  away from the H I emission. However, such absorption-line studies are not sensitive to the overall morphology of the ionized gas. Using targeted H $\alpha$  emission observations of the Magellanic Stream, Barger et al. 2015 find that although the warm ionized gas tracks the neutral gas, it often spans a few degrees away from the H I emission at slightly offset velocities. Using WHAM's unprecedented sensitivity to diffuse emission ( $\sim 10\sigma$  of mR) and its velocity resolution (12 km/s) to isolate Stream emission, we are now conducting the first full H $\alpha$  survey of its ionized component. Here we present early results, including spatial and kinematic comparisons to the well-established neutral profile of the Stream. WHAM research and operations are supported through NSF Award AST-1108911.

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**Institution(s):** 1. *Texas Christian University*, 2. *University of Wisconsin*

### 136.13 – The Extended Ionized Halos and Bridge of the Magellanic Clouds

The Wisconsin H-Alpha Mapper (WHAM) has revealed ubiquitous ionized emission throughout the gas complexes formed by the dynamic history of the Magellanic Clouds. We present an overview of the immediate environment around the galaxies themselves, including ionized halos of the Small and Large Magellanic Clouds (SMC & LMC) as well as the bridge of material between them. Using WHAM, Barger et al. (2013) found H $\alpha$  emission extending throughout and beyond H I in the Bridge. We add these new maps of the SMC and LMC to provide the first complete view of the diffuse ionized gas near the interacting system. At  $R \sim 30,000$ , WHAM can cleanly separate diffuse emission at Magellanic velocities from the Milky Way and terrestrial sources to the limit of atmospheric line confusion ( $\sim 10\sigma$  of mR). We find that ionized gas extends at least  $5^\circ$  beyond the traditional boundary of the SMC when compared to recent deep-imaging surveys (e.g., MCELS; Smith et al. 2005). The diffuse ionized emission extent is similar to the neutral gas extent as traced by 21 cm emission. We compare the kinematic signatures between the neutral and ionized components throughout the region. Comprehensive multi-wavelength surveys are also underway to examine how physical parameters and ionization processes vary in these extended systems. WHAM research and operations are supported through NSF Award AST-1108911.

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**Institution(s):** 1. Haverford College, 2. Texas Christian University, 3. The University of Toronto, 4. University of Cambridge, 5. University of Wisconsin-Madison

### 136.14 – Physical Properties of the Magellanic Bridge Tidal Remnant through Mapped H $\alpha$ , [SII], and [NII] Emission

We present the first kinematically resolved [S II]  $\lambda 6716$  and [N II]  $\lambda 6583$  emission maps of the entire Magellanic Bridge that were observed with the Wisconsin H $\alpha$  Mapper Telescope. Combining these maps with the complementary H $\alpha$  maps of Barger et al. (2013), we explore the temperature, sulfur and nitrogen ionization state, and sources of the ionization of the warm-ionized gas in the Magellanic Bridge, the SMC-Tail, and the LMC-Bridge interface region. Within the Magellanic Bridge, we find that the low velocity (+100 to +200 km s<sup>-1</sup>) and the high velocity (+200 to +300 km s<sup>-1</sup>) gas have different properties, suggesting that it is composed of at least two separate and coherent filaments. Within the high-velocity filament, a high-velocity ridge of gas—with different properties from the high-velocity structure—extends along the high-latitude edge of the H $\alpha$  SMC-Tail to low latitude edge LMC-Bridge interface. This ridge coincides with a strip of early-type stars, suggesting that these stars are influencing this gas. We further find that the properties of both the SMC-Tail and LMC-Bridge interface regions have similar properties and therefore are likely affected by similar ionization sources.

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### 136.15 – The Discovery of Galaxy Groups with Only Low Mass, Dwarf Members

Cosmological simulations predict that groups of dwarf galaxies should be extremely rare if not nonexistent. However, we have observationally identified several candidate groups consisting of only three to five low mass members that have accordant positions within 80 kpc and redshifts within 400 km/s. We present broadband optical imaging of these groups which reveals morphologies consistent with inter-group interactions between the dwarf galaxies. We further present very narrowband (< 10 Å) H $\alpha$  imaging obtained using the Maryland Magellan Tunable Filter which highlight the regions of recent star formation, possibly triggered by the interactions. The evolution of massive galaxies in close or compact groups is known to be characteristically different than in either pair-wise mergers or galaxy clusters. These environmental effects are likely to be even more significant in the shallow gravitational potential wells of dwarf galaxies. However, the role played by the close group environment in the evolution of dwarf galaxies is mostly uncharted territory. Determining the effects of interactions and mergers on the gas supplies, star formation, and subsequent enrichment of the ISM in low mass galaxies is a crucial step in understanding hierarchical assembly, as dwarf galaxies are expected to be the building blocks of more massive systems.

**Author(s):** Sabrina Stierwalt<sup>4</sup>, Sandra Liss<sup>4</sup>, Kelsey E. Johnson<sup>4</sup>, Gurtina Besla<sup>3</sup>, Nitya Kallivayalil<sup>4</sup>, David R. Patton<sup>2</sup>, Mary E. Putman<sup>1</sup>

**Institution(s):** 1. Columbia University, 2. Trent University, 3. University of Arizona, 4. University of Virginia

### 136.16 – The Spectral Energy Distributions of Interacting Dwarf Galaxies

We present spectral energy distributions (SEDs) for the TiNy Titans survey, the first systematic study of interactions between dwarf galaxies. Galaxy interactions are known to be of fundamental importance to the evolution of massive galaxies -- they have been observed to impact morphology, star formation rates, and ISM composition. Such interactions also occur frequently between low mass dwarf galaxies, but this process is poorly understood and largely overlooked in comparison. Although the majority of mergers

at all redshifts are expected to take place between low mass galaxies, until now there have not been comparable systematic studies of dwarf galaxy interactions, leaving open the question of whether interactions between low mass galaxies can strongly affect their own evolution. The TiNy Titans survey, a complete sample of isolated dwarf galaxy pairs selected from the Sloan Digital Sky Survey (SDSS), is specifically designed to address this gap in our understanding of galaxy evolution. The SEDs presented here, generated from archival WISE, SDSS, and GALEX photometric data, allow us to characterize the typical interacting dwarf galaxy, as well as quantify the deviations from this average distribution. We also present trends in the SEDs as a function of projected radial separation, a proxy for interaction stage.

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**Institution(s):** 1. Trent University, 2. Universidad de Concepción, 3. University of Arizona, 4. University of Virginia

### 136.17 – Using Rotation Curves for Low Surface Brightness Galaxies to Evaluate LCDM

$\Lambda$  Cold Dark Matter (ACDM) has been a successful paradigm for explaining large-scale structure in the universe. However, this model does not provide a satisfactory explanation for local, smaller scale features, such as the dynamics of dark matter dominated low surface brightness galaxies. Dubbed the core-cusp problem, the inner slope of these rotation curves is much lower than expected in pure  $\Lambda$ CDM simulations. High-resolution hydrodynamic simulations have attempted to alleviate this discrepancy by invoking baryonic feedback from supernovae driven gas outflows. These simulations can be tested by comparing to observed rotation curves directly. In applying this test, we take care to treat the simulations and the data in the same fashion, so that a direct comparison can be made. This publication was made possible through the support of the John Templeton Foundation. The opinions expressed in this are those of the author and do not necessarily reflect the views of the John Templeton Foundation.

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**Institution(s):** 1. Case Western Reserve University

### 136.18 – Stable State Simulations of Andromeda Dwarf Spheroidal Satellite Galaxies Using MOND

We present the results of numerical simulations of the stable state condition of several dwarf spheroidal galaxies orbiting the Andromeda galaxy. Using Modified Newtonian Dynamics, we calculate the motion of ten thousand stars in a spherically symmetric Hernquist potential to obtain both the line of sight bulk velocity dispersion and the dispersion profile, i.e. the velocity dispersion as a function of distance from the galactic center. Our results for the bulk dispersion show excellent agreement with observed values and previously published theoretical results and provide reliable estimates of the mass to luminosity ratio. We predict relatively flat radial dispersion profiles for several of the Andromeda dwarf spheroidal galaxies that are similar to those measured for the Milky Way dwarf spheroidals.

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**Institution(s):** 1. Miami University

### 136.19 – Getting to Know the Neighbors: Deep Imaging of the Andromeda Satellite Dwarf Galaxy Cassiopeia III with WIYN pODI

We present results from WIYN pODI imaging of Cassiopeia III/Andromeda XXXII (Cas III/And XXXII), an Andromeda satellite dwarf galaxy recently discovered by Martin et al. (2013) in Pan-STARRS1 survey data. Detailed studies of satellite dwarf galaxies in the Local Group and its environs provide important insight into how low-mass galaxies form and evolve as well as how more massive galaxies are assembled in a hierarchical universe. The goal of this project is to obtain deep, wide-field photometry of Cas III in order to

study its stellar population in more detail. The images used for this analysis were taken in October 2013 with the 24' x 24' pODI camera on the WIYN 3.5-m telescope in the SDSS g and i filters. Calibrated photometry was performed on all point sources in the g and i images and then used to quantify the radial distribution of stars in Cas III and to construct a color-magnitude diagram (CMD). We present this CMD along with a map of the resolved stellar population and measurements of the galaxy magnitude and structural properties. This research was supported by the NSF Research Experiences for Undergraduates program (grant number AST-1358980).

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**Institution(s):** 1. Indiana University, 2. Maria Mitchell Observatory

### 136.20 – Photometric Calibration of DECam Images of the Sextans Dwarf Spheroidal Galaxy

As part of an ongoing study on the variable star population of the Sextans Dwarf Spheroidal Galaxy, we present here details on the photometric calibration of the data, which were obtained with the Dark Energy Camera (DECam) at the Blanco 4m Telescope at the Cerro Tololo Interamerican Observatory. Since DECam is a relatively new instrument, we tested different calibration strategies including calibrating each chip individually and all together. Our results indicate that the color terms and zero points are constant across the camera, at least in the g, r and i bands. We present preliminary results on the location of variable stars in the Sextans dwarf galaxy.

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### 136.21 – Mapping the Tidal Destruction of the Hercules Dwarf: A Wide-Field DECam Imaging Search for RR Lyrae

Kinematic studies of ultra-faint dwarfs assume these objects to be in dynamic equilibrium, but conclusions based on this assumption will be incorrect if ultra-faint dwarfs are actually being tidally stripped by the Milky Way. Additionally, the speed and severity of hierarchical merging of small galaxies with larger hosts is an important test of cosmology that requires a knowledge of the kinematic states of the host's dwarf population. In this study, we explore the impact of tidal disruption in the Hercules dwarf, a highly spatially extended ultra-faint dwarf which previous studies have suggested may have evidence of extra-tidal features. We performed time series imaging with the CTIO 4m/DECam to trace the extended structure of this galaxy with RR Lyrae stars. Our imaging covers 3 sq. degrees around Hercules -- significantly larger than previous studies. We report the discovery of five new RR Lyrae candidates, three of which lie outside the dwarf's tidal radius and along its elongated major axis and predicted orbit. This result provides additional evidence that Hercules is being tidally disrupted. This work was supported by NSF AST-1151462.

**Author(s):** Christopher Garling<sup>1</sup>, Beth Willman<sup>1</sup>, Jonathan R. Hargis<sup>1</sup>, David J. Sand<sup>2</sup>, Denija Crnojevic<sup>2</sup>

**Institution(s):** 1. Haverford College, 2. Texas Tech University

### 136.22 – Ghostly Halos in Dwarf Galaxies: a probe of star formation in the Early Universe

We carry out numerical simulations to characterize the size, stellar mass, and stellar mass surface density of extended stellar halos in dwarf galaxies as a function of dark matter halo mass. We expect that for galaxies smaller than a critical value, these ghostly halos will not exist because the smaller galactic subunits that build it up, do not form any stars. The detection of ghostly halos around isolated dwarf galaxies is a sensitive test of the efficiency of star formation in the first galaxies and of whether ultra-faint dwarf satellites of the Milky Way are fossils of the first galaxies.

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**Institution(s):** 1. University of Maryland

### 136.23 – The Resolved Stellar Halo and Dwarf Satellite Population of NGC 3109

The stellar halo and halo substructure of dwarf galaxies provides an important window into both LCDM cosmology and galaxy formation theory on the smallest scales. We are undertaking a deep, wide-field imaging survey of nearby, isolated sub-Milky Way mass galaxies in order to (1) map the substructure, spatial extent, and metallicity of their stellar halos in resolved stars, and (2) search for faint dwarf satellite companions (i.e., the "dwarfs of dwarfs"). These studies will allow us to explore the role of in-situ versus accretion processes in forming stellar halos in dwarfs, as well as constrain the faint end of the satellite galaxy luminosity function. This work presents a preliminary analysis of the pilot galaxy in our survey: NGC 3109 ( $M_V = -15$  mag), a nearby ( $d = 1.3$  Mpc) dwarf irregular, approximately 1/6th the stellar mass of the SMC. We imaged ~40 sq. deg around NGC 3109 (projected radius of ~100 kpc) using CTIO 4m/DECam to depths ~2 mag below the TRGB. We discovered a new gas-rich dwarf satellite of NGC 3109, dubbed Antlia B ( $M_V = -9.7$  mag), similar to the recently-discovered Leo P. We also discovered five candidate dwarf satellites, with sizes (~100 pc) and luminosities ( $M_V \sim -6$  mag) consistent with being ultra-faint dwarfs at the distance of NGC 3109. Lastly, we present stellar halo maps of resolved RGB stars on both large and small scales. We discuss the various substructures found in these maps and the future directions of our survey. This work was supported by NSF AST-1151462.

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### 136.24 – A Survey of Localized Star Clusters in NGC 1427A

It is well established that galactic clusters provide dynamic environments in which to examine galaxy evolution. The starbursting dwarf irregular NGC 1427A presents an interesting case as it is being pulled into the nearby Fornax cluster at supersonic speeds, producing a visibly exceptional star formation rate and notably blue colors. It has been suggested that the highly deformed structure of NGC 1427A is due to ram pressure stripping as a result of interacting with a super-heated ICM provided by several nearby elliptical galaxies. The gas density profile of its leading edge is similar to a "bow-shock", containing several dozen super-star clusters (SSCs) and thousands of smaller star forming clusters. It is clearly evident that the properties of NGC 1427A change rapidly over relatively short distances. Using dithered HST/ACS images in Sloan equivalent g' r' i' z' and H $\alpha$  filters, we present a morphological and photometric study of NGC 1427A using a novel approach in which stellar properties are measured from sources grouped within localized regions. Apertures are fitted for ~5000 sources at  $4\sigma$  using a filter-combined master image. Four characteristic regions are chosen to study stellar properties, selected interactively through DS9. We then introduce COMET, a specially-designed source catalog handler for producing graphical figures of each region, cropping both spatially and photometrically. These are then batch-reviewed and analyzed using synthetic isochrones corresponding of each region. H $\alpha$  bright sources are indicated to illustrate the significance of SSCs. Secondary analysis is carried out using smoothed color maps of source-subtracted diffuse light, yielding penetrative mapping of underlying stellar populations. We show for the first time how the dynamical stellar populations of NGC 1427A differ as a function of position across the surface of the galaxy, ultimately furthering our understanding of cluster interactions and the evolution of irregular galaxies. This work is generously supported by NSF grant #1358980.

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### 136.25 – Characterizing Dw1335-29, a Recently Discovered Dwarf Satellite of M83

Simulations of galaxy formation in a cosmological context predict

that galaxies should be surrounded by hundreds of relatively massive dark matter subhalos, each of which was expected to host a dwarf satellite galaxy. Large numbers of luminous dwarf galaxies do not exist around the Milky Way or M31 - this has been termed the missing satellite problem. There are a number of possible physical drivers of this discrepancy, some of which might predict significant differences from galaxy to galaxy. Accordingly, there are a number of efforts whose goal is to solidify and augment the census of dwarf satellites of external galaxies, outside the Local Group. Recently, Mueller, Jergen & Bingelli (2015; arXiv.1509.04931) presented 16 dwarf galaxy candidates in the vicinity of M83 using the Dark Energy CAMera (DECAM). With a field from the HST/GHOSTS survey that partly covers dw1335-29 (Radburn-Smith et al. 2011; ApJS, 195, 18) in conjunction with complementary ground-based images from VIMOS that cover the whole dwarf, we confirm that one of the candidates dw1335-29 is a dwarf satellite of M83, at a projected distance from M83 of 26 kpc and a with distance modulus of  $m-M = 28.5_{-0.1}^{+0.3}$ , placing it in the M83 group. From our VIMOS imaging that covers the entire dwarf, we estimate an absolute magnitude of  $M_V = -9.8_{-0.1}^{+0.3}$ , show that it is elongated with an ellipticity of  $0.35_{-0.15}^{+0.15}$ , and has a half light radius of  $500_{-50}^{+50}$  pc. Dw1335-29 has both a somewhat irregular shape and has superimposed young stars in the resolved stellar population maps, leading us to classify this galaxy as a faint dwarf irregular or transition dwarf. This is especially curious, as with a projected distance of only 26 kpc from M83, our prior expectation from study of the Local Group (following e.g., Grebel et al. 2003; AJ, 125, 1926, Slater & Bell 2013; ApJ, 772, 15) would be that dw1335-29 would lack recent star formation. Further study of M83's dwarf population will reveal if star formation in its dwarfs is commonplace (suggesting a lack of a hot gas envelope for M83 that would quench star formation) or rare (suggesting that dw1335-29 is at much larger 3D distance from M83, and is fortuitously projected to small radii).

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## 137 – Extrasolar Planets: Detection Poster Session

### 137.01 – CELESTA: A Catalog of Earth-Like Exoplanet Survey Targets

Locating planets in circumstellar Habitable Zones is a priority for many exoplanet surveys. Space-based and ground-based surveys alike require robust toolsets to aid in target selection and mission planning. We present the Catalog of Earth-Like Exoplanet Survey Targets (CELESTA), a database of Habitable Zones around 36,000 nearby stars. We calculated stellar parameters, including effective temperatures, masses, and radii, and we quantified the orbital distances and periods corresponding to the circumstellar Habitable Zones. We gauged the accuracy of our predictions by contrasting CELESTA's computed parameters to observational data. We ascertain a potential return on investment by computing the number of Habitable Zones probed for a given survey duration. A versatile framework for extending the functionality of CELESTA into the future enables ongoing comparisons to new observations, and recalculations when updates to Habitable Zone models, stellar temperatures, or parallax data become available. We expect to upgrade and expand CELESTA using data from the Gaia mission as the data becomes available.

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### 137.02 – Science Yield Modeling with EXOSIMS

Accurately modeling science yield of an exoplanet direct imaging mission to build confidence in the achievement of science goals can be almost as complicated as designing the mission itself. It is challenging to compare science simulation results and systematically

test the effects of changing instrument or mission designs. EXOSIMS (Exoplanet Open-Source Imaging Mission Simulator) addresses this by generating ensembles of mission simulations for exoplanet direct imaging missions to estimate distributions of science yield. EXOSIMS consists of stand-alone modules written in Python which may be individually modified without requiring modifications to the code elsewhere. This structure allows for user driven systemic exploration of the effects of changing designs on the estimated science yield.

The modules of EXOSIMS are classified as either input or simulation modules. Input modules contain specific mission design parameters and functions. These include Planet Population, Star Catalog, Optical System, Zodiacal Light, Planet Physical Model, Observatory, Time Keeping, and Post-Processing. Simulation modules perform tasks requiring input from one or more input modules as well as calling functions from other simulation modules. These include Completeness, Target List, Simulated Universe, Survey Simulation, and Survey Ensemble. The required parameters and functionality of each of these modules is defined in the documentation for EXOSIMS. EXOSIMS is available to the public at <https://github.com/dsavransky/EXOSIMS>. Included in the documentation is an interface control document which defines the required inputs and outputs to each input and simulation module. Future development of EXOSIMS is intended to be community-driven. Mission planners and instrument designers may quickly write their own modules, following the guidelines in the interface control document, and drop them directly into the code without making additional modifications elsewhere. It is expected that EXOSIMS will be highly useful for designing and planning future exoplanet direct imaging missions.

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### 137.03 – Archival Legacy Investigation of Circumstellar Environments (ALICE). Survey results

We report on the status of the ALICE project (Archival Legacy Investigation of Circumstellar Environments. HST/AR-12652), which consists in a consistent reanalysis of the entire HST-NICMOS coronagraphic archive with advanced post-processing techniques. Over the last two years, we have developed a sophisticated pipeline able to handle the data of the 400 stars of the archive. We present the results of the overall reduction campaign and discuss the first statistical analysis of the candidate detections. As we will deliver high-level science products to the STScI MAST archive, we are defining a new standard format for high-contrast science products, which will be compatible with every new high-contrast imaging instrument and used by the JWST coronagraphs. We present here an update and overview of the specifications of this standard.

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### 137.04 – A Search for Rocky Planets in Close Orbits around White Dwarfs with COS

The search for transiting habitable exoplanets has broadened to include several types of stars that are smaller than the Sun in order to increase the observed transit depth and hence the atmospheric signal of the planet. Of all current spectral types, white dwarfs are the most favorable for this type of investigation. The fraction of white dwarfs that possess close-in rocky planets is unknown, but several large angle surveys of stars have the photometric precision and cadence to discover at least one if they are common. Ultraviolet observations of white dwarfs may allow for detection of molecular oxygen or ozone in the atmosphere of a terrestrial planet. We use archival Hubble Space Telescope data from the Cosmic Origins Spectrograph to search for transiting rocky planets around UV-bright white dwarfs. In the process, we discovered unusual variability in the pulsating white dwarf GD-133, which shows slow sinusoidal variations in the UV. While we detect no planets around our small

sample of targets, we do place stringent limits on the possibility of transiting planets, down to sub-lunar radii.

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### 137.05 – Cloud-Kepler: Towards Efficient Identification and Characterization of Aperiodic and Infrequent Transit Events

The Kepler mission has revolutionized the study of exoplanets by dramatically increasing the available sample size. However, the catalog of planet candidates created by the mission team is constrained to stars that exhibit at least three transit-like events. Cloud-Kepler is an open-source software package designed to search archived Kepler data for planets that may have been missed by looking for either aperiodic or single- and double-transit events. It uses a variant of the Box-Least Squares (BLS) algorithm that we call “BLS-pulse” which identifies the single best-fitting transit-like event in a given segment of a light curve. While testing the program on a random sample of Kepler Objects of Interests (KOIs), we found a single transit-like event (probably a stellar eclipse) of KIC 1717717 centered at MJD = 56271.70. Using a Markov Chain Monte-Carlo (MCMC) analysis, we compared viable star-planet and star-star solutions to constrain physical parameters based on the available observables (e.g., depth, duration, host star colors, coverage of the photometry). We present our analysis on the KIC 1717717 system, along with plans to further adapt this MCMC method to use with missions like K2 and TESS that have even shorter observing baselines, and will therefore expect to find many more such single- and double-transit events.

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### 137.06 – An Aperture Photometry Pipeline for K2 Data

As part of an ongoing research program with undergraduate students at Florida Gulf Coast University, we have constructed an aperture photometry pipeline for K2 data. The pipeline performs dynamic automated aperture mask definition for all targets in the K2 fields, followed by aperture photometry and detrending. Our pipeline is currently used to support a number of projects, including studies of stellar rotation and activity, red giant asteroseismology, gyrochronology, and exoplanet searches. In addition, output is used to support an undergraduate class on exoplanets aimed at a student audience of both majors and non-majors. The pipeline is designed for both batch and single-target use, and is easily extensible to data from other missions, and pipeline output is available to the community. This paper will describe our pipeline and its capabilities and illustrate the quality of the results, drawing on all of the applications for which it is currently used.

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### 137.07 – The Detection of Kepler K2 Campaigns 3 and 4 Planet Candidates

The K2 mission, developed to repurpose the *Kepler* spacecraft, is providing light curve data quality that exceeds initial K2 design specifications despite the failure of two reaction wheels. We discuss the modification of the five modules of the *Kepler* Science Processing Pipeline for K2 data planet transit detection. The modified pipeline was applied to K2 Campaign 3 and 4 data sets. Despite the inherently noisier K2 light curves, which are mostly due to spacecraft roll motion, the modified pipeline proved to be effective at detecting transiting planets in K2 light curves. From the Campaign 3 data set, which consists of 70 days of observations of 16,375 targets, we present a catalog of 41 planet candidates in 33 systems. We calculate stellar radii for these 33 stars to obtain initial planet parameters. The catalog contains many systems of interest, including 26 planets with radii less than four Earth radii and two three-planet systems.

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### 137.08 – A Systematic Search for Exoplanet Candidates in K2 Data

We present a catalog of 41 promising exoplanet candidates in 33 stellar systems from the K2 Campaign 3 data. The *K2 Mission* was developed upon the mechanical failure of the second of four reaction wheels, as the *Kepler* Spacecraft could not continue the original *Kepler Mission*. The *Kepler Mission* was a 4-year mission designed to determine the prevalence of exoplanets in our galaxy, and the configuration and diversity of those planetary systems discovered. The *K2 Mission* has a similar goal, though the spacecraft now points at fields along the ecliptic in ~75 day campaigns (Howell et al. 2014). Although the light curves in K2 data are noisier and have significant motion-induced systematics, it has been shown that there is success in finding exoplanets and exoplanet candidates (Foreman-Mackey et al. 2015; Montet et al. 2015). Utilizing the Transiting Planet Search and Data Validation from the *Kepler* Processing Pipeline, we systematically search K2 Campaign 3 for potential exoplanet candidates. Setting a 7.1s maximum folded statistic threshold minimum for a minimum of three transit events, we define our initial candidate list. Our list is further narrowed by the results from Data Validation, as it allows us to statistically identify false positives, such as eclipsing binaries or uncorrected roll-drift, in our sample. We further draw parallels between our results and other transit-searching pipeline results published for Campaign 3.

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### 137.09 – Modeling Starspots on Kepler-78

Kepler-78 is a late G-type star which hosts Kepler-78b, an Earth-sized planet in an 8.5 hour orbit. The mass of Kepler-78b has been measured using the radial velocity technique, but this measurement is complicated by significant stellar activity, especially starspots. We present a new method for modeling starspots by applying a Markov Chain Monte Carlo process to the SOAP 2.0 starspot model. We apply this method to all available data simultaneously, including measurements of radial velocity, bisector span, and full width at half maximum. We recover the mass of Kepler-78b with excellent agreement to previous mass estimates. We also characterize the starspots of Kepler-78, constraining the latitude, longitude, size, and temperature of each spot group, and finding evidence of starspot evolution. Importantly, using both radial velocity measurements and line shape diagnostics seems to break the degeneracy between spot size and spot temperature. If this is correct, we also find that the starspots are warmer than one would expect of a G-type star. Our method of modeling starspots will allow us to better understand the surface phenomena of stars, as well as the properties of their planetary systems.

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### 137.10 – A CubeSat to Search for Transiting Planets Around the Young Star Beta Pictoris

The goal of this project is to further our growing knowledge of exoplanets in the solar neighborhood. The nearby star Beta Pictoris, which is nearly twice the mass of the Sun, is encircled by a huge disk of dust and gas reaching out 500-800 AU from the star. This so-called “debris disk” is the product of collisions between large numbers of asteroids and comets orbiting this relatively young star. The presence of these small planetary bodies hinted that there might be planets in the disk as well, which was recently confirmed when a ground-based telescope directly imaged a super-Jupiter exoplanet orbiting the star.

The debris disk of Beta Pic tells us that this planetary system is

edge-on from our vantage point on Earth. Therefore, it is an ideal system to use transit photometry to search for additional planets. We hope to do so by monitoring the brightness of the star over a given period, using a telescope on small satellite (a CubeSat). A CubeSat is a very small satellite tasked with a single purpose and, in this case, a single target. The advantage of a CubeSat over a larger telescope is the low cost and fast development schedule. Since we wish to study only one star's system, a CubeSat is an economical choice, although the limited lifetime of a CubeSat means that only planets with relatively short (up to few month) periods may be found. Our preliminary calculations show that, in principle, we can discover planets from Jupiter-size down to Neptune-size around Beta Pic with a telescope sized to fit in a CubeSat.

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**Institution(s):** 1. Howard University, 2. NASA GSFC

### 137.11 – Transit Photometry results on WASP 58b and a KELT target

We present transit photometry of exoplanet host stars from the Red Buttes Observatory (RBO). Targets identified by Kepler and KELT (Kilodegree Extremely Little Telescope) exoplanet surveys were observed by our group at the University of Wyoming from the RBO. RBO is a .6 meter telescope and through partial automation it can be used remotely. We present two light curves one of WASP-58b, a confirmed exoplanet, and one a KELT target both observed multiple times. Both targets showed a dip in brightness in their light curves indicative of a transit event. Comparisons to previous light curves have shown similar results. RBO will continue to be used to gather data for determining the light curves of various targets.

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**Institution(s):** 1. University of Wyoming

### 137.12 – Enabling Remote and Automated Operations at The Red Buttes Observatory

The Red Buttes Observatory (RBO) is a 60 centimeter Cassegrain telescope located ten miles south of Laramie, Wyoming. The size and proximity of the telescope comfortably make the site ideal for remote and automated observations. This task required development of confidence in control systems for the dome, telescope, and camera. Python and WinSCP script routines were created for the management of science images and weather. These scripts control the observatory via the ASCOM standard libraries and allow autonomous operation after initiation.

The automation tasks were completed primarily to rejuvenate an aging and underutilized observatory with hopes to contribute to an international exoplanet hunting team with other interests in potentially hazardous asteroid detection. RBO is owned and operated solely by the University of Wyoming. The updates and proprietor status have encouraged the development of an undergraduate astronomical methods course including hands-on experience with a research telescope, a rarity in bachelor programs for astrophysics.

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### 137.13 – Design Considerations: Falcon M Dwarf Habitable Exoplanet Survey

The Falcon Telescope Network (FTN) is an assemblage of twelve automated 20-inch telescopes positioned around the globe, controlled from the Cadet Space Operations Center (CSOC) at the US Air Force Academy (USAFA) in Colorado Springs, Colorado. Five of the 12 sites are currently installed, with full operational capability expected by the end of 2016. Though optimized for studying near-earth objects to accomplish its primary mission of Space Situational Awareness (SSA), the Falcon telescopes are in many ways similar to those used by ongoing and planned exoplanet transit surveys targeting individual M dwarf stars (e.g., MEarth, APACHE, SPECULOOS). The network's worldwide geographic distribution

provides additional potential advantages. We have performed analytical and empirical studies exploring the viability of employing the FTN for a future survey of nearby late-type M dwarfs tailored to detect transits of 1-2R<sub>Earth</sub> exoplanets in habitable-zone orbits. We present empirical results on photometric precision derived from data collected with multiple Falcon telescopes on a set of nearby (< 25 pc) M dwarfs using infrared filters and a range of exposure times, as well as sample light curves created from images gathered during known transits of varying transit depths. An investigation of survey design parameters is also described, including an analysis of site-specific weather data, anticipated telescope time allocation and the percentage of nearby M dwarfs with sufficient check stars within the Falcons' 11' x 11' field-of-view required to perform effective differential photometry. The results of this ongoing effort will inform the likelihood of discovering one (or more) habitable-zone exoplanets given current occurrence rate estimates over a nominal five-year campaign, and will dictate specific survey design features in preparation for initiating project execution when the FTN begins full-scale automated operations.

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**Institution(s):** 1. US Air Force Academy

### 137.14 – The First Year of Robotic Science with MINERVA

Detection of low-mass exoplanets orbiting Sun-like stars requires high cadence, long time-baseline observations that are impossible to obtain on shared large telescopes. MINERVA is a dedicated observatory for exoplanet detection that consists of four robotic 0.7-meter PlaneWave telescopes located at Whipple Observatory on Mt Hopkins, Arizona. First light science began in May 2015 with photometric monitoring of transit and microlensing events. The four telescopes can observe different targets, or provide simultaneous multi-color light curves of a single event. We will add a purpose-built, temperature-stabilized, high precision iodine cell spectrometer from Callaghan Innovation in 2016 to facilitate velocimetric search for low-mass exoplanets around nearby stars. The flexibility of the MINERVA array provides a natural avenue for educational and public outreach activities. One telescope in the array can break formation to observe targets from a queue or respond to remote operations from astronomy courses at a partner institution. MINERVA is a collaboration among Harvard U., Penn State U., U. Montana, and U. New South Wales.

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**Institution(s):** 1. Caltech, 2. Harvard CfA, 3. Pennsylvania State University, 4. U. New South Wales, 5. University of Montana

### 137.15 – Calibrating Images from the MINERVA Cameras

The MINiature Exoplanet Radial Velocity Array (MINERVA) consists of an array of robotic telescopes located on Mount Hopkins, Arizona with the purpose of performing transit photometry and spectroscopy to find Earth-like planets around Sun-like stars. In order to make photometric observations, it is necessary to perform calibrations on the CCD cameras of the telescopes to take into account possible instrument error on the data. In this project, we developed a pipeline that takes optical images, calibrates them using sky flats, darks, and biases to generate a transit light curve.

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### 137.16 – High Precision Photometry of Bright Transiting Exoplanet Hosts

Within the past two decades, the successful search for exoplanets and the characterization of their physical properties have shown the immense progress that has been made towards finding planets with characteristics similar to Earth. For most exoplanets with a radius about the size of Earth, evaluating their physical properties, such as

the mass, radius and equilibrium temperature, cannot be determined with satisfactory precision. The MINiature Exoplanet Radial Velocity Array (MINERVA) was recently built to obtain spectroscopic and photometric measurements to find, confirm, and characterize Earth-like exoplanets. MINERVA's spectroscopic survey targets the brightest, nearby stars which are well-suited to the array's capabilities, while its primary photometric goal is to search for transits around these bright targets. Typically, it is difficult to find satisfactory comparison stars within a telescope's field of view when the primary target is very bright. This issue is resolved by using one of MINERVA's telescopes to observe the primary bright star while the other telescopes observe a distinct field of view that contains satisfactory bright comparison stars. We describe the code used to identify nearby comparison stars, schedule the four telescopes, produce differential photometry from multiple telescopes, and show the first results from this effort.

This work has been funded by the Ronald E. McNair Post-Baccalaureate Achievement Program, the ERAU Honors Program, the ERAU Undergraduate Research Spark Fund, and the Banneker Institute at the Harvard-Smithsonian Center for Astrophysics.

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**Institution(s):** 1. Embry-Riddle Aeronautical, 2. Harvard-Smithsonian Center for Astrophysics

### 137.17 – An Infrared Radial Velocity Search for 'Hot Jupiters' Around Young Stars

We present initial findings from our infrared RV survey of young stars in search of young hot Jupiters utilizing high dispersion IR (2.3micron) spectra from Gemini South Phoenix, VLT CRILES and Keck NIRSPEC. Our technique uses telluric features as an absolute wavelength reference, allowing us to achieve a precision of ~40m/s for slowly rotating field stars. Although RV jitter is lower at IR wavelengths, it is still ~100m/s, thus limiting our sensitivity to hot Jupiters. With this survey of young (8-12Myr) associations using multi-epoch RV data, we hope to put constraints on the current theories of formation and early migration as it allows for the detection of planets in the process of formation, or soon after they have formed.

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**Institution(s):** 1. Georgia State University, 2. University of Michigan

### 137.18 – Pipeline Development and Early Performance of the High-resolution, High-precision Radial Velocity TOU Spectrograph

TOU is a very high resolution (R~100,000) optical spectrograph with broad wavelength coverage (380-900 nm), operated in vacuum. It was designed and built for the on-going Dharma planet survey, aiming at detecting and characterizing habitable rocky planets around nearby bright FGKM dwarfs. After a hardware upgrade in September 2015, it has reached a super stable status in terms of temperature control (1-2mk), pressure control and instrument drifts (1m/s) monitored with Thorium-Argon, iodine and Sine calibration sources. A major effort has been taken since 2014 to develop a data processing pipeline aiming at reaching sub m/s Doppler precision for bright survey targets. Early pipeline progress and stellar radial velocity measurement results will be presented.

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**Institution(s):** 1. University of Florida

### 137.19 – Telluric Line Effect on High Precision Radial Velocity Survey of K and M Dwarfs

The red and NIR region, where K and M dwarfs emit most of light, is the desirable region for radial velocity (RV) measurements for detecting low mass planets, but this wavelength region is heavily contaminated with telluric absorption lines. Variation in the telluric line depths and centroids can result in large RV measurement uncertainties, limiting the sensitivity to detect low mass planets.

Here we use simulations to study effect of telluric removal and the residuals on RV measurements and determine the level of correction needed to minimize the effect. Simulated spectra from three representative spectrographs with spectral resolutions, R=60K, 80K, 100K and 120K for wavelength coverage at 0.38-0.62  $\mu\text{m}$  (called the optical spectrograph), 0.38-0.90  $\mu\text{m}$  (called the broad optical spectrograph) and 0.90-2.4  $\mu\text{m}$  (called the NIR spectrograph), have been studied. Two methods are used to study the RV effect by the telluric lines. The first one is a 'Masking' method, in which the telluric lines are identified and removed from RV calculation. The other method is a 'Removal' method, in which all heavily saturated lines are masked out and the remaining lines are subtracted by synthetic atmospheric spectra to a desired level. Our results show that, in case of late M dwarfs, the broad optical spectrograph can gain additional RV sensitivity over the optical spectrograph if telluric lines can be modeled and subtracted to better than 10%, or all lines deeper than 5% are masked out from RV calculation. For the earlier type stars, it requires better than 2% modeling and subtracting precision with the broad optical spectrograph to gain additional Doppler sensitivity over the optical spectrograph. Besides the photon gain with the NIR spectrograph over the optical spectrograph for late M dwarf observations, the NIR can gain additional advantage of Doppler sensitivity over the optical tool for late M dwarfs when telluric residuals can be subtracted to below 1%. However, it is never better than the broad optical spectrograph in any cases with the same residual levels. These indicate the broad optical spectrograph can potentially be an optimal spectrograph for high precision RV surveys for low mass planets.

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### 137.20 – Simulations of Detectability of Extrasolar Planets by a Joint Doppler and WFIRST-AFTA Coronagraph Survey

A long-term goal for the astronomical community is to image and characterize an Earth-like planet. The WFIRST-AFTA space mission will make advancements towards this goal. WFIRST will include a coronagraphic instrument to discover and characterize new exoplanets and to better characterize already known exoplanets. We present results of simulations using a Doppler survey to find lower mass planets as possible targets for WFIRST. For simulations, simplified completeness estimates (Howard & Fulton 2014) are used to test the sensitivity of a prospective Doppler campaign. We use data from the HARPS spectrograph to determine exposure times needed to achieve 1 m/s uncertainty. Stellar jitter was randomly sampled from a uniform distribution based on spectral type, treating OBA-type, FGK-type, and M-type stars separately. For survey parameters, we use campaign parameters from the WIYN telescope, assuming 10 hours per night at 100 nights per year over 6 years. In any one simulation, we find roughly 45-50 new planets that are potentially observable by WFIRST. By limiting our targets to FGKM type stars within 10 parsecs, we expect one of those planets to be less than 10 M<sub>E</sub>.

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**Institution(s):** 1. Department of Physics, State University of New York at Albany, 2. Kavli Institute for Particle Astrophysics and Cosmology, Stanford University

### 137.21 – Estimation of chromatic errors from broadband images for high contrast imaging: sensitivity analysis

Many concepts have been proposed to enable direct imaging of planets around nearby stars, and which would enable spectroscopic observations of their atmospheric observations and the potential discovery of biomarkers. The main technical challenge associated with direct imaging of exoplanets is to effectively control both the diffraction and scattered light from the star so that the dim planetary companion can be seen. Usage of an internal coronagraph with an adaptive optical system for wavefront correction is one of the most mature methods and is being developed as an instrument addition to the WFIRST-AFTA space mission. In addition, such instruments as

GPI and SPHERE are already being used on the ground and are yielding spectra of giant planets. For the deformable mirror (DM) to recover a dark hole region with sufficiently high contrast in the image plane, mid-spatial frequency wavefront errors must be estimated. To date, most broadband lab demonstrations use narrowband filters to obtain an estimate of the chromaticity of the wavefront error and this can result in usage of a large percentage of the total integration time. Previously, we have proposed a method to estimate the chromaticity of wavefront errors using only broadband images; we have demonstrated that under idealized conditions wavefront errors can be estimated from images composed of discrete wavelengths. This is achieved by using DM probes with sufficient spatially-localized chromatic diversity. Here we report on the results of a study of the performance of this method with respect to realistic broadband images including noise. Additionally, we study optimal probe patterns that enable reduction of the number of probes used and compare the integration time with narrowband and IFS estimation methods.

**Author(s):** Dan Sirbu<sup>1</sup>, Ruslan Belikov<sup>1</sup>  
**Institution(s):** 1. NASA ARC

### 137.22 – Managing the optical wavefront for high contrast exoplanet imaging with the WFIRST-AFTA coronagraph

The prospect of extreme high contrast astronomical imaging from space has inspired developments of new coronagraph methods for exoplanet imaging and spectroscopy. However, the requisite contrast, at levels of a billion to one or better for the direct imaging of cool mature exoplanets in reflected visible starlight, leads to challenging new requirements on the stability and control of the optical wavefront at levels currently beyond the reach of ground based telescopes. We briefly review the designs, laboratory validations, and science prospects for direct imaging and spectroscopic characterization of exoplanet systems with an actively corrected Lyot coronagraph. We review exoplanet science performance predicted for NASA's WFIRST-AFTA coronagraph. Together with a pair of deformable mirrors for optical wavefront control, the Lyot coronagraph creates high contrast dark fields of view extending to angular separations within 0.1 arcsec from the central star at visible wavelengths. Performance metrics are presented, including image contrast and spectral bandwidth, and laboratory validation experience.

**Author(s):** John T. Trauger<sup>1</sup>, John E. Krist<sup>1</sup>, Dwight Moody<sup>1</sup>  
**Institution(s):** 1. JPL

### 137.23 – Characterizing Exoplanet Motions Using Random Orbit Generation for the Gemini Planet Imager Exoplanet Survey

Next generation planet-finders like the Gemini Planet Imager (GPI) allow for direct imaging of exoplanets that are close enough to their host stars to undergo detectable orbital motion on monthly timescales, creating a need for methods that rapidly characterize newly discovered planets using short astrometric baselines. We present a computationally efficient Monte Carlo method that fits randomly generated orbital parameters to astrometry of directly imaged exoplanets from a fraction of an orbit. This code quickly and efficiently produces distributions of plausible orbital parameters, while a traditional Markov-Chain Monte Carlo algorithm would take much longer to converge given the same inputs (future work will directly compare the computational efficiencies and outputs of both algorithms). This technique allows us to predict the future motion of a planet by randomly generating plausible orbits that fit just a few epochs of astrometry, or even a single epoch. We first applied this method to predicting the future position of 51 Eri b, a giant exoplanet discovered by GPIES, using astrometry with only a 1-month baseline. Subsequent observations of 51 Eri b after seven months found the planet at the peak of the probability distributions predicting future motion. We demonstrate how this method can be applied to GPIES and the future WFIRST-AFTA space mission, from distinguishing bound planets from background objects to constraining orbital parameters given data from only a few observational epochs after discovery.

This material is based on work supported by the National Science Foundation REU Program under Grant No. AST-1359346.

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**Institution(s):** 1. Brown University, 2. National Research Council of Canada Herzberg, 3. SETI Institute, 4. Space Telescope Science Institute, 5. Stanford University, 6. Université de Montréal, 7. University of California at Berkeley, 8. University of California at San Diego

**Contributing team(s):** The GPIES Collaboration

### 137.25 – First Experimental Results Using Sparse Aperture Mask for Low Order Wavefront Sensing

We can determine the existence of life outside of earth by analyzing the spectra of exoplanets. Such direct imaging will provide the capability to thoroughly characterize an exoplanet's atmosphere. Direct imaging of exoplanets, however, has many technical challenges and difficulties: scattering and diffraction of light and the large difference in contrast, which is the ratio of brightness between the bright star and the dimmer planet. A coronagraph is an optical device that manipulates the diffraction of starlight and creates a region of high contrast (dark hole) where the dimmer planets can be seen. While in principle the level of contrast required for direct imaging of exoplanets can be achieved by stellar coronagraphic imaging, the resulting dark hole is highly sensitive to phase aberrations. In order to effectively suppress starlight for exoplanet imaging applications, low-order wavefront aberrations entering a coronagraph such as tip-tilt, defocus and coma must be determined and compensated for. A sparse-aperture mask (SAM) can be integrated in the telescopic imaging system to make precise estimate of low-order wavefront aberrations. In this technique, the starlight rejected by the coronagraph's focal plane stop is collimated to a relay pupil, where the mask forms an interference fringe pattern on a detector and the phase aberrations are inferred from this fringe pattern. At Princeton's High Contrast Imaging Lab (HCIL), we have numerically proved this concept and we are currently working on verifying it experimentally.

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**Institution(s):** 1. Princeton University

### 137.26 – Progress on an external occulter testbed at flight Fresnel numbers

An external occulter is a spacecraft flown along the line-of-sight of a space telescope to suppress starlight and enable high-contrast direct imaging of exoplanets. Laboratory verification of occulter designs is necessary to validate the optical models used to design and predict occulter performance. At Princeton, we have designed and built a testbed that allows verification of scaled occulter designs whose suppressed shadow is mathematically identical to that of space occulters. The occulter testbed uses 78 m optical propagation distance to realize the flight Fresnel numbers. We will use an etched silicon mask as the occulter. The occulter is illuminated by a diverging laser beam to reduce the aberrations from the optics before the occulter. Here, we present first light result of a sample design operating at a flight Fresnel number and the mechanical design of the testbed. We compare the experimental results with simulations that predict the ultimate contrast performance.

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**Institution(s):** 1. NASA Ames, 2. Princeton University

### 137.27 – Suppression of Astronomical Sources Using Starshades and the McMath-Pierce Solar Telescope

The external starshade is a method for the direct detection and spectral characterization of terrestrial planets around other stars, a key goal identified in ASTRO2010. Tests of this approach have been and continue to be conducted in the lab and in the field (Samuele et

al., 2010, Glassman et al., 2014) using non-collimated light sources with a spherical wavefront. We extend the current approach to performing night-time observations of astronomical objects using small-scale (approximately 1/300th) starshades and the McMath-Pierce Solar Telescope at Kitt Peak National Observatory. We placed a starshade directly in the path of the beam from an astronomical object in front of the main heliostat. Using only flat mirrors, we then directed the light through the observatory path and reflected it off the West heliostat to an external telescope located approximately 270m away, for an effective baseline of 420m.

This configuration allowed us to make measurements of flat wavefront sources with a Fresnel number close to those expected in proposed full-scale space configurations. We present the results of our engineering runs conducted in 2015.

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**Institution(s):** 1. Northrop Grumman Aerospace Systems, 2. University of Colorado

### 137.28 – Measurements of High-Contrast Starshade Performance in the Field

The external Starshade is a method for the direct detection and spectral characterization of terrestrial planets around other stars, a key goal identified in ASTRO2010. In an effort to validate the starlight-suppression performance of the Starshade, we have measured contrast better than  $1 \times 10^{-9}$  using 60 cm Starshades at points just beyond the Starshade tips. These measurements were made over a 50% spectral bandpass, using an incoherent light source (a white LED), and in challenging outdoor test environments. Our experimental setup is designed to provide Starshade to telescope separation and telescope aperture size that are scaled as closely as possible to the flight system. The measurements confirm not only the overall starlight-suppression capability of the Starshade concept but also the robustness of the setup to optical disturbances such as atmospheric effects at the test site. The spectral coverage is limited only by the optics and detectors in our test setup, not by the Starshade itself. Here we describe our latest results as well as detailed comparisons of the measured results to model predictions. Plans and status of the next phase of ground testing are also discussed.

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**Institution(s):** 1. Colorado University, 2. Jet Propulsion Laboratory, 3. Northrop Grumman

### 137.29 – WFIRST Exoplanet Imaging: Can Broadband Colors Efficiently Discriminate Planets from the Background?

As part of the WFIRST Preparatory Science program, we have begun exploring the broadband color combinations for WFIRST that will most efficiently (1) discriminate planets from background sources in a single image and (2) shed some light on the nature of those planets. This is a first look at the color-color space, and color-magnitude space, occupied by planets orbiting nearby K-F main sequence stars. We explore (1) Solar System analog planets, (2) a variety of Earths/Super-Earths having optically thin or partially cloudy Earth-like atmospheres over desert/forest/ocean/icy surfaces, and (3) mini-Neptunes through Jupiter-mass planets at a range of temperatures where they would potentially be detectable to WFIRST. These colors are compared to the expected Galactic and extragalactic background sources for the Galactic coordinates of high priority targets. We offer some preliminary conclusions about the expected background contamination in these fields and how well color information can be used to mitigate that threat to WFIRST's exoplanet science.

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**Institution(s):** 1. JPL, 2. SETI Institute, 3. University of Wisconsin

## 138 – Extrasolar Planets: Characterization and Theory Poster Session

### 138.01 – Detection and Characterization of Exoplanets using Projections on Karhunen-Loeve Eigenimages: Forward Modeling

A new class of high-contrast image analysis algorithms, that empirically fit and subtract systematic noise has lead to recent discoveries of faint exoplanet /substellar companions and scattered light images of circumstellar disks. The consensus emerging in the community is that these methods are extremely efficient at enhancing the detectability of faint astrophysical signal, but do generally create systematic biases in their observed properties. This poster provides a solution this outstanding problem. We present an analytical derivation of a linear expansion that captures the impact of astrophysical over/self-subtraction in current image analysis techniques. We examine the general case for which the reference images of the astrophysical scene moves azimuthally and/or radially across the field of view as a result of the observation strategy. Our new method method is based on perturbing the covariance matrix underlying any least-squares speckles problem and propagating this perturbation through the data analysis algorithm. This work is presented in the framework of Karhunen-Loeve Image Processing (KLIP) but it can be easily generalized to methods relying on linear combination of images (instead of eigen-modes). Based on this linear expansion, obtained in the most general case, we then demonstrate practical applications of this new algorithm. We first consider the case of the spectral extraction of faint point sources in IFS data and illustrate, using public Gemini Planet Imager commissioning data, that our novel perturbation based Forward Modeling (which we named KLIP-FM) can indeed alleviate algorithmic biases. We then apply KLIP-FM to the detection of point sources and show how it decreases the rate of false negatives while keeping the rate of false positives unchanged when compared to classical KLIP. This can potentially have important consequences on the design of follow-up strategies of ongoing direct imaging surveys.

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**Institution(s):** 1. Space Telescope Science Institute

### 138.02 – Symplectic Integrators: Variational Integrators for Nonconservative systems

Symplectic integrators are widely used for long-term integration of conservative astrophysical problems due to their ability to preserve the constants of motion; however, they cannot in general be applied in the presence of nonconservative interactions. In this Letter, we develop the “symplectic” integrator, a new type of numerical integrator that shares many of the benefits of traditional symplectic integrators yet is applicable to general nonconservative systems. We utilize a fixed-time-step variational integrator formalism applied to the principle of stationary nonconservative action developed in Galley et al. As a result, the generalized momenta and energy (Noether current) evolutions are well-tracked. We discuss several example systems, including damped harmonic oscillators, Poynting–Robertson drag, and gravitational radiation reaction, by utilizing our new publicly available code to demonstrate the symplectic integrator algorithm. Symplectic integrators are well-suited for integrations of systems where nonconservative effects play an important role in the long-term dynamical evolution. As such they are particularly appropriate for cosmological or celestial N-body dynamics problems where nonconservative interactions, e.g., gas interactions or dissipative tides, can play an important role.

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**Institution(s):** 1. University of Maryland

### 138.03 – Variability in the pre-transit signal of HD 189733 b

Hot planets, i.e., those with orbital periods of a few days, can interact strongly with their host stars via gravitational tides, magnetic interactions, or via collisions between planetary and stellar winds or the planetary magnetosphere and the stellar wind. Recently, pre-transit absorption signals, caused by material orbiting ahead of

the planet, have been detected around a handful of exoplanets. Two of these measurements, those for WASP-12 b (Llama et al. 2011) and HD 189733 b (Cauley et al. 2015), were interpreted as being the result of compressed material in a bow shock formed by the planetary magnetosphere plowing through the stellar wind. These signals are expected to be variable at some level as the planet passes through an inhomogeneous stellar wind or corona and stellar activity levels change. To investigate this potential variability and confirm the detected signal, we have recently obtained followup observations to the 2013 transit reported in Cauley et al. (2015). The new measurements confirm the existence of the pre- and in-transit absorption detected in the 2013 data. However, the new signal is not consistent with the specific bow shock geometry presented in Cauley et al. (2015). We have performed a more detailed examination of the Ca II H and K line core flux, which is a proxy for the stellar activity level, for the 2013 data. We find a weak correlation between the H $\alpha$  core flux and the Ca II core flux, suggesting that some, but not all, of the pre-transit absorption signature may be a result of changing stellar activity levels during the observations. Our examination of the Ca II core flux measurements uncover variability that is not seen using the SHK activity index. We are evaluating techniques to calibrate our H $\alpha$  signal with these more detailed Ca II measurements and suggest that the core flux is a better proxy of low level stellar variability for a single epoch. In addition, the 2015 transit confirms that pre-transit absorption signals are variable and likely orbit through a highly dynamic environment that is dependent on the stellar activity level. We acknowledge funding for this work through NSF Astronomy and Astrophysics grant AST-1313268 and NASA Keck PI Data Award 1536707.

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**Institution(s):** 1. University of Arizona, 2. University of Nebraska Kearney, 3. University of Texas at Austin, 4. Wesleyan University

### 138.04 – Stellar Angular Diameter Relations for Microlensing Surveys

Determining the physical properties of microlensing events depends on having accurate angular radii of the source star. Using long-baseline optical interferometry we are able to determine the angular sizes of nearby stars with uncertainties less than 2 percent. We present empirical estimates of angular diameters for both dwarfs/subgiants and giant stars as functions of five color indices which are relevant to planned microlensing surveys. We find in all considered colors that metallicity does not play a statistically significant role in predicting stellar size for the samples of stars considered.

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### 138.05 – Astrometry of Directly Imaged Exoplanets after PSF Subtraction using MCMC Forward Modeling

Direct imaging allows for the characterization of the orbits of exoplanets. However, to remove the glare of the host star, we must use observing strategies (e.g., angular differential imaging and spectral differential imaging) and data reduction techniques (e.g., Karhunen-Loève Image Projection; KLIP) that distort the apparent position of an exoplanet. Using recent methods to forward model the point spread function of a planet after using KLIP to subtract out the stellar light (Pueyo 2015), we are able to account for these astrometric biases. With the forward models, we can use a Markov chain Monte Carlo (MCMC) algorithm to derive the posterior distribution on the position of an exoplanet. To test our methodology, we apply our technique to Gemini Planet Imager integral field spectroscopy (IFS) data of the newly discovered exoplanet around 51 Eri and the extensively studied exoplanet beta Pictoris b. In general, this technique is applicable to any broadband direct imaging data and IFS data where the spectrum is assumed to be known.

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**Contributing team(s):** GPIES Collaboration

### 138.06 – Adaptive Optics Imaging of Exoplanet Host Stars

With the Arizona Infrared imager and Echelle Spectrograph (ARIES) instrument on the 6.5m MMT telescope, we obtained high angular resolution adaptive optics images of 12 exoplanet host stars. The targets are all systems with exoplanets in extremely close orbits such that the planets transit the host stars and cause regular brightness changes in the stars. The transit depth of the light curve is used to infer the radius and, in combination with radial velocity measurements, the density of the planet, but the results can be biased if the light from the host star is the combined light of a pair of stars in a binary system or a chance alignment of two stars. Given the high frequency of binary star systems and the increasing number of transit exoplanet discoveries from Kepler, K2, and anticipated discoveries with the Transiting Exoplanet Survey Satellite (TESS), this is a crucial point to consider when interpreting exoplanet properties. Companions were identified around five of the twelve targets at separations close enough that the brightness measurements of these host stars are in fact the combined brightness of two stars. Images of the resolved stellar systems and reanalysis of the exoplanet properties accounting for the presence of two stars are presented.

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### 138.07 – A Study of the Effects of Underlying Assumptions in the Reduction of Multi-Object Photometry of Transiting Exoplanets

The analysis of ground-based photometric observations of planetary transits must treat the effects of the Earth's atmosphere, which exceed the signal of the extrasolar planet. Generally, this is achieved by dividing the signal of the host star and planet from that of nearby field stars. For bright hot Jupiter exoplanets this procedure reveals the lightcurve. The lightcurve is then fit to a model of the planet's orbit and the physical characteristics, also taking into account the characteristics of the star. The fit to the in-transit data coupled with the fit of the out-of-transit data establish the depth of the lightcurve. The question then arises, what is the best way to select and treat the reference stars such that we can best characterize and remove the shared atmospheric systematics that plague our transit signal. To explore these questions we examine the effects of several assumptions that underlie the calculation of the light curve depth. Our study involves photometric observations of hot Jupiter primary transits in the U and B filters taken with the University of Arizona's Kuiper 1.55m telescope and Mont4K CCD. The data consists of repeated transit observations of a variety of exoplanets, each of which offers a unique field with stars of various brightness, spectral types, and angular distance from the host star. While these observations are part of a larger study of the Rayleigh scattering signature of hot Jupiter exoplanets, here we study the effects of various choices during the reduction phase, specifically the treatment of the reference stars and atmospheric systematics. Our study calculates the lightcurve for all permutations of the reference stars, considering several different out-of-transit assumptions (e.g. linear, quadratic or exponential). We assess the sensitivity of the transit depths based on the spread of the values and look for characteristics that minimize the scatter in the reduced lightcurve as well as analyze the effects of the treatment of individual variables on the resultant model. This research group, referred to as AzGOE, is made of primarily undergraduate students from the University of Arizona, in cooperation with the University of Arizona Astronomy Club.

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**Contributing team(s):** AzGOE

### 138.08 – Lithium Abundance in Planet Search Stars

Since most lithium in the universe is primordial and is destroyed in stars, lithium abundance can be used as a stellar age indicator. Some research seems to show that planet formation may also affect lithium abundance in exoplanet host stars (EHS). However, small and heterogeneous samples have made both of these phenomena unclear. Further study of lithium abundance in EHS is needed to better understand possible physical roles of lithium in planet formation theory. We use a large homogeneous sample with accurate stellar parameters on which we will use equivalent width analysis to determine precise lithium abundances. From these abundance values we determine an age vs. abundance relation. Additionally, we aim to explore correlation between lithium abundance and planet formation.

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**Contributing team(s):** Yale Exoplanets

### 138.09 – Investigating Detailed Abundance Patterns in the Hyades Cluster

We have derived the parameters and abundances of up to 17 elements for seven stars within the Hyades open star cluster, through an analysis of high-resolution, high signal-to-noise ratio spectra obtained via the Harlan J. Smith 2.7 m telescope and the 2dcoude cross-dispersed echelle spectrometer at the McDonald Observatory. Four of the stars are solar-type dwarves while three giants were also analyzed to better calculate an overall metallicity of the entire cluster. In addition, we investigated whether there are differences in various stellar abundance trends across the open cluster. Here we present the results of our abundance analysis and stellar parameter derivations of the seven stars and discuss the implications of stellar abundance patterns across star clusters.

We acknowledge support provided by grant NNX12AD19G to S.C.S. from the National Aeronautics and Space Administration as part of the Kepler Participating Scientist Program.

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### 138.10 – Detailed Abundances of Stars with Small Planets Discovered by Kepler

We present newly derived stellar parameters and the detailed abundances of 19 elements of seven stars with small planets discovered by NASA's Kepler Mission. Each star save one has at least one planet with a radius less than 2  $R_{\text{Earth}}$ , suggesting a primarily rocky composition. The stellar parameters and abundances are derived from high signal-to-noise ratio, high-resolution echelle spectroscopy obtained with the 10-m Keck I telescope and HIRES spectrometer using standard spectroscopic techniques. We compare the abundances to those of a general Galactic disk population and investigate possible abundance trends with condensation temperature of the elements.

S.C.S. acknowledges support provided by grant NNX12AD19G to S.C.S. from the National Aeronautics and Space Administration as part of the Kepler Participating Scientist Program.

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### 138.11 – Abundance Analysis of 10 Kepler Planetary Hosts

This study aims to identify possible connections between the detailed chemical abundances of stars and the existence of small planets discovered by NASA's Kepler spacecraft. We have analyzed high quality Keck/HIRES spectra of the planetary hosts Kepler-65, Kepler-93, Kepler-97, Kepler-98, Kepler-102, Kepler 128, Kepler-406, Kepler-408, Kepler-409, and Kepler-411 and derived the abundances of up to 17 elements for these stars. Results from previous studies have suggested that stellar abundance patterns or "signatures" may indicate the presence of planets, possibly terrestrial planets in particular. Should such patterns exist, they could be used to identify stars with small planets. Here we present the results of our abundance analysis of 10 stars with a variety of exoplanet systems discovered by Kepler and address the hypothesis that chemical abundance signatures can indicate the presence of small planets.

This work is generously supported by NASA through a Kepler Participating Scientist grant to SCS (Grant #NNX13AH78G).

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### 138.12 – Characterizing the Period Ratio Distribution of Kepler Exoplanetary Systems

Many of the exoplanetary systems discovered by the Kepler space telescope demonstrate unusual properties which need to be explored in order to better understand planetary system formation and evolution. Among these interesting properties is an excess in the number of planets orbiting in resonance or near-resonance with their neighbors. The prevailing assumption in the planetary sciences community is that these are real features of the exoplanet population, but many theories developed on this assumption produce a resonance structure quite different from what we see. In our work we explore the possibility that the actual resonances may not be as we observe them, and may instead be explained by a combination of real resonance features and/or observational bias resulting from geometric effects. In particular, if the near-resonant systems have a different inclination distribution than other systems, then it is possible for them to be over or under-represented.

We analyze the existing Kepler data and generate models which approximately represent the empirical period ratio distribution. The 2:1 and 3:2 just-wide-of-resonance excesses are included in the model, along with the deficit of period ratios just short of the 2:1 resonance. We test the Kepler data set against these models using the Python emcee package in order to determine the best-fit parameters for each model. We then address the inclination distribution question by generating two-planet systems with different inclination distributions for the near-resonant systems. We use the CORBITS package (<https://github.com/jbrakensiek/CORBITS>, Brakensiek & Ragozzine, submitted) to determine the probability of detecting both planets in transit. These tests adjust the relative sizes of the resonance excesses as well as orbital parameters (primarily inclination and nodal alignments) in order to determine which combinations of parameters would create in an observational bias resulting in the resonance excesses seen in the Kepler data.

Initial results using first-approximation synthetic data show that some of the observed resonance excesses can be created in the observed data purely from geometric effects resulting from inclination varying as a function of period ratio.

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### 138.13 – The mass of the super-Earth orbiting the brightest Kepler planet hosting star

HD 179070, aka Kepler-21, is a  $V = 8.25$  oscillating F6IV star and the

brightest exoplanet host discovered by *Kepler*. An early analysis of the Q0 – Q5 *Kepler* light curves by Howell et al. (2012) revealed transits of a planetary companion, Kepler-21b, with a radius of 1.6  $R_{\text{Earth}}$  and an orbital period of 2.7857 days. However, they could not determine the mass of the planet from the initial radial velocity observations with Keck-HIRES, and were only able to impose a 2 $\sigma$  upper limit of about 10  $M_{\text{Earth}}$ . Here we present 82 new radial velocity observations of this system obtained with the HARPS-N spectrograph. We detect the Doppler shift signal of Kepler-21b at the 3.6 $\sigma$  level, and measure a planetary mass of  $5.9 \pm 1.6 M_{\text{Earth}}$ . We also update the radius of the planet to  $1.65 \pm 0.08 R_{\text{Earth}}$ , using the now available *Kepler* Q0 – Q17 photometry for this target. The mass of Kepler-21b appears to fall on the apparent dividing line between super-Earths that have lost all the material in their outer layers and those that have retained a significant amount of volatiles. Based on our results Kepler-21b belongs to the first group. Acknowledgement: This work was supported by funding from the NASA XRP Program and the John Templeton Foundation.

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**Contributing team(s):** HARPS-N Team

### 138.14 – Transit, Secondary Eclipse, and Phase Curve Modeling to Characterize Kepler Exoplanet Candidates

The high sensitivity and continuous coverage of *Kepler* allows for analysis of optical phase curves, which provide detailed exoplanet characterization by fitting photometric features caused by thermal emission, reflected light, Doppler boosting, and ellipsoidal variations. Combined with transit and secondary eclipse analysis to reduce model degeneracy, phase curves can resolve atmospheric characteristics, dayside-nightside temperatures, and even mass using single-band photometry. We will present an integrated phase curve, transit, and secondary eclipse analysis of *Kepler* exoplanet candidates, building on the phase curve model constructed by Serindag & Redfield (2015). Phase curves can also be present in non-transiting systems. We will explore the feasibility of detecting and characterizing these non-transiting exoplanets. We will also investigate the possibility of analyzing exoplanet phase curves in K2 data. We gratefully acknowledge support through a grant (14-K2GO1\_2-0071) associated with the K2 Guest Observer – Cycle 1 program of Research Opportunities in Space and Earth Sciences (ROSES-2014; NNH14ZDA001N).

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### 138.15 – Spitzer Meets K2: Spitzer Studies of Candidate Exoplanets Identified by K2

We are in the midst of a ~450 hr program of *Spitzer* photometry of candidate transiting planets orbiting M dwarf stars, identified in the K2 fields. Whereas the *Kepler* prime mission eschewed M stars, they have become a major focus of the community-driven target selection for K2. M stars are the most common stars in the galaxy, and planets orbiting M stars can be very attractive candidates for transit and eclipse atmospheric studies, including studies aimed at exploring potentially habitable exoplanets. We will review and show the results of the observations planned and executed to date, which total 21 transits of 16 planets orbiting 13 stars. Our results greatly improve on the characterization of the exoplanets and their orbits over what is possible from the K2 data alone. In addition, the improved ephemerides we generate will facilitate studies of interesting K2 targets from JWST.

This work is based in part on observations made with the *Spitzer* Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. Support for this work was provided by NASA through an award issued by JPL/Caltech.

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**Contributing team(s):** Spitzer/K2 Study Team

### 138.16 – The HERMES K2 Follow-up Program at the Anglo-Australian Telescope

One of the lessons learned from the *Kepler* prime mission is that our understanding of the detailed properties of transiting planets is fundamentally limited by our knowledge of the host star's properties. There is a critical need for self-consistent, spectroscopically-determined stellar parameters for the entire K2 sample. The innovative HERMES spectrograph on the Anglo-Australian Telescope offers a way forward, with the ability to obtain 400 spectra in a single pointing. HERMES operates at R=28,000 in four bandpasses specifically chosen to maximise the information on physical parameters such as chemical compositions, temperatures, and gravities. We describe an ongoing program to obtain spectra for as many K2 targets as possible down to V~14.75. The result will be a uniform catalog of stellar properties which will be invaluable for characterising the K2 exoplanet sample, and for informing studies of the population statistics (including non-planet hosts). Synergy with the K2 asteroseismology program will help to calibrate the evolutionary models used to determine stellar radii and masses, improving the accuracy and precision of the radii and masses of K2's planets, ultimately improving our understanding of the transition between Earth-like and Neptune-like worlds.

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### 138.17 – A Habitability Test of the Exoplanetary System K2-3

The question of habitability is one of the most interesting questions in exoplanetary science. By studying the orbital properties of a planet, like its eccentricity and habitable zone inner edge distance we can answer this question. Here we answer the habitability question for the planets in the exoplanetary system K2-3 discovered by the *Kepler* 2 spacecraft. The system is composed of three planets with radii 1.61-2.17  $R_{\text{Earth}}$ , and with orbital periods of 10-45 days. The most outer planet in this system known as K2-3d is particularly interesting due to its proximity towards the habitable zone. The eccentricities of the planets in K2-3 were calculated using a method known as stellar density profiling, and from these eccentricities the range of the semi-major axis were determined. The planet K2-3d was calculated to have a semi-major axis of 0.18 AU, which puts it outside the habitable zone where inner edge of the habitable zone is 0.27 AU from its host star. This project was supported by the The Harvard Banneker Institute.

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### 138.18 – Home Sweet Home?: Determining Habitability From the Eccentricities of Kepler-186

In the search for habitable exoplanets, astronomers' primary criterion has historically been that the planet's equilibrium temperature be suitable for liquid water. Equilibrium temperature is often determined assuming a circular orbit and, therefore, a constant star-planet separation, especially for low-mass transiting exoplanets. Using photometric data from the first *Kepler* mission, we analyze the transit light curves of *Kepler* 186, an exoplanetary system located approximately 150pc from Earth. In this poster, we report new lower limits on the eccentricities of the system found using the astrodensity profiling method and discuss how those values effect habitability. We also report other orbital, stellar, and planetary properties, which are consistent with, though slightly more precise than, the values reported in Quintana et al, 2014. We assert that, with an eccentricity of 0.092, a semimajor axis of 0.35 AU, and a radius of 1.06 Earth radii, *Kepler* 186f is an Earth-sized exoplanet that spends its entire orbit in the habitable zone of its star.

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### 138.19 – Investigating the Orbital Period Valley of

## Giant Planets in *Kepler* Data

Transit light curves contain a wealth of information about the basic properties of a planet, such as its radius, semi-major axis, and orbital period. For the latter property, there is a distinct lack of planets with periods between 10 to 100 days. This gap could be caused by something as simple as observational bias, or as prominent as planetary formation or migration. Here, we report an investigation into the atmosphere of planets within this orbital period valley, to search for differences that may indicate a different formation mechanism or migration path to those outside of it. We do this by searching for the secondary eclipse of planets in the valley in order to measure their albedos. We determined an optimal target for this: KOI-366 b ( $P \sim 75$  days). However, we find that despite the exquisite precision of *Kepler* data, it cannot constrain the albedo for this long-orbit planet candidate. We measure a  $1\sigma$  upper limit on the geometric albedo of Ag,  $1\sigma \leq 2.0$ . We highlight that additional scatter in the light curve is likely caused by a  $\sim 2$ -day pulsation of the giant host star, and that further data is required to measure the secondary eclipse. KOI-366 is one of the best suited of all host stars with long period exoplanet candidates for follow-up due to its relatively bright magnitude ( $K_p = 11.7$  mag), but the full investigation of the reflective properties of long period planets may require space-based observations from future instruments, such as WFIRST, that will be more sensitive to objects further away from their host stars. This work was supported in part by the NSF REU and DoD ASSURE programs under NSF grant no. 1262851 and by the Smithsonian Institution. This work was performed in part under contract with the Jet Propulsion Laboratory (JPL) funded by NASA through the Sagan Fellowship Program executed by the NASA Exoplanet Science Institute.

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## 138.20 – Are there exoplanets near their Roche limits?

We survey the *Kepler* catalog for planets that are potentially at or very near the Roche limit separation ( $a_{\text{R}}$ ) from their host stars. The main challenge is of course that, albeit they have known radii, most candidate planets have unknown masses. We first determine the required mean densities ( $\rho_{\text{R}}$ ) for the candidate planets if they were truly at  $a_{\text{R}}$ . We then compare these  $\rho_{\text{R}}$  values with the planetary densities previously measured via a combination of transit, TTV, and radial velocity measurements. We identify several planet candidates for which  $\rho_{\text{R}}$  is within the observed range of planetary densities. Detailed study of mass loss via Roche-lobe overflow is potentially interesting for these systems.

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## 138.21 – Introducing an unknown companion in the *Kepler*-56 system (via radial velocity observations and dynamical analysis)

While the vast majority of multiple-planet systems have their orbital angular momentum axes aligned with the spin axis of their host star, *Kepler*-56 is an exception: its two transiting planets are coplanar yet misaligned by 40 degrees with respect to their host star. Additional follow-up observations of *Kepler*-56 suggest the presence of a massive, non-transiting companion that may help explain this misalignment. We model the transit data along with Keck/HIRES and HARPS radial velocity data to update the orbital parameters of the two transiting planets and infer the physical properties of the third, nontransiting planet. We employ a Markov Chain Monte Carlo sampler to calculate the best-fitting orbital parameters and the uncertainties, calculating posterior distributions on the physical parameters of each planet.

We find a maximally likely scenario in which the additional RV signal beyond the two transiting planets come from only one planet with a period of 1000 days and minimum mass of 6 Jupiter masses. Given

this minimum mass, the perturber could be a giant planet or brown dwarf, either of which would have implications on the formation of the *Kepler*-56 system. To further refine the allowed parameters of *Kepler*-56d, we use REBOUND to test the gravitational stability of simulated *Kepler*-56 systems to determine which of our RV-allowed systems are dynamically stable over the lifetime of this planetary system.

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## 138.22 – Characterizing Transiting Exoplanet Atmospheres with JWST

The James Webb Space Telescope (JWST) will advance our ability to determine the fundamental properties of the atmospheres of transiting planets. Its high signal-to-noise, moderate spectral resolution, and broad wavelength range spectra will provide an unprecedented look into the atmospheres of large to small and hot to temperate planets. In this contribution we explore the degree to which JWST spectra will be able to realistically constrain bulk atmospheric properties including molecular volume mixing ratios and thermal structures. We start by modeling the atmospheres of archetypal hot Jupiter, warm Neptune, warm sub-Neptune, and cool super-Earth planets with clear, cloudy, or high mean molecular weight variations. Next we simulate the  $\lambda = 1 - 11 \mu\text{m}$  transmission and emission spectra of these systems for several JWST instrument modes with realistic signal and noise components. We then perform atmospheric retrievals to determine how well temperatures and molecular mixing ratios ( $\text{CH}_4$ ,  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{NH}_3$ ) can be constrained. Using these results, we assess what instrument modes will be most useful for determining these values, and then we infer the metallicities and carbon-to-oxygen ratios for the chosen planet archetypes. We also examine how well the expected constraints on the molecular abundances and temperatures enable the exploration of disequilibrium chemistry and planet formation. We will not know the exact noise properties of JWST data until after its launch, but we expect that these results will provide realistic predictions of the scientific value of single event (transit or secondary eclipse) spectra.

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## 138.23 – The Effect of Atmospheric Hydrogen on the Albedo and Surface Temperature of Mars

The presence of hydrogen in planetary atmospheres has been shown to have the potential to dramatically effect the temperatures of planets. The collision-induced absorption (CIA) of hydrogen with carbon dioxide or nitrogen has been shown to have a substantial effect on the atmospheric temperature and albedo of a planet, possibly to the point at which life could exist on a planet where without such CIA the planet would be too cold. Using a single-column radiative-convective climate model, we investigated the effect of the presence of hydrogen on planetary temperatures and albedos across different amounts of hydrogen and across host stars of different temperatures using present-day Mars-like planets. We found that the addition of hydrogen in a planet's atmosphere increased the surface temperature of the planet. This effect was stronger for the planets orbiting hotter stars. The water vapor profiles showed that this was the case due to the presence of more water vapor in the atmospheres of planets orbiting hotter stars across all percentages of hydrogen. The water vapor concentrations also varied more with the addition of more hydrogen for the planets orbiting hotter stars.

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## 138.24 – Measuring Doppler Beaming with *Kepler* and TESS

The Kepler mission offered unparalleled insight into stellar systems. Due to Kepler's high precision photometry, we can study the reflected light from a planet, the ellipsoidal variations of a star, and the small Doppler beaming signal due to the gravitational interaction between a planet and host star. To predict how the beaming signal varies as a function of stellar system parameters, we numerically simulate the beaming signals both Kepler and the upcoming Transiting Exoplanet Survey Satellite (TESS) would detect. We predict what mass planets TESS will be capable of detecting given the solar neighborhood population of stars and known population of exoplanets. Doppler beaming is largest for massive, short-period planets around cool stars and is more easily detectable by Kepler than TESS. Kepler's advantage is its bluer bandpass, longer time baseline, and higher precision.

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### 138.25 – Determining the Atmospheric Nature of Super-Earth and Sub-Neptune Exoplanets

Proper characterization of the atmospheric composition of super-Earth and sub-Neptune planets will constrain the models that describe the formation and evolution of exoplanetary systems, yet the transition between Earth-mass and Neptune-mass exoplanets is still not well understood. Due to degeneracies between the bulk density and composition of planets in this range, even the basic make-up of many planets is unknown. Transit spectroscopy offers a method to characterize exoplanetary atmospheres and break this compositional degeneracy. We will present preliminary analysis and data reduction techniques for an ongoing large-scale Hubble Space Telescope survey of five planets between 1 and 22 Earth-masses. Using both optical and infrared primary transit spectra from STIS and WFC3, we will measure molecular signatures in the atmospheres of these small, cool planets, as well as any high-altitude clouds and hazes that may dampen such signatures. Results from this investigation will pave the way for future observations of small planets, especially in preparation for the James Webb Space Telescope (JWST) and the Transiting Exoplanet Survey Satellite (TESS).

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### 138.26 – Atmospheric heating in an irradiated transiting super-Earth and super-Neptune

We present new Chandra observations of HD 97658 (13 ks) and HAT-P-11 (8 ks), obtained to determine the high-energy radiation incident upon their short-period transiting planets. HD 97658 b is a hot super-Earth with a density between Earth and ice giants, while HAT-P-11 b is a hot super-Neptune orbiting an active K4 star. Our measurement of the stellar X-ray (and UV, from Swift) luminosities provides a current epoch estimate of atmospheric heating. We discuss whether these planets are likely to have experienced significant mass loss through atmospheric evaporation over their total lifetimes. These observations provide essential empirical input for understanding and modeling the potential evolutionary transformation of hot gas giants into less massive and more dense remnants.

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### 138.27 – The Role of Exotic Molecules In Model Exoplanet Spectra

We present the absorption signatures of 21 elemental and molecular

species normally found in observed planetary spectra. Fifty model exoplanet spectra that span temperatures from 400 to 2000 K, gravities from 100 to 1000 m/s<sup>2</sup>, and are 0.3-3 times solar metallicity composition are obtained by converting the pressure-temperature profiles through publicly available radiative transfer code (DISORT), assuming chemical equilibrium conditions. We explore the dependency of an individual specie's effect on a spectrum in the near-IR by removing its equilibrium abundance or enriching the specie's abundance. While testing for the individual effect of each species, it is found that the temperature is a key property for identifying absorption features in this diverse set of model spectra. Strong and abundant absorbers such as CO and CH<sub>4</sub> are not as prevalent in high temperature models over 1200 K as H<sub>2</sub>O at 0.9-2.2 and 2.3-4.1 microns. In addition, we investigate the vertical mixing and disequilibrium of CO and CH<sub>4</sub> and find features of these carbon species at 3.3-4.2 and 4.3-5.0 microns across all models. Trace species such as NH<sub>3</sub> and Na exhibit prevalent signatures in cold planets (~400-800 K) at the 1-1.1, 1.3-1.5, and 1.6-1.8 micron ranges. A consistent PH<sub>3</sub> feature is identified for 400 K spectra at 4-4.8 microns. In our hot model spectra with temperatures greater than 1400 K, TiO shows more significant absorption features than VO, suggesting that these molecules potentially play separate roles in determining thermal inversions. Hydrocarbons such as C<sub>2</sub>H<sub>2</sub> with abundances higher than 10<sup>-4</sup> exhibit prevalent absorption features at ~4.2-4.5 microns, indicating that photochemical reactions may be needed to further enrich these abundances. A table of these signatures at their respective temperatures, gravities, and metallicities is presented here. This research presented here was conducted by high-school students under the auspices of the University of California Santa Cruz's Science Internship Program.

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### 138.28 – Understanding dynamical instability in 4-planet systems with equal orbital spacing ( $\Delta$ )

The orbital spacing,  $\Delta$ , between two planets in units of their mutual Hill radii gives insight into their dynamical stability. A well-defined power law relationship derived through numerical simulations gives the average time to instability for systems with equally spaced planets of a certain  $\Delta$ . Previous work has established the change in the relationship between  $\Delta$  and instability time for various planet masses and planet multiplicity, however, less work has been done to understand the distribution of instability times for an ensemble of systems with fixed initial  $\Delta$ . We use Mercury6 to simulate thousands of planetary systems that all have equally spaced planets. We find that the distribution of instability time, measured in time from initial condition until a close-encounter of less than one Hill radius, for four, near-circular and coplanar bodies of a given initial  $\Delta$  is log-normal and spreads over more than an order of magnitude. New insight into planetary system instability is found when we compare the time until a close-encounter of a pair of planets in a system to the time until a planetary collision in the same system. Collisions are the most common manifestation of instability in these simulations. A large fraction of simulated systems do not have collisions on the same time scale as their close-encounters. This fraction of systems form an approximately log-uniform 'tail' to the distribution of instability times that expands many orders of magnitude past the log-normal distribution. The fraction of systems in the tail is dependent on the innermost planet's semi-major axis, while the distribution of close-encounter times is scale-invariant. With these findings we aim to give insight into tightly-packed exoplanetary systems and post-gas disk formation of planetary systems where these dynamics that depend on orbital spacing are essential.

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### 138.29 – From Sub-Neptunes to Earth-like Exoplanets: Modeling Optically Thick and Thin Planetary Atmospheres

Exoplanet surveys have revealed a wide diversity of planet properties

in the Milky Way. Here, we present the results from two projects modeling planet atmospheres; one considering the hydrogen/helium envelopes of sub-Neptune-mass planets, and the other, the climate of Earth-like planets.

First, we modify the state-of-the-art stellar evolution code Modules for Experimental Astrophysics (MESA) to model the thermal evolution of gaseous Sub-Neptune sized planets. Including photo-evaporation, we find a resulting convergent evolution trend that could potentially imprint itself on the close-in planet population as a preferred H/He mass fraction of 0.5-3%.

We also use an updated version of a radiative-convective climate model to calculate the upper atmospheric conditions of planets warmer than the present Earth. In our simulations, cold, dry stratospheres are predicted at lower surface temperatures. However, onset of moist greenhouse water-loss limit to habitability emerges when the surface temperature reaches above 350 K. This result places constraint on a more accurate calculation of the inner edge of the habitable zone around Sun-like stars.

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### 138.30 – Proxima Centauri's Influence on Planet Formation in Alpha Centauri

It is likely that the nearby M dwarf Proxima Centauri is in a loosely bound orbit around the Alpha Centauri binary and that the system formed as a more tightly-bound triple but evolved to its current state. We quantify how this evolution would have affected the protoplanetary disks around the stars, and characterize the size and location of planets that may be found there. These three stars are our closest neighbors, and thus present an excellent opportunity for detailed observations of any planets they may harbor, so it is particularly important to understand this system as thoroughly as possible. In addition, it gives us additional insight into planet formation in multistellar systems, which contain a large fraction of potential planet host stars.

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## 139 – Cosmology, Dark Matter & CMB Poster Session

### 139.01 – The Formation and Evolution of Stripped Dark Matter Halos

We implement a model to describe the density profiles of stripped dark matter halos. Our model generalizes the Navarro-Frenk-White (NFW) distribution to allow for more flexibility in the slope of the outer halo. We find that the density distributions of stripped halos tend to have outer slopes steeper than assumed by the NFW distribution. We also examine the relationship between severity of stripping and halo shape, spin parameter and concentration, and find that highly stripped halos are more spheroidal, have lower spin parameters, and have higher concentrations compared to less stripped halos.

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### 139.02 – Cosmology from CMB polarization with POLARBEAR and the Simons Array

POLARBEAR is a cosmic microwave background (CMB) polarization experiment located in the Atacama desert in Chile. The science goals of the POLARBEAR project are to do a deep search for CMB B-mode polarization created by inflationary gravitational waves, as well as characterize the CMB B-mode signal from gravitational lensing. POLARBEAR-1 started observations in 2012. The POLARBEAR team has published results from its first season of observations on a small fraction of the sky, including a measurement of a non-zero B-mode

polarization angular power spectrum at sub-degree scales, where the dominant signal is gravitational lensing of the CMB. Improving these measurements requires precision characterization of the CMB polarization signal over large fractions of the sky, at multiple frequencies. To achieve these goals, POLARBEAR has begun expanding to include an additional two 3.5 meter telescopes with multi-chroic receivers, known as the Simons Array. With high sensitivity and large sky coverage, the Simons Array will create a detailed survey of B-mode polarization, and its spectral information will be used to extract the CMB signal from astrophysical foregrounds. The Simons Array data will place strong constraints on the sum of the neutrino masses, when combined with data from the next generation of baryon acoustic oscillation measurements. We present the status of this funded instrument and its expected capabilities.

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### 139.03 – Optimization of the WFIRST Type Ia Supernova Survey

The Wide Field InfraRed Survey Telescope (WFIRST), which is expected to launch in about a decade, will conduct a supernova (SN) program to discover and measure distances to high-redshift SNe. Using open-source tools, including ones we have built and released, we have produced the first fully simulated realization of the survey. We made dramatically different strategic decisions and examined how the survey and its cosmological utility change with those choices. For these different strategies, we estimate how well the WFIRST SN survey can constrain the nature of dark energy. We discuss these results and make suggestions for optimizing the survey.

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### 139.04 – Effects of Neutrino Decay on Oscillation Probabilities

It is now well accepted that neutrinos oscillate as a quantum mechanical result of a misalignment between their mass-eigenstates and the flavor-eigenstates. We study neutrino decay—the idea that there may be new, light states that the three Standard Model flavors may be able to decay into. We consider what effects this neutrino decay would have on the observed oscillation probabilities.

The Hamiltonian governs how the states change with time, so we use it to calculate an oscillation amplitude, and from that, the oscillation probability. We simplify the theoretical probabilities using results from experimental data, such as the neutrino mixing angles and mass differences. By exploring what values of the decay parameters are physically allowable, we can begin to understand just how large the decay parameters can be. We compare the probabilities in the case of no neutrino decay and in the case of maximum neutrino decay to determine how much of an effect neutrino decay could have on observations, and discuss the ability of future experiments to detect these differences.

We also examine neutrino decay in the realm of CP invariance, and found that it is a new source of CP violation. Our work indicates that there is a difference in the oscillation probabilities between particle transitions and their corresponding antiparticle transitions. If neutrino decay were proven true, it could be an important factor in understanding leptogenesis and the particle-antiparticle asymmetry present in our Universe.

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### 139.05 – Constraining Cosmological Parameters Using the Correlation Function

As the ESA prepares to launch the space telescope *Euclid* in 2020, we

are interested in the possibility of using its galaxy clustering observations as a new tool to constrain the cosmological constants  $\Omega_M$  and  $\Omega_\Lambda$ . In this work, we use data simulated by *Magneticum* (a high-resolution cosmological structure simulation) to model the correlation functions of both galaxies and clusters at several redshifts. We fit analytic models to the simulated data centered at the baryon acoustic oscillation peak to extract  $\Omega_M$  and  $\Omega_\Lambda$ . We will report the results of our latest models, and their implication for the validity of the method.

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### 139.06 – Understanding the Intrinsic Properties of SDSS Galaxies

We observe that galaxies become redder and fainter as they are more inclined. Since luminosity depends on disk inclination angle, there is a discrepancy between a galaxy's apparent luminosity and its intrinsic luminosity. Thus, the observed properties of galaxies can be different from their intrinsic (inclination-independent) properties. We use a sample of  $\sim 1$  million galaxies from the Sloan Digital Sky Survey (SDSS) that have mass estimates and disk+bulge component fits from the literature to study the dependence of galaxy luminosity on inclination. We identify mass-to-light ratio (M/L) dependence on inclination to correct luminosities (and confirm that galaxies with corrected luminosities have colors that are inclination independent) to create an intrinsic sample. With this sample we can investigate the luminosity function, the distribution of the bulge-to-disk ratios, and other galaxy properties. Inclination independent measurements of these parameters will give a better understanding of how galaxies form and evolve.

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### 139.07 – How to define dark matter halo mass

The masses of dark matter (DM) halos in cosmological simulations are often assumed to correlate directly with the stellar mass of galaxies. However, these halos are defined differently; there is no single widely-accepted definition of the mass of a DM halo. Thus, in some cases this assumption may not be valid. We present a comparison of common methods of defining dark matter halo mass in order to determine which functions best for the purpose of correlating halos to galaxies. We analyze a simulation that was run using the cosmological hydrodynamical code RAMSES, containing dark matter and gas. In order to avoid the irrelevant complexities of feedback, star formation is inhibited by introducing artificial pressure at a certain density to support the cold dense gas. This allows us to isolate the star-forming gas and analyze how this gas mass scales with halo mass. We compare using the total dark matter mass to including only bound dark matter particles, and we test various common definitions of the halo radius, such as  $R_{200}$ ,  $R_{500}$ ,  $R_{vir}$ , etc. We determine that using the total dark matter mass produces halos with a star-forming gas fraction significantly closer to the cosmic baryon fraction,  $\Omega_b/\Omega_{dm}$ , compared with using only bound particles. We find that  $R_{vir}$  produces halos in which the fraction of star-forming gas to dark matter correlates most closely with  $\Omega_b/\Omega_{dm}$ , giving a mean difference of less than 1%. This is important for populating halos in dark matter-only simulations with galaxies, so that  $\Omega_b/\Omega_{dm}$  can be used to determine the gas and stellar mass from the host halo's DM mass. We conclude that of the commonly used halo mass definitions,  $R_{vir}$  using the total DM mass gives the most accurate results in simulation analyses, though a better definition may be possible and necessary.

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### 139.08 – Reconsidering the Effects of Local Star Formation On Type Ia Supernova Cosmology

Recent studies found a correlation with  $\approx 3$  sigma significance between the local star formation measured by GALEX in Type Ia

supernova (SN Ia) host galaxies and the distances or dispersions derived from these SNe. We search for these effects by using data from recent cosmological analyses to greatly increase the SN Ia sample; we include 179 GALEX-imaged SN Ia hosts with distances from the JLA and Pan-STARRS SN Ia cosmology samples and 157 GALEX-imaged SN Ia hosts with distances from the Riess et al. (2011)  $H_0$  measurement. We find little evidence that SNe Ia in locally star-forming environments are fainter after light curve correction than SNe Ia in locally passive environments. We find a difference of only  $0.000 \pm 0.018$  (stat+sys) mag for SNe fit with SALT2 and  $0.029 \pm 0.027$  (stat+sys) mag for SNe fit with MLCS2k2 ( $R_V = 2.5$ ), which suggests that proposed changes to recent measurements of  $H_0$  and  $w$  are not significant and numerically smaller than the parameter measurement uncertainties. We find that both populations have more similar dispersion in distance than found by Rigault et al. (2013), Rigault et al. (2015), and Kelly et al. (2015). The greatly reduced significance of these distance modulus differences compared to Rigault et al. (2013) and Rigault et al. (2015) result from two improvements with fairly equal effects, our larger sample size and the use of JLA and Riess et al. (2011) sample selection criteria. We caution that SN sample selection has a significant effect on local star formation biases.

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### 139.09 – Sampling the Probability Distribution of Type Ia Supernova Lightcurve Parameters in Cosmological Analysis

In order to obtain robust cosmological constraints from Type Ia supernova (SN Ia) data, we have applied Markov Chain Monte Carlo (MCMC) to SN Ia lightcurve fitting. We develop a method for sampling the resultant probability density distributions (pdf) of the SN Ia lightcurve parameters in the MCMC likelihood analysis to constrain cosmological parameters. Applying this method to the Joint Lightcurve Analysis (JLA) data set of SNe Ia, we find that sampling the SN Ia lightcurve parameter pdf's leads to cosmological parameters closer to that of a flat Universe with a cosmological constant, compared to the usual practice of using only the best fit values of the SN Ia lightcurve parameters. Our method will be useful in the use of SN Ia data for precision cosmology.

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### 139.10 – See Change: Classifying single observation transients from HST using SNCosmo

The Supernova Cosmology Project (SCP) is executing "See Change", a large HST program to look for possible variation in dark energy using supernovae at  $z > 1$ . As part of the survey, we often must make time-critical follow-up decisions based on multicolor detection at a single epoch. We demonstrate the use of the SNCosmo software package to obtain simulated fluxes in the HST filters for type Ia and core-collapse supernovae at various redshifts. These simulations allow us to compare photometric data from HST with the distribution of the simulated SNe through methods such as Random Forest, a learning method for classification, and Gaussian Kernel Estimation. The results help us make informed decisions about triggered follow up using HST and ground based observatories to provide time-critical information needed about transients. Examples of this technique applied in the context of See Change are shown.

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### 139.11 – Measuring Dark Matter With MilkyWay@home

We perform N-body simulations of two component dwarf galaxies (dark matter and stars follow separate distributions) falling into the Milky Way and the forming of tidal streams. Using MilkyWay@home we optimize the parameters of the progenitor dwarf galaxy and the orbital time to fit the simulated distribution of stars along the tidal stream to the observed distribution of stars. Our initial dwarf galaxy models are constructed with two separate Plummer profiles (one for the dark matter and one for the baryonic matter), sampled using a generalized distribution function for spherically symmetric systems. We perform rigorous testing to ensure that our simulated galaxies are in virial equilibrium, and stable over a simulation time. The N-body simulations are performed using a Barnes-Hut Tree algorithm. Optimization traverses the likelihood surface from our six model parameters using particle swarm and differential evolution methods. We have generated simulated data with known model parameters that are similar to those of the Orphan Stream. We show that we are able to recover a majority of our model parameters, and most importantly the mass-to-light ratio of the now disrupted progenitor galaxy, using MilkyWay@home. This research is supported by generous gifts from the Marvin Clan, Babette Josephs, Mani Limlami, and the MilkyWay@home volunteers.

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### 139.12 – New measurement of the Joint Fluctuations of the CXB and the CIB with Chandra and Spitzer

We present the most recent results on the angles cross-power spectrum between the CIB and the CXB fluctuations in the UDS field. The fluctuations arise from Spitzer sources with  $m_{AB} > 25$  and Chandra sources with  $0.5-2$  keV X-ray flux  $\log(S) < 17.0$ . We evaluate the contribution of known sources like AGN, galaxies and clusters and discuss potential new classes of sources as responsible for the observed signal.

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### 139.14 – Mapping the Galaxy Color-Redshift Relation:

### Optimal Photo-z Calibration Strategies for Cosmology Surveys

A primary objective of the upcoming dark energy surveys LSST, *Euclid*, and *WFIRST* is to map the 3D distribution of matter over a significant fraction of the universe via the weak lensing cosmic shear field. Doing so will require accurate distance estimates to billions of faint galaxies, meaning that photo-z's will be essential for the ultimate scientific success of these missions. Because galaxy colors drive photo-z estimates, spectroscopic calibration samples must *at least* be representative in color. Here we present a technique, based on the *self-organizing map* (Kohonen 1990), to map the empirical distribution of galaxies in the high-dimensional color space of a given survey. We apply the technique to *Euclid*-like data for ~131k galaxies from the COSMOS survey, allowing us to determine where – in galaxy color space – spectroscopic coverage exists and where it is systematically missing. We show that the mapping technique lets us develop efficient spectroscopic sampling strategies to measure the color-redshift relation by focusing effort on poorly constrained regions of multicolor space. We discuss the nature of the galaxies in un-sampled regions of galaxy color space, and show that a fiducial survey with Keck (making use of LRIS, DEIMOS, and MOSFIRE) could meet the *Euclid* calibration requirements in ~40 nights of observing.

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### 139.15 – Detecting Bias in a Self-Organizing Map of Galaxy Photometry Data

High redshift (very distant) galaxy surveys record broad-band photometry for billions of galaxies in order to measure distances in a faster, more cost-effective way than spectroscopy. Knowing these distances (more specifically, the redshifts) helps cosmologists learn more about the early universe and how it evolved, but calibrating the redshifts from photometry requires a color-selection technique. One such technique is the Self-Organizing Map (SOM), a machine-learning algorithm that projects high-dimensional photometry data onto a visual, two-dimensional map. High-redshift galaxies can be identified efficiently in such a mapping. However, there is a chance that high-redshift galaxies are lost to low-redshift regions and vice versa due to photometric error; this effect was analyzed. A Monte Carlo simulation was run on objects selected from along the boundary between high- and low-redshift regions. Roughly 18% of selected objects scattered from high- to low-redshift, and about 16% scattered the other way. Further research will design a better metric of the scattering percentages based on the number density of galaxies in the map, and future work should use these analysis techniques on other high-redshift data.

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### 139.16 – Inclination Dependence of Estimated Galaxy Masses and Star Formation Rates

We examine the inclination dependence of inferred star formation rates and galaxy mass estimates in the Sloan Digital Sky Survey by combining the disk/bulge de-convolved catalog of Simard et al 2011 with stellar mass estimates catalog of Mendel et al 2014 and star formation rates measured from spectra by Brinchmann et al 2004. We know that optical star formation indicators are reddened by dust, but calculated star formation rates and stellar mass estimates should account for this. However, we find that face-on galaxies have a higher calculated average star formation rates than edge-on galaxies. We also find edge-on galaxies have, on average, slightly smaller but similar estimated masses to face-on galaxies, suggesting that there are issues with the applied dust corrections for both models.

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### 139.17 – Estimating the Supernova Cosmological Constraints Possible With the Wide-Field Infrared Survey Telescope

The proposed Wide-Field Infrared Survey Telescope (WFIRST) supernova survey will measure precision distances continuously in redshift to 1.7 with excellent systematics control. However, the Science Definition Team report presented a idealized version of the survey, and we now work to add realism. Using SNe from HST programs, we investigate the expected contamination from the host-galaxy light to estimate required exposure times. We also present estimates of purity and completeness, generated by degrading well-measured nearby SN spectra to WFIRST resolution and signal-to-noise. We conclude with a more accurate prediction of the cosmological constraints possible with WFIRST SNe.

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### 139.18 – The Union3 Supernova Ia Compilation

High-redshift supernovae observed with the Hubble Space Telescope (HST) are crucial for constraining any time variation in dark energy. In a forthcoming paper (Rubin+, in prep), we will present a cosmological analysis incorporating existing supernovae with improved calibrations, and new HST-observed supernovae (six above  $z=1$ ). We combine these data with current literature data, and fit them using SALT2-4 to create the Union3 Supernova compilation. We build on the Unified Inference for Type Ia cosmology (UNIFY) framework (Rubin+ 2015b), incorporating non-linear light-curve width and color relations, a model for unexplained dispersion, an outlier model, and a redshift-dependent host-mass correction.

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**Contributing team(s):** Supernova Cosmology Project

## 140 – Large Scale Structure, Cosmic Distance Scale Poster Session

### 140.01 – The Cosmic Web in 2MASS

We present a method to recover and study the projected tidal forces from a galaxy survey containing little or no redshift information. We apply the method to a simulated galaxy survey and study the accuracy with which the cosmic web can be recovered in the presence of different observational effects, showing that the projected tidal forces can be estimated with a reasonable precision over large regions of the sky. We also apply our method to the 2MASS galaxy sample, and present a publicly available full-sky map of the projected tidal forces in the local Universe. We further study the distribution of galaxy luminosities across the different elements of the cosmic web, finding that, in agreement with the standard models of galaxy

formation, more luminous galaxies are found preferentially in the most dense environments.

**Author(s):** Boryana Hadzhiyska<sup>2</sup>, David Alonso<sup>1</sup>, Michael A. Strauss<sup>2</sup>

**Institution(s):** 1. Oxford University, 2. Princeton University

### 140.02 – Dark Matter Halo Properties From Thermal Sunyaev-Zel'dovich and Soft X-ray Emission Cross-Correlation

We develop a semi-analytic halo model for the cross-correlation of the thermal Sunyaev-Zel'dovich (SZ) effect and soft x-ray emission (0.4 – 0.6 keV), which together probe gas properties in dark matter halos. To model individual halos, we use the universal pressure and electron density profiles from the REXCESS cluster sample. We distribute halos via the Tinker et al (2008) mass function. We compare contributions from the warm-hot ( $10^5 - 10^7$  K) and hot ( $T > 10^7$  K) components of the gas, and examine the dependence on halo mass. Finally, we discuss the detectability of the signal.

**Author(s):** Vincent James Lakey<sup>1</sup>, Kevin Huffenberger<sup>1</sup>

**Institution(s):** 1. Florida State University

### 140.03 – Full-depth Coadds of the WISE and NEOWISE-Reactivation Data

Thanks to the Wide-field Infrared Survey Explorer (WISE) mission's NEOWISE-Reactivation program, an entire year of post-reactivation W1 and W2 exposures has been made publicly available in 2015. This data set consists of ~2.5 million new exposures in each band, effectively doubling the amount of WISE imaging available at 3.4  $\mu$ m and 4.6  $\mu$ m relative to the AllWISE release. However, no full sky coadds have yet been published which incorporate both pre and post-reactivation WISE imaging. We are creating a custom, full-sky set of coadds combining all W1 and W2 exposures from both the AllWISE and NEOWISE-Reactivation mission phases, employing the unWISE image coaddition framework (Lang 2014), which preserves the native WISE angular resolution and is optimized for forced photometry. We anticipate that our resulting unWISE data products will have a broad range of applications, from studies of quasar variability to the identification of faint moving objects in the solar neighborhood. Using our full-depth coadds, we plan to perform W1 and W2 forced photometry at the positions of ~400 million SDSS sources, extending to WISE depths 0.4 magnitudes fainter than previously possible. Our full-depth unWISE coadds will represent an important input for DESI target selection, and preliminary versions are already in use within the DECam Legacy Survey (DECaLS) reduction pipeline.

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**Institution(s):** 1. Berkeley Center for Cosmological Physics, 2. Lawrence Berkeley National Laboratory, 3. University of Toronto

### 140.04 – Probing the Stellar Content of Galaxy Groups with Value-Added Group Catalogues in the SDSS DR7

We present galaxy group catalogues from the Sloan Digital Sky Survey (SDSS) Data Release 7 (DR7). Specifically, we use the Berlind et. al. (2006) Friends-of-Friends group finding algorithm to identify galaxy groups and clusters in three volume-limited samples. We assign group masses,  $M_{\text{group}}$ , to the galaxy groups via abundance matching based on their total luminosity, and we designate galaxies as centrals or satellites, where each central galaxy is the brightest member of its group. Additionally, we assign stellar masses,  $M_{\text{star}}$ , and star formation rates, SFRs, to the galaxies from the MPA-JHU value-added catalogue. We explore the relationships between  $M_{\text{star}}$ , SFR, and  $M_{\text{group}}$  for central and satellite galaxies, as well as for galaxy groups as a whole. We also present a set of mock group catalogues that are constructed from N-body simulations and we use them to estimate the impact of group-finding errors on our results. The SDSS and mock group catalogues will be made publicly available.

**Author(s):** Victor Calderon<sup>3</sup>, Andreas A. Berlind<sup>3</sup>, Manodeep Sinha<sup>3</sup>, Cameron McBride<sup>1</sup>, Roman Scoccimarro<sup>2</sup>  
**Institution(s):** 1. Center for Astrophysics at Harvard University, 2. New York University, 3. Vanderbilt University

#### **140.05 – Refining the Expanding Photosphere Method: Comparison of Velocity and Temperature Parameters**

The Expanding Photosphere Method (EPM) is used to measure the distance to a supernova by determining the temperature and expansion velocity of the supernova's photosphere at different epochs, and calculating its luminosity. To account for the supernova's deviation from a true blackbody, flux dilution factors, empirically derived from methods by Hamuy et al. (2001) and Dessart and Hillier (2005), were applied to our calculations for several Type II-P supernovae. In this work, we compare different lines used to measure the expansion velocity, H-alpha vs. Fe II vs. Sc II, and we compare blackbody-fit temperatures vs. color temperatures. Our goal is to determine the combination of specific line velocities, temperature calculation, and other parameters that produce the most reliable distance determination for a supernova.

**Author(s):** Robert C. Mitchell<sup>1</sup>  
**Institution(s):** 1. St. Ambrose University

#### **140.06 – Estimating the angular power spectrum of $z > 2$ BOSS QSOs using the MASTER method**

We implement the MASTER method for angular power spectrum estimation and apply it to  $z > 2$  quasars selected by the SDSS-III BOSS survey. Quasars are filtered for completeness and bad spectra, and include ~100,000 QSOs in the CORE sample and ~75,000 in the non-uniform BONUS sample. We estimate the angular power spectrum in redshift shells to constrain the matter power spectrum and quasar properties. In the future, we will jointly analyze overlapping Cosmic Microwave Background lensing maps from the Atacama Cosmology Telescope to place further constraints.

**Author(s):** Felipe Maldonado<sup>1</sup>, Kevin Huffenberger<sup>1</sup>, Aditya Rotti<sup>1</sup>  
**Institution(s):** 1. Florida State University

#### **140.07 – Foreground Characterization for the Murchison Widefield Array Using the Jansky Very Large Array**

One of the most compelling questions in astrophysics today is how the process of galaxy formation unfolded during the Epoch of Reionization (EoR). A new generation of radio telescopes, including the Murchison Widefield Array (MWA) and others, are attempting to capture the redshifted 21cm signal from neutral hydrogen during the EoR. Mapping the reionization of the intergalactic medium (IGM) is one of the core objectives of 21 cm observatories. A pressing concern of these observations is the bright foreground sources in the telescope's sidelobes outside the primary beam of the MWA. These sources, including AGN, radio galaxies and local Galactic sources, are numerous and difficult to deal with. These foreground contaminants are five orders of magnitude brighter than the redshifted 21 cm emission expected from the IGM during the EoR. The Jansky Very Large Array (JVLA) in New Mexico can provide sensitive characterization of these sources in the MWA's northern sidelobe. We observed 100 bright radio sources using the JVLA in P-band and characterized these sources by extracting the spectral fits and fluxes for each source. By creating a foreground model for these data, the MWA will be able to better subtract these sources from future EoR measurements. We report the current status of the creation of the foreground model.

**Author(s):** Michael P Busch<sup>1</sup>, Judd D. Bowman<sup>1</sup>, Piyanat Kittiwisit<sup>1</sup>, Danny Jacobs<sup>1</sup>  
**Institution(s):** 1. Arizona State University

#### **141.01 – Solar Meridional Flows Inferred with Helioseismology**

Helioseismology is a tool to understand the physical processes that occur beneath the solar surface using acoustic waves. This project focuses on inferring the meridional circulation in the solar convection zone, which consists of large scale plasma flows of low velocities that have been difficult to measure. In particular, using numerical simulations and ray theory, we target the plasma flow in the outward, radial direction that is critical for understanding mass conservation in the Sun. This research has important implications for solar dynamo theory and the nature of the solar cycle.

**Author(s):** Han Tang<sup>1</sup>, Jason Jackiewicz<sup>1</sup>  
**Institution(s):** 1. New Mexico State University

#### **141.03 – The plasmoid instability and Hall effect during chromospheric magnetic reconnection**

Magnetic reconnection is a ubiquitous process in the partially ionized solar chromosphere. Recent two-dimensional simulations have shown that the plasmoid instability onsets during partially ionized reconnection [1-4]. We use the plasma-neutral module of the HiFi framework to simulate the nonlinear evolution of the plasmoid instability during symmetric and asymmetric reconnection. These simulations model the plasma and neutrals as separate fluids and include ionization, recombination, charge exchange, thermal conduction, and the Hall effect. The Hall effect leads to the development of significant out-of-plane magnetic fields in the current sheet region in the laminar phase, but we do not observe shortening of the current sheet or significant acceleration of the reconnection rate as a result. After the onset of the plasmoid instability, structure develops on scales comparable to the ion inertial length. We compare simulations of the plasmoid instability with and without the Hall effect to determine its impact on the reconnection process. Finally, we discuss ongoing efforts to connect these simulations with solar observations and laboratory experiments.

[1] Leake et al. 2012, ApJ, 760, 109 [2] Leake et al. 2013, PhPl, 20, 062102 [3] Ni et al. 2015, ApJ, 799, 79 [4] Murphy & Lukin 2015, ApJ, 805, 134

**Author(s):** Nicholas Arnold Murphy<sup>1</sup>, Vyacheslav Lukin<sup>2</sup>  
**Institution(s):** 1. Harvard-Smithsonian Center for Astrophysics, 2. National Science Foundation

#### **141.04 – Solar Coronal Oscillations and the Coronal Heating Problem**

The *solar coronal heating problem* asks why temperature is increasing away from the surface of the sun. We hypothesize that the dissipating waves along coronal loops is responsible for this extra energy. We analysed these waves in IDL to determine if they have enough energy to heat the coronal loops. Our group found that there is likely enough energy to heat the loops, but we still need a more accurate measurement of the proton density.

**Author(s):** Tze Goh<sup>1</sup>  
**Institution(s):** 1. Columbia University  
**Contributing team(s):** Savin Group

#### **141.05 – Probing Solar Wind Turbulence Using JVAS and VLA Calibrator Sources**

Bastian (1999) looked at several point sources located in the solar corona. He measured how the sources scattered and in which direction they elongated based on their location in order to characterize the solar wind. When observed using interferometry, the angular broadening of the source can be calculated from the variation in observed intensity across the array's baselines. In a follow-up observation with the VLA, more point sources were observed and the amplitude versus baseline of the array was calculated for each source in order to make sure the sources were resolved.

We intend to present the beginning reductions and analysis from the follow-up observation. We will discuss how the angular broadening of the sources can be calculated from interferometry and how measuring the baselines of the array shows the resolution of the

## **141 – The Sun and Solar System Poster Session**

**Author(s): Sarah Betti<sup>1</sup>**

**Institution(s):** 1. National Radio Astronomy Observatory

**Contributing team(s):** Adam Kobelski, Tim Bastian

#### 141.06 – Tracing Dust Grains from Supernovae to The Solar Nebulae

Short-lived radioisotopes (SLRs) were present in the early solar system, providing evidence that the solar system was impacted by a supernova prior to or during its formation. However, hydrodynamical models of the injection of SLRs fail to achieve sufficient mixing, presenting a challenge to this hypothesis. We propose the injection of SLRs via dust grains in an attempt to overcome the mixing barrier. To test this hypothesis we simulate injection into a presolar gas cloud under various assumptions. Our results suggest that SLR transport in dust grains is a viable mechanism for generating observed SLR abundances.

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**Institution(s):** 1. Macalester College, 2. The University of North Carolina at Chapel Hill

#### 141.07 – Mapping Buried Impact Craters in the Chryse Basin to Understand the Distribution of Outflow Channel Sediment

The Chryse Basin's location in the northern hemisphere of Mars allowed it to collect water from a number of major outflow channels. These outflows likely deposited significant amounts of sediment within the Basin. This project's goal was to see if mapping buried impact craters, revealed as Quasi-Circular Depressions (QCDs) in Mars Orbiter Laser Altimeter (MOLA) data, could be used to determine the distribution and variation of sediment thickness within the Basin. QCDs, including likely buried impact craters, were mapped to test the hypothesis that further into the basin there would be fewer smaller craters because thicker sediments would have preferentially covered them. Mapping was done using Gridview, an interactive graphics program that manipulates data, in this case topographic data from MOLA. It should be possible to estimate the thickness of the sediment from the smallest buried craters found in a given area, and therefore map out the change in sediment thickness across the basin. The smallest QCDs beginning to be completely covered by sediment were just below 30 km in diameter. The minimum sediment needed to cover a QCD of this size was calculated to be between 1-2km. Therefore, the absence of QCDs below 30 km in the NE corner of Chryse could be explained by sediment at least that thick. Lower thickness is expected elsewhere in the basin, especially in the SW, where more QCDs with smaller diameters were found. The method of mapping buried impact craters provides a way to determine variations in sediment thickness within the Chryse Basin. This method could be used on other sediment-covered areas to learn about past water flow.

**Author(s): Moira Miller<sup>2</sup>, Herbert V. Frey<sup>1</sup>**

**Institution(s):** 1. NASA Goddard Space Flight Center, 2. Virginia Tech

#### 141.08 – Thermophysical Model of S-complex NEAs: 1627 Ivar

We present an updated thermophysical model of 1627 Ivar, an Amor class near Earth asteroid (NEA) with a taxonomic type of Sqw [1]. Ivar's large size and close approach to Earth in 2013 (minimum distance 0.32 AU) provided an opportunity to observe the asteroid over many different viewing angles for an extended period of time, which we have utilized to generate a shape and thermophysical model of Ivar, allowing us to discuss the implications that these results have on the regolith of this asteroid.

Using the software SHAPE [2,3], we updated the nonconvex shape model of Ivar, which was constructed by Kaasalainen et al. [4] using photometry. We incorporated 2013 radar data and CCD lightcurves using the Arecibo Observatory's 2380Mz radar and the 0.35m telescope at the Palmer Divide Station respectively, to create a shape model with higher surface detail. We found Ivar to be elongated with maximum extended lengths along principal axes of 12 x 5 x 6 km and

a rotation rate of  $4.795162 \pm 5.4 \times 10^{-6}$  hrs [5].

In addition to these radar data and lightcurves, we also observed Ivar in the near IR using the SpeX instrument at the NASA IRTF. These data cover a wide range of Ivar's rotational longitudes and viewing geometries. We have used SHERMAN [6,7] with input parameters such as the asteroid's IR emissivity, optical scattering law, and thermal inertia, in order to complete thermal computations based on our shape model and known spin state. Using this procedure, we find which reflective, thermal, and surface properties best reproduce the observed spectra. This allows us to characterize properties of the asteroid's regolith and study heterogeneity of the surface. We will compare these results with those of other S-complex asteroids to better understand this asteroid type and the uniqueness of 1627 Ivar. [1] DeMeo et al. 2009, Icarus 202, 160-180 [2] Magri, C. et al. 2011, Icarus 214, 210-227. [3] Crowell, J. et al. 2014, AAS/DPS 46 [4] Kaasalainen, M. et al. 2004, Icarus 167, 178-196. [5] Crowell, J. et al. 2015, LPSC 46 [6] Crowell, J. et al. 2015, TherMoPS II. [7] Howell, E. et al. 2012, AAS/DPS 44. This work is partially supported by NSF (AST-1109855), NASA (NNX13AQ46G), CLASS (NNA14AB05A), and USRA (06810-05).

**Author(s): Jenna Crowell<sup>5</sup>, Ellen S. Howell<sup>3</sup>, Christopher Magri<sup>6</sup>, Yanga R. Fernandez<sup>5</sup>, Sean E. Marshall<sup>2</sup>, Brian D. Warner<sup>1</sup>, Ronald J. Vervack, Jr.<sup>4</sup>**

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#### 141.09 – Determining the Shape of an Asteroid

We studied the asteroid Wallenbergia with the purpose of finding its shape. From asteroids' shape we can find out important information about their formation process, their composition, and whether or not they have encountered recent collisions. Findings about the history of individual asteroids can then give clues about the formation and history of the asteroid belt as a whole.

We selected an asteroid with a known and short rotation period so that we could sample the whole period in one night. We also selected an asteroid with a magnitude less than 15 and a declination near 0 during the month of August so that it would be observable by the all of the telescopes in our network. Wallenbergia has a period of 4.096 hours, so in our 15 hours of observation we have been able to sample multiple periods. After obtaining images of the asteroid every two minutes, we extracted the apparent magnitude and built a lightcurve. Then we used a program to figure out the shape based on the lightcurve.

**Author(s): Krista Hibert<sup>1</sup>, Helene Flohic<sup>1</sup>**

**Institution(s):** 1. University of the Pacific

#### 141.10 – Hilda Asteroid Colors: Insight into Giant Planet Migration?

The Hilda asteroids are a unique population of small bodies that are locked in a 3:2 mean motion resonance with Jupiter. Unlike other resonances in the asteroid belt, the 3:2 is a stable resonance at 3.95 AU. Objects at this resonance have stable orbits for at least 2 Gyr and, more likely, for the age of the Solar System. In an instantaneous top down view of the solar system, the Hildas approximately trace a triangle with over-densities of asteroids near the L3, L4 and L5 Jovian Lagrange points. This configuration is cited as evidence that Jupiter migrated inwards by ~0.4 AU. Stable Hilda orbits have mean eccentricities of 0.16 with typical perihelia of 3.15 AU. These latter properties, in terms of observability and accessibility to spacecraft, are a major advantage that distinguishes the Hildas from other populations of potential scientific interest such as the Jovian Trojans. The Outer Main Belt (OMB) also has many objects that may have originated in the outer protoplanetary disk (OPD). However, the OMB appears to be more mixed with objects from elsewhere in the Main Belt and enjoys only a small advantage in terms of brightness for a given diameter and albedo. The intrinsic collisional probability for objects in the Hilda population is also a factor of 3 to 5 less than the collisional probabilities for Trojan and OMB populations. Thus, the Hildas likely represent a significant population of objects unaltered due to collisional processing. Here we discuss findings of our ongoing NASA Planetary Astronomy program to obtain Sloan

optical (g' r' i' z') colors of Hilda-group asteroids. The loci of these colors are compared to the Kuiper Belt populations to test post-formation migration effects of the giant planets in our solar system on the small body population. In part, this work was conducted as part of a University of Minnesota Undergraduate Research Scholarship, and is supported by NASA PAST Award NNX13AJ11G.

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#### 141.11 – Detecting Mass Loss in Main Belt Asteroids

Sandberg, E., Rajagopal, J., Ridgway, S.E., Kotulla, R., Valdes, F., Allen, L.  
The Dark Energy Camera (DECam) on the 4m Blanco telescope at the Cerro Tololo Inter-American Observatory (CTIO) is being used for a survey of Near Earth Objects (NEOs). Here we attempt to identify mass loss in main belt asteroids (MBAs) from these data. A primary motivation is to understand the role that asteroids may play in supplying dust and gas for debris disks. This work focuses on finding methods to automatically pick out asteroids that have qualities indicating possible mass loss. Two methods were chosen: looking for flux above a certain threshold in the asteroid's radial profile, and comparing its PSF to that of a point source. After sifting through 490 asteroids, several have passed these tests and should be followed up with a more rigorous analysis. Sandberg was supported by the NOAO/KPNO Research Experience for Undergraduates (REU) Program which is funded by the National Science Foundation Research Experiences for Undergraduates Program (AST-1262829)

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**Institution(s):** 1. NOAO, 2. NOAO/KPNO REU, 3. University of Wisconsin - Milwaukee

#### 141.12 – Small Jovian Trojan Asteroids: An Excess of Slow Rotators

Several lines of evidence support a common origin for, and possible hereditary link between, cometary nuclei and jovian Trojan asteroids. Due to their distance and low albedos, few comet-sized Trojans have been studied. We discuss the rotation properties of Jovian Trojan asteroids less than 30 km in diameter. Approximately half of the objects discussed here were studied using densely sampled lightcurves (French *et al.* 2015a, b); Stephens *et al.* 2015), and the other half were sparse lightcurves obtained by the Palomar Transient Factory (PTF; Wozniak *et al.* 2015).

A significant fraction (~40%) of the objects in the ground-based sample rotate slowly ( $P > 24$ h), with measured periods as long as 375 h (Warner and Stephens 2011). The PTF data show a similar excess of slow rotators. Only 5 objects in the combined data set have rotation periods of less than six hours. Three of these fast rotators were contained in the data set of French *et al.*; these three had a geometric mean rotation period of 5.29 hours. A prolate spheroid held together by gravity rotating with this period would have a critical density of 0.43 gm/cm<sup>3</sup>, a density similar to that of comets (Lamy *et al.* 2004).

Harris *et al.* (2012) and Warner *et al.* (2011) have explored the possible effects on asteroid rotational statistics with the results from wide-field surveys. We will examine Trojan rotation statistics with and without the results from the PTF.

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**Institution(s):** 1. Illinois Wesleyan Univ.

#### 141.13 – A Continuing Analysis of Possible Activity Drivers for the Enigmatic Comet 29P/Schwassmann-Wachmann 1

We present results from our effort to understand activity drivers in Comet 29P/Schwassmann-Wachmann 1 (SW1). In a nearly circular

orbit around 6 AU, outside of the water-sublimation zone, SW1 is continuously active and experiences frequent outbursts. Our group's effort is focusing on finding constraints on physical and dynamical properties of SW1's nucleus and their incorporation into a thermophysical model [1,2] to explain this behavior. We are currently analyzing coma morphology of SW1 before, during, and after outburst placing constraints on the spin-pole direction, spin period, and surface areas of activity. In addition, we are using the thermal model to investigate if the continuous activity comes from one or multiple processes, such as the release of trapped supervolatiles during the amorphous to crystalline (A-C) water ice phase transition and/or the direct sublimation of pockets of supervolatile ices. The supervolatile ices may be primordial or from the condensation of gases released during the A-C phase transition. To explain the possibly quasi-periodic but frequent outbursts, we are looking into subsurface cavities where internal pressures can build, reaching and exceeding surrounding material strengths [3,4] and/or thermal waves reaching a pocket of supervolatile ices, causing a rapid increase in the sublimation rate. For all these phenomena, the model is constrained by comparing the output dust mass loss rate and its variability with what has been observed through optical imaging of the comet at various points in its orbit. We will present preliminary thermal modeling of a homogeneous progenitor nucleus that evolves into a body showing internal material layering, the generation of CO and CO<sub>2</sub> ice pockets, and the production of outbursts, thus bringing us closer to explaining the behavior of this intriguing comet. [1] Sarid, G., et al.: 2005, PASP, **117**, 843. [2] Sarid, G.: 2009, PhD Thesis, Tel Aviv Univ. [3] Gronkowski, P., 2014, Astron. Nachr./AN **2**, No. **335**, 124-134. [4] Gronkowski, P. and Wesolowski, M., 2015, MNRAS, **451**, 3068-3077. We thank the NASA Outer Planets Research Program (NNX12AK50G) and the Center for Lunar and Asteroid Surface Science (CLASS, NNA14AB05A) for support of this work.

**Author(s): Charles Schambeau<sup>5</sup>, Yanga Fernández<sup>5</sup>, Nalin H. Samarasinha<sup>4</sup>, Beatrice E. A. Mueller<sup>4</sup>, Gal Sarid<sup>2</sup>, Karen Jean Meech<sup>3</sup>, Laura Woodney<sup>1</sup>**

**Institution(s):** 1. California State University, San Bernardino, 2. Florida Space Institute, 3. Institute for Astronomy, 4. Planetary Science Institute, 5. University of Central Florida

#### 141.14 – Searching for Simpler Models of Astrophysical Pattern Formation

While theories of synchronization in two- or three-body astronomical systems are well understood, a generalization to many-bodied systems remains largely unexplored. Historically, problems of resonant capture among astronomical bodies have been treated primarily using methods from conservative classical mechanics. We investigate the possibility of using nonconservative models together with perturbation theory and numerical methods to understand the phenomenon of resonant capture in large-scale structures such as rings, planetary systems and galactic spiral arms. In particular, we focus on  $N$ -body dissipative systems such as circumplanetary discs and use methods drawn from the study of coupled oscillators. One such method is inspired by the Kuramoto model, which describes mean-field behavior in large ensembles of coupled nonlinear oscillators. The Kuramoto model can be modified to allow for non-mean-field coupling, leading to the existence of chimera states, in which most of the oscillators synchronize. These chimera states can appear as clusters or spirals of synced oscillators, and may be suggestive of objects in astronomical contexts. As an illustrative example, we develop a mean-field model for  $N$  small particles in a dust ring around a massive planet and integrate it numerically using code developed in MATLAB and Python. Preliminary results show promise that this approach will yield new insight into astronomical synchronization phenomena across a wide range of length scales.

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**Institution(s):** 1. Northwestern University, 2. University of Oregon

#### 141.15 – Orbit Refinement of Asteroids and Comets Using a Robotic Telescope Network

We report on a multi-semester project to refine the orbits of asteroids and comets in our Solar System. One of the newest fields of

research for undergraduate Astrophysics students at Columbus State University is that of asteroid astrometry. By measuring the positions of an asteroid in a set of images, we can reduce the overall uncertainty in the accepted orbital parameters of that object. These measurements, using our WestRock Observatory (WRO) and several other telescopes around the world, are being published through the Minor Planet Center (MPC) and benefit the global community. Three different methods are used to obtain these observations. First, we use our own 24-inch telescope at WRO, located in at CSU's Coca-Cola Space Science Center in downtown Columbus, Georgia. Second, we have access to data from the 20-inch telescope at Stone Edge Observatory in El Verano, California. Finally, we may request images remotely using Skynet, an online worldwide network of robotic telescopes. Our primary and long-time collaborator on Skynet has been the "41-inch" reflecting telescope at Yerkes Observatory in Williams Bay, Wisconsin. Thus far, we have used these various telescopes to refine the orbits of more than 15 asteroids and comets. We have also confirmed the resulting reduction in orbit-model uncertainties using Monte Carlo simulations and orbit visualizations, using *Find\_Orb* and *OrbitMaster* software, respectively.

Before any observatory site can be used for official orbit refinement projects, it must first become a trusted source of astrometry data for the MPC. We have therefore obtained Observatory Codes not only for our own WestRock Observatory (W22), but also for 3 Skynet telescopes that we may use in the future: Dark Sky Observatory in Boone, North Carolina (W38); Hume Observatory in Santa Rosa, California (U54); and Athabasca University Geophysical Observatory in Athabasca, Alberta, Canada (U96).

**Author(s):** Austin Lantz Caughey<sup>1</sup>, Johnny Brown<sup>1</sup>, Andrew W. Puckett<sup>1</sup>, Vivian L. Hoette<sup>2</sup>, Michael Johnson<sup>1</sup>, Cameron B. McCarty<sup>1</sup>, Kevin Whitmore<sup>1</sup>

**Institution(s):** 1. Columbus State University, 2. The University of Chicago, Yerkes Observatory

**Contributing team(s):** UNC-Chapel Hill SKYNET team

#### 141.16 – 5 – 14 $\mu\text{m}$ Spitzer spectra of the Themis and Veritas asteroid families

Spectroscopic studies of primitive asteroid families provide constraints on the composition of the solar nebula and the distribution of volatiles in the asteroid belt. Results from visible and near-infrared spectroscopy show diversity between primitive families. We aim to better constrain the composition of two primitive families with very different ages: Themis (~2.5 Gyr) and Veritas (~8 Myr). We analyzed 5 – 14  $\mu\text{m}$  Spitzer Space Telescope spectra of 11 Themis asteroids and nine Veritas asteroids, for a total of 20 asteroids. We report the presence of a broad 10- $\mu\text{m}$  emission feature, attributed to a layer of fine-grained silicates, in the spectra of all 11 Themis asteroids and six of nine Veritas asteroids in our sample. Spectral contrast in statistically significant detections of the 10- $\mu\text{m}$  feature ranges from  $1\% \pm 0.1\%$  to  $8.5\% \pm 0.9\%$ . Comparison with the spectra of primitive meteorites (McAdam et al. 2015, Icarus, 245, 320) suggests asteroids in both families are similar to meteorites with lower abundances of phyllosilicates. We used the Near-Earth Asteroid Thermal Model to derive diameters, beaming parameters and albedos for our sample. Asteroids in both families have beaming parameters near unity and low to moderate albedos. We find that contrast of the silicate emission feature is not correlated with asteroid diameter; however, higher 10- $\mu\text{m}$  contrast may be associated with flatter spectral slopes in the near-infrared. The spectra of both families are consistent with icy bodies with some amount of fine-grained silicates, but with coarser grains or denser surface structure than Trojan asteroids and comets. The range of spectral contrast of the 10- $\mu\text{m}$  emission feature within each family suggests diversity in regolith porosity and/or grain size.

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#### 141.17 – A hard X-ray study of the Jovian magnetosphere with

#### NuSTAR

We report the first high-resolution hard X-ray observation of Jupiter with Nuclear Spectroscopic Telescope Array (NuSTAR) in February 2015. This observation was targeted to probing a high energy extension of the X-ray continuum component detected from the Jovian aurorae by XMM-Newton, while the previous in-situ observation by the Ulysses failed to detect hard X-ray emission in the 27-48 keV band. NuSTAR has the unique capabilities of spatially resolving the two polar regions above 10 keV and detecting a spectral break which is expected between the XMM-Newton and Ulysses energy band. With 100 ksec exposure, our detection of X-ray emission from the south pole was only marginal possibly due to time variation of the auroral X-ray emission, while the north pole was hidden during our observation. In this poster, we present our imaging and spectral analysis, then discuss follow-up deeper NuSTAR observations.

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#### 141.18 – Images Analysis of the Propeller Bleriot orbiting in Saturn's outer A Ring

More than 150 propeller structures have been observed by the cameras of the Cassini-spacecraft in Saturn's A ring (Tiscareno et al. 2006, 2008, 2010, Sremcevic et al. 2007). These S-shaped density structures are caused by moonlets embedded in Saturn's rings which are not massive enough to clear and maintain a complete circumferential gap like the larger ring-moons Pan and Daphnis do (Spahn, Sremcevic, 2000 and Spahn, Sremcevic, Duschl, 2002). More than 150 propeller structures have been observed by the cameras of the Cassini-spacecraft (Tiscareno et al. 2006, 2008, 2010, Sremcevic et al. 2007).

We analyze Cassini ISS images of the propeller Bleriot, which orbits in Saturn's outer A ring between the Encke and Keeler gaps. As of today, Bleriot is the only propeller which shows clearly visible propeller-gaps.

In order to determine the radial position of the gap-minimum, we fit a Gaussian to the radial brightness profile of the propeller at different azimuthal location downstream of the propeller-moonlet. We estimate the ring viscosity from the azimuthal brightness evolution at the gap minimum by fitting it to the theoretical azimuthal gap evolution (Sremcevic, Spahn, Duschl, 2002). Further, we measure a separation of the propeller-gaps of 1.1 km for Bleriot which corresponds to a moonlet Hill radius of about 0.28 km.

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#### 141.19 – Observations of HCN and its Isotopologues on Titan using ALMA

Titan's atmosphere is primarily composed of molecular nitrogen ( $\text{N}_2$ , 98%) and methane ( $\text{CH}_4$ ,  $\approx 2\%$ ), but also hosts a myriad of trace organic species; the simplest and most abundant of these is hydrogen cyanide (HCN). The advent of ALMA provides the opportunity to observe rotational transitions in this molecule and many of its isotopologues with unprecedented sensitivity and spatial resolution. In this study we make use of publicly available ALMA calibration observations of Titan taken between April and July 2014, each lasting around 160 seconds. We report the detection of a new HCN isotopologue on Titan,  $\text{H}^{13}\text{C}^{15}\text{N}$ , and determine the isotopic ratios  $^{14}\text{N}/^{15}\text{N}$ ,  $^{12}\text{C}/^{13}\text{C}$ , and D/H using high signal-to-noise observations of HCN,  $\text{H}^{13}\text{CN}$ ,  $\text{HC}^{15}\text{N}$ , and DCN. Isotopic ratios are known to diverge throughout the solar system in planetary atmospheres due to a variety of processes, including mass-dependent escape, photochemistry, and condensation. Therefore, accurate knowledge of isotopic ratios can provide important constraints on models of the origin and evolution of planetary atmospheres.

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### 141.20 – Chemistry of the Upper Atmosphere of Neptune

It has been previously asserted that sulfur-bearing species such as CS and SO<sub>2</sub> may be present in the upper atmosphere of Neptune, as remnants of cometary impacts (Iino et al., 2014). Based on the example of the SL9 event on Jupiter, CS in particular may be one of the most abundant tracers of past cometary impacts. We present the results of our search for spectral (sub)mm signatures of HCN, CS, and SO<sub>2</sub> in Neptune's stratosphere, performed on archival public data from the Atacama Large Millimeter/submillimeter Array (ALMA). Neither CS or SO<sub>2</sub> were detected on Neptune. We estimated an upper limit on the S/O stratospheric ratio significantly lower than the S/O ratio in comets, suggesting that S and O cannot both solely originate from a cometary impact.

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**Contributing team(s):** Arielle Moullet, Bryan Butler

### 141.21 – Stardust Under a Microscope - 3D maps of Wild 2/81P Cometary Samples in Aerogel

The NASA Stardust mission to comet Wild 2 returned to Earth in 2006 with cometary and interstellar material captured in aerogel. Cometary particles impacted an aerogel collector at a relative velocity of 6.1 km/s, creating three-dimensional (3D) impact tracks of melted and crushed aerogel, void space, and fragmented cometary material. Each track represents the history of a unique hypervelocity capture event. The nature of each impact, including the original state of the impactor, is recorded in track morphology and material distribution. Using a combination of 3D morphological data, chemical data, and microphysical models, it is possible to reconstruct track formation events and a model of the original impactor.

The focus of this work is to fully characterize whole tracks both morphologically and chemically using solely non-destructive methods. To achieve this, we combine high-resolution laser scanning confocal microscope (LSCM) 3D imaging with synchrotron X-ray fluorescence (SXRF) chemical mapping. We are also beginning to incorporate Raman spectroscopy to perform mineral phase analysis of fine track wall material. Using a Zeiss LSM 710 LSCM located in the American Museum of Natural History, we have imaged the morphology of over a dozen, whole Stardust tracks at high resolution (<80 nm/pixel in XY). We obtain the distribution of fine material along the track walls both quickly and without disturbing the sample. Complementary chemical data is acquired using the GSECARS X-ray microbe on beamline 13-ID-E at the Advance Photon Source (APS) of Argonne National Laboratory. X-ray fluorescence maps of each track were collected with 100ms/pixel dwell time at a resolution of 1 or 2 micron/pixel. Many tracks were tilted and mapped a second time for stereo measurements.

A thorough understanding of how cometary material and aerogel is distributed along tracks is required to understand the events which occurred after impact and to back-calculate properties of the original impactor using hydrodynamic simulations of hypervelocity impacts in aerogel. Here we present track map and chemical data.

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### 141.22 – The Distribution of Geometric Albedos of Jupiter-Family Comets From SEPPCoN and Visible-Wavelength Photometry

Cometary nuclei are some of the least reflective natural objects in the Solar System, although the number of comets for which the reflectivity has heretofore actually been measured is small due to the difficulty of the requisite measurements. When no other information

is present, it is common to assume a geometric albedo of 4%, and this is consistent with the limited number of known albedos. However the true average albedo, median albedo, and spread of the distribution are not well constrained. Knowing the ensemble properties of cometary albedos would aid in understanding the surface scattering properties as well as the interior thermal evolution and surface evolution of the population. We present here a preliminary estimate of the distribution of geometric albedos among the Jupiter-family comet (JFC) population. We make use of and build on the results of the Survey of Ensemble Physical Properties of Cometary Nuclei (SEPPCoN), in which we obtained new and independent estimates of the radii of 89 JFCs [1,2]. We will present our preliminary albedo estimates for ~50 JFC nuclei (by far the most ever obtained), and we will discuss the implications of the ensemble of the results. These JFCs were all observed in R-band, and were all observed at relatively large heliocentric distances (usually >4 AU from the Sun) where the comets appeared inactive, thus minimizing coma contamination. We acknowledge the support of NASA grant NNX09AB44G, of NSF grant AST-0808004, and of the Astrophysical Research Consortium/Apache Point Observatory for this work. References: [1] Y. R. Fernandez et al., 2013, *Icarus* 226, 1138. [2] M. S. Kelley et al., 2013, *Icarus* 225, 475.

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## 142 – Stars: Red Dwarfs, White Dwarfs and Brown Dwarfs Poster Session

### 142.01 – The Census of Objects within 10 Parsecs

The sample of stars, brown dwarfs, and exoplanets known within 10 parsecs of our Solar System as of January 1, 2015 is presented. All systems have trigonometric parallaxes of 100 mas or more with errors of 10 mas or less. Included in the sample are 12 systems in the southern sky added to the sample via new parallaxes from the RECONS (REsearch Consortium On Nearby Stars, [www.recons.org](http://www.recons.org)) effort at the CTIO/SMARTS 0.9m.

The census consists of 366 stars (including the Sun and white dwarfs), 37 brown dwarfs, and 34 planets (eight in our Solar System and 26 exoplanets). Red dwarfs clearly dominate the sample, accounting for 75% of all stars known within 10 pc, while brown dwarfs are currently outnumbered 10 to 1 by stars. The completeness of the sample is assessed, indicating that additional discoveries of red, brown, and white dwarfs within 10 pc, both as primaries and secondaries, are likely, although we estimate that roughly 90% of the stellar systems have been identified. The evolution of the 10 pc sample over the past 70 years is outlined to illustrate the growth of the sample.

The luminosity and mass functions are described. In contrast to many studies, once all known close multiples are resolved into individual components, the true stellar mass function rises to the end of the main sequence. With far fewer brown dwarfs than stars, different formation scenarios for objects that fuse hydrogen and those that do not are likely. Of 270 stellar primaries, 28% have companion stars, only 2% have brown dwarf companions, and 6% have detected planets. The planetary rate so far is low but climbing, while searches for brown dwarf companions to stars within 10 pc have been quite rigorous, so the brown dwarf companion rate is unlikely to rise noticeably. Overall, the solar neighborhood is dominated by small stars that are potentially orbited by many small, as yet unseen, planets.

This effort has been supported by the NSF through grants AST-0908402, AST-1109445, and AST-1412026, and via observations made possible by the SMARTS Consortium.

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**Contributing team(s):** RECONS Team

#### 142.02 – Characterizing the Stars Closest to the Sun

Next generation direct exoplanet imaging campaigns will likely focus in part on imaging the planetary population surround stars located within 30 pc of the Sun. Despite this focus, surprisingly, the fundamental properties of many stars located within 30 pc remain unknown or are poorly characterized. We present an analysis of the fundamental atmospheric parameters of 26 nearby, bright, solar-type stars, using spectra obtained with the ARCES spectrograph on the Apache Point Observatory 3.5m telescope. We determined each star's effective temperature and iron abundance by measuring the equivalent widths of approximately 250 Fe I and Fe II lines with an automated line fitting program (ROBOSPECT), and solving for the fundamental atmospheric parameters using TGVIT. In addition, we compare a subset of our results to those already in the literature to assess the accuracy of our method.

LD acknowledges support from the NSF-REU program at the University of Oklahoma. This work is also supported by NSF-AST-100934.

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#### 142.03 – Knowing Our Neighbors: Two In and One Out

Obtaining a well-understood, volume-limited (and ultimately volume-complete) sample of nearby stars is necessary for determining a host of interesting astrophysical quantities, including the stellar luminosity and mass functions, the distribution of stellar velocities, and the stellar multiplicity fraction. Furthermore, such a sample provides insight into the local star formation history. Towards that end, the Research Consortium on Nearby Stars (RECONS) team measures trigonometric parallaxes to establish which systems truly lie within the Solar Neighborhood, emphasizing those within 25 pc. Less accurate photometric and spectroscopic estimates previously suggested LP 991-84, LHS 6167AB, and LHS 2880 as possible members of the 10-pc sample, which made them desirable candidates.

Recent measurements with the CTIO/SMARTS 0.9-m telescope place LP 991-84 and LHS 6167AB at  $8.6 \pm 0.1$  and  $9.68 \pm 0.09$  pc, respectively, which is consistent with earlier estimates of their distances. However, the final parallax for LHS 2880 places it beyond 25 pc, at a distance of  $31 \pm 1$  pc, despite its previous identification as a member of the 10-pc sample. The proper motions of these systems are  $0.2589 \pm 0.0004$ ,  $0.4394 \pm 0.0003$ , and  $0.7113 \pm 0.0009$  arcsec yr<sup>-1</sup>, respectively.

To characterize these systems more fully, the RECONS team obtained VRI photometry for each; they range from 13.8–14.5 mag. in V. LHS 6167AB also shows signs of long-term variability in V, including a possible flare. In addition, CTIO 1.5-m spectroscopy identifies LP 991-84 and LHS 6167AB as M4.5 V systems. Even as we aspire to identify all the stars within 25 pc, we find that the 10-pc volume still holds some surprises.

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#### 142.04 – The Motion Verified Red Stars (MoVeRS) Catalog and Low-Mass Field Stars with Warm Dust

We present the Motion Verified Red Stars (MoVeRS) catalog of proper motion selected low-mass stars from SDSS, 2MASS, and WISE. These surveys provide a time baseline of ~12 years for sources found in all three surveys, and a precision better than 10 mas/year. The MoVeRS catalog is augmented with proper motions from SDSS+USNO-B and the full sample contains 8,735,004 photometric point-sources selected based on colors and their significant (2 $\sigma$ ) proper motions. This catalog will be useful for finding new low-mass common proper motion systems, along with providing a large input catalog for numerous studies of low-mass stars. In addition, we use the MoVeRS catalog to present a preliminary sample of low-mass field stars exhibiting signatures of warm dust (mid-infrared excesses). Such systems are thought to originate from collisions of terrestrial planets, raising even more questions about the habitability of planetary systems around low-mass stars.

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#### 142.05 – Mapping the Abyss: A Breakthrough in Mass Determinations for Stars and Brown Dwarfs using HST and RECONS Astrometry

We present astrometric results for 7 close binary systems from the ongoing RECONS (REsearch Consortium On Nearby Stars, [www.recons.org](http://www.recons.org)) astrometry program on the CTIO/SMARTS 0.9m telescope. The systems consist of red and brown dwarf components with masses of 0.05-0.30 solar masses that straddle the transition region between stars and substellar objects. We report trigonometric parallaxes with errors less than 3 milliarcseconds that place the objects at distances between 10 and 33 parsecs.

Measurements of the long-term perturbations in the systems' photocenters over 5-13 years allows us to derive orbital periods that are on the order of one decade for all seven systems. Followup analysis is underway using measurements from HST-WFC3 to measure the optical fluxes, separations, and position angles of the individual components in these systems. These new resolved astrometric data, coupled with the long-term ground-based work, will be used to convert the photocentric orbits into relative orbits to provide critical mass ratios and mass measurements for both components in each system. The 14 carefully characterized objects will comprise a fundamental set of standards that will stress-test theoretical models of the smallest stars and brown dwarfs for years to come. The results will be combined with our previous mass-luminosity relation work for stars with masses 0.08-0.60 M<sub>sun</sub> to extend our understanding into the realm of brown dwarfs. We will then have a detailed map covering a factor of more than 10 in mass for the most common objects in the Galaxy.

This effort has been supported by the NSF through grants AST-0908402, AST-1109445, and AST-1412026, STScI grant HST-GO-13724.001-A, and via observations made possible by the SMARTS Consortium.

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**Institution(s):** 1. Georgia State University, 2. RECONS Institute

**Contributing team(s):** RECONS Team

#### 142.06 – A Study of the Wide Main Sequence: The Long-Term Photometric Variability of Low Mass Stars

The RECONS (REsearch Consortium On Nearby Stars,

www.recons.org) team has carried out a long-term photometric variability study using the SMARTS 0.9m telescope at the Cerro Tololo Inter-American Observatory (CTIO). The program has obtained up to 15 years of observations in the V band for hundreds of M dwarf stars. This unique study has provided insight into how the ubiquitous M dwarfs change over decadal timescales, revealing their long-term magnetic cycles and how the presence or lack of such activity may affect their sizes and consequent luminosities, and thus their positions on the H-R Diagram.

Using carefully vetted parallaxes and photometric colors, many measured by the RECONS team, we have created a highly accurate H-R Diagram of the nearest (within 25pc) stars using their V-K colors to represent temperatures and absolute V magnitudes as proxies for luminosities. We find that for M dwarfs, the main sequence widens significantly, by up to four magnitudes in  $M_V$ , corresponding to a factor of almost 40 in optical flux. This spread implies a wide range of stellar radii for M dwarfs of the same temperature. Our study of long-term photometric variability indicates that there is a trend in cyclic activity that is highest for the most luminous red dwarfs and lowest for the rare, cool red subdwarfs. This provides valuable insight into the complex interplay of age, metallicity, and magnetic fields that molds the character of the red dwarfs.

This effort has been supported by the NSF through grants AST-0908402, AST-1109445, and AST-1412026, STScI grant HST-GO-13724.001-A, and via observations made possible by the SMARTS Consortium.

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**Contributing team(s):** RECONS Team

#### 142.07 – Potential Nearby M Dwarf Stars Selected from the 2MASS Catalogs

Potential nearby red dwarf stars have been selected from the 2MASS catalogs using assumptions about apparent magnitudes and colors. Candidate stars in this study are north of the celestial equator and have been restricted to galactic latitudes greater than 20 degrees from the galactic plane to permit subsequent aperture photometry with small telescopes. Stars with close companions have also been eliminated. Most probable M giant stars were eliminated using the (J-H) – (H-K) two-color diagram. Proper motions were obtained from the USNO-B catalog. Additional potential M giant stars were eliminated by removing stars with very low proper motions. Known nearby stars were removed from the list and stars with proper motions greater than  $0.175 \text{ arcsec yr}^{-1}$  were also removed, since such stars will likely be studied in other programs devoted to stars of known proper motion. Photometric parallaxes for the candidate stars were computed using 2MASS photometry and stars having average photometric distances of 25 pc or less were retained. A sample of 121 stars was produced. These stars are being observed using Kron-Cousins R, I and CaH photometry. To date about 75% of the program stars have been observed. All are confirmed dwarf stars and about 50% have distances of 25 pc or less based on photometric parallaxes using Kron-Cousins photometry.

*This publication makes use of data products from the Two Micron All Sky Survey and the U.S. Naval Observatory B1.0 Catalog. Services and products provided by the Strasbourg Astronomical Data Center (CDS) and US Virtual Astronomical Observatory (VAO) were used in processing the data. Observations have been obtained using the telescopes of the Southeastern Association for Research in Astronomy (SARA).*

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#### 142.09 – Stellar & Planetary Parameters for K2's M dwarf Systems

The ongoing K2 mission uses photometry in order to find planets around stars of various types. M dwarfs are of high interests since they have been shown to host more planets than any other main sequence stars and transiting planets around M dwarfs are easier to find. In this poster, we present stellar parameters from M dwarfs hosting transiting planet candidates discovered by our team. Spectra of various bright M dwarfs and K2 objects were obtained in the J, H, and K bands (0.95 microns to 2.52 microns) at  $R \sim 1000$ . We measure equivalent widths of spectra features to obtain stellar radii and effective temperatures. Since planet radii and equilibrium temperatures depend on calculating the parameters of its host stars, understanding the nature of the hosts stars improves the precision with which we can measure these K2 objects of interest.

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#### 142.11 – White Dwarf-M Dwarf Binaries in the Solar Neighborhood

As the most populous constituents of our galaxy, low-mass dwarfs are vital to understanding our galaxy's structure and kinematics. While wide White dwarf-M dwarf binaries (WD+dMs) can provide significant constraints on M dwarf age-activity relations, close WD+dMs can aid our understanding of the nature of common envelope evolution and its products (e.g. cataclysmic variables). We present the discovery and characterization of 186 new WD+dMs from the SUPERBLINK proper motion survey. These WD+dMs were discovered as a result of a search for post-common envelope binaries (PCEBs) and are part of an ongoing project to understand the space density and distribution of WD+dMs and PCEBs. In order to identify the sample of WD+dMs in SUPERBLINK, we utilized NUV-V and V-Ks colors. Here, we describe the discovery method and color selection, as well as present a detailed description of the properties of our sample based on two-component fits to our optical spectroscopy obtained at the MDM Observatory.

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#### 142.12 – Quantitative Spectral Morphology Analysis of Unusually Red and Blue L Dwarfs

In an effort to constrain the properties of photometric color outliers, we present a quantitative spectral morphology analysis of medium-resolution NIRSPEC ( $R \sim 2,000$ ), SpeX cross-dispersed ( $R \sim 2,000$ ), Palomar TripleSpec ( $R \sim 2600$ ), and Magellan FIRE ( $R \sim 6000$ ) J-band spectra for a sample of unusually red and blue L dwarfs. Some red L dwarfs are low surface gravity, young objects whose spectra present weak Na I doublets and FeH absorption bands, but strong VO features (Cruz et al. 2009). Some blue L dwarfs are subdwarfs with low metallicity spectral features such as greater  $H_2$  absorption, stronger metal hydride bands, and enhanced TiO absorption (Burgasser et al 2008c). We fit 3<sup>rd</sup> order polynomials to the pseudo-continuum in order to provide a quantitative comparison of spectral morphology with other peculiar L dwarfs, field standards, young L dwarfs, and L subdwarf. The results indicated that the coefficients of the fit correlate with spectral type, but are independent of color. This newly found trend provides a parameter which can be utilized as an additional tool in characterizing quantifiable differences in the spectra of brown dwarfs. Furthermore, this method can be applied in studying the atmospheric properties of exoplanets, given their similarities with brown dwarfs in mass and photospheric properties.

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**Contributing team(s):** Brown Dwarfs in New York City (BDNYC)

#### 142.13 – Combing the Brown Dwarf Desert with the APOGEE Catalog of Stellar and Substellar Companion Candidates

While both exoplanets and stellar-mass companions have been found in extremely short-period orbits, there has been a paucity of brown dwarf (BD) companions orbiting Sun-like stars, a phenomenon known as the “Brown Dwarf Desert.” However, more recent work has shown that this Desert might be limited in extent, only existing for small separation ( $a < 5\text{--}10$  AU) companions, and may not be as “dry” as initially thought. It has been previously suggested that there may be an “F Dwarf Oasis,” where the BD Desert observed for Solar-like stars ceases to exist for F dwarf stars. The Sloan Digital Sky Survey (SDSS-III) Apache Point Galactic Evolution Experiment (APOGEE) has compiled a catalog of  $\sim 400$  of its most compelling stellar and substellar companion candidates orbiting host stars of various spectral types and evolutionary states. Among these candidates, approximately 100 had a derived companion mass in the BD regime ( $13\text{--}80 M_{\text{Jup}}$ ), which is a significant increase compared to the number of known small separation ( $a < 1$  AU) BD companions. Our sample appears to manifest the BD desert, but only for separations  $< 0.2$  AU rather than the previously held 5 AU. This is explained by one of the unique qualities of our sample when compared to previous companions surveys: Two-thirds of the BD candidates in our sample are orbiting evolved stars, most of which were F dwarfs during their main sequence lifetime, consistent with the notion of an F Dwarf Oasis. Using this sample, we further test this hypothesis by constraining the formation mechanisms of BD companions, and exploring their orbital evolution as their host evolves off the main sequence.

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**Contributing team(s):** APOGEE Substellar Companions Working Group

#### 142.14 – Photometry, Astrometry, and Young Discoveries of Ultracool Dwarfs in the Pan-STARRS1 $3\pi$ Survey

The Pan-STARRS1  $3\pi$  Survey (PS1) has observed three-quarters of the sky in five optical bands (*grizy*) over multiple epochs spanning four years, creating an unprecedented resource for discovering and characterizing ultracool dwarfs. We present an analysis of the PS1 photometry and astrometry of all known L and T dwarfs. We will also highlight some especially interesting and serendipitous discoveries of young ultracool dwarfs.

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#### 142.15 – Quantifying Slopes of L Dwarfs’ and Planetary Mass Objects’ K Band Spectra

We present a method to quantify the overall shape of the K band of brown dwarfs and exoplanets. Using this method, we determine the slopes of two portions of the K band spectra and note linear correlations between these slopes and the objects’ optical spectral types. We therefore find that the overall K band shape depends on optical spectral type. We also find that the K band of several low gravity L dwarfs and planetary mass objects are flatter than those of

field gravity dwarfs, with the K band of 2M1207b essentially horizontal at wavelengths just before the CO absorption peak. A few notable exceptions include the spectra of HR8799b and c, which have steeper K bands than average, likely due to their deep water absorption bands. This new method allows us to quantify subtle differences in the strikingly similar spectra of planetary mass objects and field and low gravity L dwarfs of the same optical spectral type. It also allows us to verify the assigned optical spectral types of field gravity L dwarfs.

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#### 142.16 – High-Resolution Spectral Line Analysis of Unusually Red and Blue L Dwarfs

L dwarfs, the warmest spectral class of brown dwarfs, have a wide range of near-infrared colors at a given spectral type. The presence of extreme colors for some L dwarfs suggests that secondary parameters like gravity, metallicity, and clouds influence their spectral morphology. Although some red L dwarfs have low-gravity signatures in their optical spectra (indicating a young object) and some blue L dwarfs have low metallicity spectral features (indicating a subdwarf), many color outliers do not exhibit clear-cut spectral diagnostics. We investigate the spread in color for these objects by comparing spectral line measurements for outliers with confirmed young objects, known subdwarfs, and near-infrared spectral standards to elucidate their underlying atmospheric and physical properties. We use high-resolution NIRSPEC J-band spectra to measure the equivalent width, line depth, and full width at half maximum of four KI absorption lines that are susceptible to pressure-broadening and therefore sensitive to differences in temperature, gravity, and metallicity. We examine trends in these measured line properties with spectral type, color deviation, and known physical properties (subdwarfs and young objects) in an attempt to disentangle the underlying causes of these color trends.

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**Contributing team(s):** BDNYC

#### 142.17 – Atmospheric Properties of T Dwarfs Inferred from Model Fits at Low Spectral Resolution

Brown dwarfs are substellar objects that cool over time because they are not massive enough to sustain hydrogen fusion at their cores. While spectral types (M, L, T, Y) generally correlate with decreasing temperature, spectral subclasses (T<sub>0</sub>, T<sub>1</sub>, T<sub>2</sub>, etc.) do not, suggesting that secondary parameters (gravity, metallicity, dust) play a role in the spectral type-temperature relationship. We investigate this relationship for T dwarfs, which make up the coolest fully-populated spectral class of substellar objects. Our sample consists of 154 T dwarfs with low resolution ( $R \sim 75\text{--}100$ ) near-infrared ( $\sim 0.8\text{--}2.5$  micron) spectra from the SpeX Prism Library and the literature. We compare each observed spectrum to synthetic spectra from four model grids using a Markov-Chain Monte Carlo analysis to determine robust best-fit parameters and uncertainties. We evaluate the best fit parameters from each model grid per object to constrain how spectral type relates to decreasing temperature and increasing surface gravity and to compare the consistency of each model grid. To test for discrepant results when fitting to relatively narrow wavelength ranges, this analysis is performed on the full spectrum of the Y, J, H, and K bands and on each band separately. New detections of cooler objects extending into the Y dwarf and exoplanet regimes motivate our model comparisons and search for trends with spectral type and other observational properties across the decreasing temperatures in order to better understand the atmospheres of substellar objects, including cool gas giant exoplanets.

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#### 142.18 – Brown Dwarf Binary Statistics in a Volume-Limited Spectroscopic Sample of 25pc

We present the status and preliminary results from our NIR spectroscopic survey of M7-L5 low mass stars and brown dwarfs up to 25pc with IRTF/SpEx intended to find spectral binaries: systems whose blended-light, unresolved spectra show absorption features that indicate the presence of a T dwarf secondary. Two new spectral binary candidates have already been identified in this survey. High resolution imaging follow-up with Keck/NIRC2 has resolved three new systems: WISE J0720-0846, 2MASS J1341-3052, SDSS J1511+0607, and tightly constrained the orbital motion of SDSS J2052-1609. A new separation distribution and binary fraction will result from this survey to help us understand the statistical properties of brown dwarfs.

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#### 142.19 – TRENDS: Compendium of Benchmark Objects

The physical properties of faint stellar and substellar objects are highly uncertain. For example, the masses of brown dwarfs are usually inferred using theoretical models, which are age dependent and have yet to be properly tested. With the goal of identifying new benchmark objects through observations with NIRC2 at Keck, we have carried out a comprehensive adaptive-optics survey as part of the TRENDS (TaRgeting bENchmark-objects with Doppler Spectroscopy) high-contrast imaging program. TRENDS targets nearby ( $d < 100$  pc), Sun-like stars showing long-term radial velocity accelerations. We present the discovery of 28 confirmed, co-moving companions as well as 19 strong candidate companions to F-, G-, and K-stars with well-determined parallaxes and metallicities. Benchmark objects of this nature lend themselves to a three dimensional orbit determination that will ultimately yield a precise dynamical mass. Unambiguous mass measurements of very low mass companions, which straddle the hydrogen-burning boundary, will allow our compendium of objects to serve as excellent testbeds to substantiate theoretical evolutionary and atmospheric models in regimes where they currently breakdown (low temperature, low mass, and old age).

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#### 142.20 – The possible false-detection of a transiting brown dwarf candidate in the overlapping fields of Kepler and MARVELS

While searching for exoplanets via the transit method, it has been documented that the periodicity of an unresolved background eclipsing binary (BEB) can be misinterpreted as the orbital companion of a target star. We explore the possibility that this false-positive contamination method can also occur in Doppler surveys if the angular separation between a BEB and a selected primary is under a certain threshold, dependent on the fiber diameter of the spectrometer instrument. The case example of this investigation is a K2 giant in the constellation Cygnus, in the region of overlap of the Kepler and MARVELS surveys. This star was originally flagged for

potentially having a 5.56d period companion as per the Kepler transit photometry. It was also imbricated with radial velocity (RV) observations performed by the SDSS-III MARVELS survey, in which Doppler information was extracted from along the dispersion direction of the fiducially-calibrated, post-pipeline-rendered spectra. The 5.56d period was corroborated after testing its probability against that of others via a Lomb-Scargle periodogram analysis. The pipeline mass determination yielded a  $\sim 17 M_{\text{Jupiter}}$  companion, within the characteristic mass-range of brown dwarfs. The MARVELS results seem to constitute an independent discovery, and hence confirmation, of the brown dwarf candidate. However, a later investigation conducted by EXPERT, intent upon refining the system's physical parameters, failed to identify the RV signal of any companion whatsoever. EXPERT, with its superior resolving power ( $R=30,000$  vs  $R=11,000$  in MARVELS), finer fiber width (1.2 vs 1.9 arcsec), and higher degree of precision ( $\sim 10$  m/s), was expected to finalize the confirmation, but now offers a major challenge to previous models of the system. Additionally, high-resolution adaptive optics imaging reveals the presence of a distinct, close-in object. The object may itself be an unbound BEB, and thus the source of the period signals reported by Kepler and MARVELS. Further endeavors are underway to better understand the underlying theoretical explanation for the possible false-detections, currently attributed to differential fiber aperture, which may have implications for future Doppler surveys.

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#### 142.21 – The Mass-Radius-Luminosity-Rotation Relationship for M Dwarf Stars

NASA's future Transiting Exoplanet Survey Satellite (TESS) mission is expected to discover hundreds of terrestrial exoplanets orbiting around M dwarf stars, which will be nearby and amenable to detailed characterization. To accurately measure radii and equilibrium temperatures of these exoplanets, we need to know the host star properties, specifically mass, radius and luminosity, to equal accuracy. However, relationships for M dwarf stellar properties are poorly constrained, which leaves us unprepared to characterize exoplanets to be discovered by the TESS mission. The best way to determine relationships for M dwarf stars is to study mutually eclipsing binaries because the photometric and spectroscopic data empirically determine the physical parameters of the stars. We are conducting an on-going survey to measure infrared eclipses and individual spectra of carefully selected M dwarf eclipsing binary targets. We are using Mimir, a near-infrared wide-field imager, on the 72-inch Perkins Telescope near Flagstaff, Arizona, to determine the J, H, and K band magnitudes of the individual stars, and we are using Keck HIRES to measure the radial velocities of each component. Combining the observations, we determine the masses, radii and the semi-major axes of each component to an accuracy of 1%. We are also using measured parallaxes to determine the individual components' absolute infrared magnitudes and bolometric luminosities.

The ultimate goal is to combine the measurements to determine the mass-radius-luminosity-rotation relationship for M dwarf stars. The relationship is critical for choosing the best TESS M dwarf exoplanets for detailed characterization.

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### 143 – Stellar Winds and Stellar Atmospheres Poster Session

#### 143.02 – Discovering Massive Runaway Stars with Infrared Bow Shock Nebulae: Four OB Stars Found in

## WISE

Supernovae, pulsars, and gamma-ray bursts are examples of the result of the death of massive (late-O and early-B type) stars. Determining stellar mass loss rates can help us predict the type of death the star will endure. We focus on stars that are located at the center of an infrared bow shock nebula, indicating that the star was flung from its birthplace at supersonic speed. Observing these massive, high-velocity, runaway stars with bow shock nebulae to determine their spectral type will help in the measurements of their stellar mass loss rates. The spectra of four OB stars driving bow shock candidates are presented. These four candidates were found by searching through the Wide-field Infrared Survey Explorer (WISE) All-Sky Data Release and were the most visible in the WISE 21 $\mu$ m band. The spectrum for each star was obtained with the Longslit Spectrograph at the Wyoming Infrared Observatory (WIRO). The spectral types of G077.3617+01.16 (HD 229159), G079.8219+00.096 ([CPR2002]A10), G092.7265+00.18, and G076.0752-02.2044 (TYC 2697-1046-1) were found to be B1.0I, O9.0V, B0.0V, and B0.0V respectively. As predicted, the candidates are all either late-O or early-B type stars. Now that the spectral types of these stars are known, further analysis can be done to determine the velocities, temperatures, masses, and stellar mass loss rates. This work is supported by the National Science Foundation under grants AST-1063146 (REU), AST-1411851 (RUI), and AST-1412845.

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### 143.03 – Discovering Massive Runaway Stars with Infrared Bow Shock Nebulae: Four New OB Runaway Candidate Stars Found in WISE Atlas Images

Determining the mass loss rates of massive stars is an important unsolved problem in astronomy because mass loss dictates the evolutionary track of the star and its fate. One way to measure mass loss rates is through studying the infrared bow shocks from massive O and B type stars. These stars form bow shocks because they have been expelled from their birth regions and are moving at high velocities through the ISM. The stars we studied in this project were discovered by searching the Wide-Field Infrared Survey Explorer (WISE) 22  $\mu$ m atlas. Using the Longslit Spectrograph at the Wyoming Infrared Observatory (WIRO) we observed each star to obtain a spectrum. Spectral types were then fit to these stars, the stars: G073.6200+1.8522 (B0V), G074.3117+1.0041 (O9V), G059.9225-1.9671 (B3V), and G063.1263+0.3327 (B5V). The spectral types of these stars agree with the predicted range of late-O to early-B type stars. These spectral types will be used to determine temperature, stellar wind velocities, space velocities, and other fundamental quantities that can be used to study stellar mass loss. This work is supported by the National Science Foundation under grants AST-1063146 (REU), AST-1411851 (RUI), and AST-1412845.

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### 143.04 – Discovering Massive Runaway Stars with Infrared Bow Shock Nebulae: First Results

We have searched the plane of the Milky Way for candidate 22  $\mu$ m and 24  $\mu$ m infrared bow shock nebulae using the Wide-Field Infrared Survey Explorer (WISE) All-Sky Data Release and Spitzer GLIMPSE mosaic images. Infrared bow shocks driven by massive, OB stars can provide new constraints on stellar mass-loss rates and reveal new runaway late O- and early B-type stars. Candidate infrared bow

shocks identified in this search were chosen using the criteria of a mostly symmetric arc-like morphology with the arc being bright in only 22 or 24  $\mu$ m along with an apparent driving star associated with the bow shock in line with its axis of symmetry. Preliminary visible spectroscopic observations of candidate bow shock driving stars obtained using the Longslit Spectrograph at the Wyoming Infrared Observatory (WIRO) reveal that these visual inspections yield a 95% success rate of finding late O- or early B-type stars.

This work is supported by the National Science Foundation under grants AST-1063146 (REU), AST-1411851 (RUI), and AST-1412845.

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### 143.05 – Discovering Massive Runaway Stars with Infrared Bowshock Nebulae: Identifying Twelve New Early-Type Stars using SMOG

Massive O and B type stars are crucial to the evolution of the interstellar medium, dominating the production of ionizing radiation, mechanical energy, and heavy elements. However, due to their short lives and relative scarcity, these stars are some of the least well understood and are difficult to locate outside of large star forming regions. A small but significant fraction of these massive stars have been observed to be high-velocity runaway stars moving rapidly away from their origin. When these stars encounter nebular gas they create characteristic arc-shaped bowshocks of heated compressed dust and gas. Using the distinct infrared emission morphology of the hot dust, these bowshock nebulae are predicted to give the location of the massive early type stars.

Visual inspection of 24-micron band images from the Spitzer Mapping of the Outer Galaxy (SMOG) revealed 12 new bowshock nebula candidates. Follow up optical spectroscopy from the Wyoming Infrared Observatory confirmed that all 12 of the associated stellar sources are early-type stars. Combined with related results from visual searches for bowshock nebulae using WISE and Spitzer surveys in the inner Galaxy, we have identified over 85 new early type bowshock supporting stellar sources, a 95% success rate. We conclude that morphological selection of arc-shaped infrared nebulae with a symmetrically placed star is an efficient way to discover early type stars.

This work is supported by the National Science Foundation under grants AST-1063146 (REU), AST-1411851 (RUI), and AST-1412845.

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### 143.06 – Identifying Massive Runaway Stars by Detecting Infrared Bowshock Nebula: Four OB Stars and a New Massive Early-B Binary System

Though the main sequence evolution of OB type stars is relatively well known, the mass loss rates for these stars are still highly uncertain. Some OB stars are gravitationally ejected from their birth sites, traveling at speeds of 30 km/s or more which results in a prominent bowshock nebulae. We identified OB bowshock candidates at low Galactic latitudes by visual inspection of the Wide-field Infrared Survey Explorer (WISE) 22-micron images. Each candidate was observed using the Longslit Spectrograph at the Wyoming Infrared Observatory (WIRO) 2.3 meter telescope. We present here the results from observing four such candidates, and all four are confirmed as early type stars: G092.3191+0.0591 (B1V) (aka ALS11826), G086.551014-1.0873935 (B2V; a probable short-period binary), G076.6921-2.4071 (B5V), and G075.5711-0.2558 (B0V) (aka HD 194303). These results enlarge the sample of candidate runaway

massive stars hosting bowshocks and provide a promising sample of such objects for studying stellar mass loss.

This work is supported by the National Science Foundation Grants AST-1063146 (REU), AST-1411851 (RUI), and AST-1412845.

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### **143.07 – Utilizing Synthetic Spectra to Refine Lambda Boo Stars' UV Classification Criteria**

Lambda Boo-type stars are a group of late B to early F-type Population I dwarfs that show deficiencies of iron-peak elements (up to 2 dex), but their C, N, O, and S abundances are near solar. This stellar class has recently regained the spotlight because of the directly-imaged planets around a confirmed Lambda Boo star, HR 8799, and a suggested Lambda Boo star Beta Pictoris. The discovery of a giant asteroid belt around Vega, another possible Lambda Boo star, also suggests hidden planets. This possible link between Lambda Boo stars and planet-bearing stars motivates us to study Lambda Boo stars systematically. Since the peculiar nature of the prototype Lambda Bootis was first noticed in 1943, Lambda Boo candidates published in the literature have been selected using widely different criteria. The Lambda Boo label has been applied to almost any peculiar A-type stars that do not fit elsewhere. In order to determine the origin of Lambda Boo stars' unique abundance pattern and to better discriminate between theories explaining the Lambda Boo phenomenon, a consistent working definition of Lambda Boo stars is needed. We have re-evaluated all published Lambda Boo candidates and their available ultraviolet and visible spectra. Using observed and synthetic spectra, we explored the classification of Lambda Boo stars and developed quantitative criteria that discriminate metal-poor stars from bona fide Lambda Boo stars. With model spectra, we demonstrated that the (C I 1657 Å/Al II 1671 Å) line ratio is the best single criterion to distinguish between Lambda Boo stars and metal weak stars, and that one cannot use a single C I/Al II cut-off value as a Lambda Boo classification criterion. The C I/Al II cut-off value is a function of a star's effective temperature and metallicity. Using these stricter Lambda Boo classification criteria, we concluded that neither Beta Pictoris nor Vega should be classified as Lambda Boo stars.

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### **143.08 – The Abundances of the Fe Group Elements in Early B Stars in the Magellanic Clouds and Bridge**

The abundances of three Fe Group elements (V, Cr, and Fe) in 9 early main-sequence band B stars in the LMC, 7 in the SMC, and two in the Magellanic Bridge have been determined from archival FUSE observations and the Hubeny/Lanz NLTE programs TLUSTY/SYNPEC. Lines from the Fe group elements, except for a few weak multiplets of Fe III, are not observable in the optical spectral region. The best set of lines in the FUSE spectral region are Fe III (UV1), V III 1150 Å, and Cr III 1137 Å. The abundances of these elements in early B stars are a marker for recent SNe Ia activity, as a single exploding white dwarf can deliver 0.5 solar masses of Ni-56 that decays into Fe to the ISM. The Fe group abundances in an older population of stars primarily reflect SNe II activity, in which a single explosion delivers only 0.07 solar masses of Ni-56 to the ISM (the rest remains trapped in the neutron star). The abundances of the Fe group elements in early B stars not only track SNe Ia activity but are also important for computing evolutionary tracks for massive stars. In general, the Fe abundance relative to the sun's value is comparable to the mean abundances for the lighter elements in the Clouds/Bridge but the values of  $[V, Cr/Fe]_{\text{sun}}$  are smaller. This presentation will discuss the spatial distribution of the Fe Group elements in the Magellanic Clouds, and compare it with our galaxy in

which the abundance of Fe declines with radial distance from the center. Support from NASA grants NAG5-13212, NNX10AD66G, STScI HST-GO-13346.22, and USC's Women in Science and Engineering (WiSE) program is greatly appreciated.

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### **143.09 – Am stars and the influence of binarity on infall**

We explore an old idea for the origin of Am star anomalies, possibly related to observations of pollution in white dwarfs (Jura & Young, ARAA, 42, 45, 2014; Gansicke, et al., Arxiv:1505.03142). It must be noted that infall of an earthlike body can explain some, but not all of the abundance anomalies of Am stars.

The ingestion of earthlike material by an a star should have observable effects that are larger than for solar-type stars. We follow dynamical arguments discussed, e.g. by Debes, et al. ApJ., 747, 148, 2012), and postulate that gravitational interactions will produce an infalling stream of low angular momentum bodies.

Note that most if not all Am stars are binary. Here we investigate only whether there is an increased frequency of collisions with a close binary relative to a single star.

We make quantitative estimates, using analytical 2-body solutions and restricted 3-body calculations with parameters similar to those of the eclipsing Am pair Beta Aur, or WW Aur. We use initial values for the binary similar to those which would lead to a certain collision on a (4M<sub>sun</sub>) single star for a parabolic trajectory. All calculations begin with a distance from the center of mass along the axis of a paraboloid of revolution at 3 or 5 AU and such that a marginal collision occurs with a single star. The perpendicular area of this figure is a cross section for a collision. We sample trajectories starting within and near this cross section, for double star systems. Based on many trials we find it about equally likely--relative to a single star--that an incoming body will be ejected from the system than that it will collide with one of the stars. Although we have sampled only a fraction of possible parameter space, we find no basis to expect that the binarity of the Am systems makes them more likely to have ingested planetary material.

Infall should probably still be considered, along with the generally accepted diffusion scenario, but it does not appear that the binarity of Am stars makes infall significantly more relevant.

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### **143.10 – Abundance analysis of five field blue horizontal-branch stars**

A detailed abundance analysis of five field blue horizontal-branch (or BHB) stars, namely Feige 86, HD 128801, HD 143459, HD 213781 and HZ 27 is presented. Spectra obtained at ESO with UVES found in the archives for Feige 86 and recent ESPaDOnS spectra from CFHT obtained by the authors for the four other stars of the sample are analysed. Since atomic diffusion can occur in the atmospheres of hot BHB stars, this study aims to verify if vertical abundance stratification is present in these stars. The abundance of each selected atomic line is obtained by line fitting using the ZEEMAN2 code. Since the various atomic lines of a given species are formed at different depths in the atmosphere, a search for potential vertical abundance stratification is therefore possible. Average abundances are also estimated, along with the rotational and radial velocities of each star. When possible, these values are compared to previous studies.

**Author(s): Francis LeBlanc<sup>1</sup>**, Issouf Kafando<sup>2</sup>, Carmelle Robert<sup>2</sup>

**Institution(s):** 1. *Université de Moncton*, 2. *Université Laval*

## 144 – Variable Stars & White Dwarfs Poster Session

### 144.01 – On The Origin of The Elements: The Spectacular Role of White Dwarfs

The final fate of stars between  $\sim 1.0 M_{\odot}$  and  $\sim 7.0 M_{\odot}$  is an electron degenerate carbon-oxygen white dwarf (WD). These WD stars play a key role in stellar and galaxy evolution, as cosmological distance indicators, iron-group element factories, cosmic-ray accelerators, kinetic energy sources, and the terminus of stellar binary evolution. However, the thermonuclear reaction rates used in these models have compounded uncertainties that can affect the final characteristics of the white dwarf. While the reaction rates are derived from experiment when possible, some crucial reactions have yet to be reproduced experimentally at energies relevant for astrophysics. We investigate the sensitivity of the WD's structure and composition to the composite uncertainties in the nuclear reaction rates using the stellar evolution toolkit, Modules for Experiments in Stellar Astrophysics (MESA). A dense grid of stellar models is evolved from the pre-main sequence to the thermally pulsing asymptotic giant branch phase. We use a sophisticated nuclear reaction network that follows 49 isotopes from  $^1\text{H}$  to  $^{34}\text{S}$  with Monte Carlo sampled reaction rates from STARLIB to provide the first statistically rigorous study of the final characteristics of WDs.

**Author(s):** Carl Fields<sup>1</sup>, Robert Farmer<sup>1</sup>, Ilka Petermann<sup>1</sup>, Francis Timmes<sup>1</sup>

**Institution(s):** 1. Arizona State University

### 144.02 – A Study of Short-term White Dwarf Variability Using gPhoton

The Galaxy Evolution Explorer (GALEX) was a UV space telescope that operated from 2003 until 2013. A new project at MAST, gPhoton takes advantage of the microchannel-plate photon detector aboard GALEX, which catalogued and time-stamped every photon event by putting the one trillion photon events into a database. Utilizing associated open-source software, gPhoton can create coadd images, movies and light curves at user-defined spatial and temporal scales. As part of early science investigations with gPhoton, 364 white dwarf stars from the McCook-Sion catalog with ample GALEX coverage were photometrically inspected for inter-visit variations during an REU program at STScI. Out of the 364 white dwarfs that were studied, three previously documented pulsating white dwarf stars were confirmed in the UV and (at least) three new pulsating white dwarf stars were discovered. Follow-up observations are conducted at Appalachian State University using optical telescopes at the Dark Sky Observatory. We compare optical and UV light curves of these new white dwarf pulsators and show a selection of other variables found with gPhoton.

**Author(s):** Michael Tucker<sup>3</sup>, Scott W. Fleming<sup>3</sup>, Daniel B. Caton<sup>1</sup>, Chase Million<sup>2</sup>, Bernie Shiao<sup>3</sup>

**Institution(s):** 1. Appalachian State University, 2. Million Concepts, 3. Space Telescope Science Institute

### 144.03 – Release of the gPhoton Database of GALEX Photon Events

The GALEX spacecraft surveyed much of the sky in two ultraviolet bands between 2003 and 2013 with non-integrating microchannel plate detectors. The Mikulski Archive for Space Telescopes (MAST) has made more than one trillion photon events observed by the spacecraft available, stored as a 130 TB database, along with an open-source, python-based software package to query this database and create calibrated lightcurves or images from these data at user-defined spatial and temporal scales. In particular, MAST users can now conduct photometry at the intra-visit level (timescales of seconds and minutes). The software, along with the fully populated database, was officially released in Aug. 2015, and improvements to both software functionality and data calibration are ongoing. We summarize the current calibration status of the gPhoton software, along with examples of early science enabled by gPhoton that include stellar flares, AGN, white dwarfs, exoplanet hosts, novae, and nearby galaxies.

**Author(s):** Scott W. Fleming<sup>3</sup>, Chase Million<sup>2</sup>, Bernie Shiao<sup>3</sup>, Michael Tucker<sup>1</sup>, R. O. Parke Loyd<sup>4</sup>

**Institution(s):** 1. Appalachian State University, 2. Million Concepts, 3. Space Telescope Science Institute, 4. University of Colorado

### 144.04 – Photometry of the old nova HZ Pup

This study of the old nova HZ Pup involved obtaining image data, removing the instrumental signature, performing photometry on the stellar images present, and generating light curves. Relative photometry between the target star and other stars in the image was used to remove atmospheric effects. A periodogram of this light curve shows the historically known periodicity close to 20 minutes. However, other periodicities are also present and it is not clear from the data which are real and which are artifacts of the sampling. These data will be combined with data from other telescopes collected contemporaneously in order to resolve this ambiguity.

**Author(s):** Tomas Cassanelli<sup>2</sup>, Tim Abbott<sup>1</sup>

**Institution(s):** 1. CTIO, 2. University of Bonn

### 144.05 – There and Back Again?: The Disappearing Pulsations of CS 1246

Hot subdwarf stars were once main sequence stars, like the sun, that deviated from normal stellar evolution due to binary interactions and evolved into extreme horizontal branch stars. Several of these stars exhibit rapid pulsations driven by iron opacity instabilities. CS 1246 is a rapidly pulsating hot subdwarf discovered in 2009 that is dominated by a single 371 second pulsation. At the time of its discovery, the pulsational amplitude was one of the largest known, making CS 1246 an ideal candidate for follow up studies. Observations in 2013 implied that the pulsational amplitude had decreased significantly. Since then we have continued monitoring the star using the robotic SKYNET telescopes in Chile, in order to further characterize any changes. Our recent observations show that the pulsational amplitude has gone down by a factor of six: CS 1246 is barely a pulsator anymore. The decay in amplitude over time is reminiscent of a damped harmonic oscillator. Here we present six years of photometry for CS 1246 and discuss possible scenarios that might explain its interesting behavior.

**Author(s):** Alan Vasquez Soto<sup>1</sup>, Brad Barlow<sup>1</sup>

**Institution(s):** 1. High Point University

### 144.06 – Time Series Photometry of the Variable Stars AN Lyn and UU Lyn

AN Lyn and UU Lyn are both variable stars observable in the same field, but with very different natures. AN Lyn is a High Amplitude Delta Scuti that is believed to be a member of a binary system, as plotted radial velocities from (Hintz et al. 2005) were shown to be increasing and changing in sync with the irregular (O – C) diagram. We present 48 new times of maximum light in the V-band, and include all previously published data in the analysis. With the inclusion of this new data, the (O – C) diagram still does not have a clear sinusoidal shape, making the possible orbital period longer than 26 years. Further observations are required to see if the period will continue to increase parabolically, or instead decrease to show the beginnings of a sinusoidal trend to support the binary hypothesis.

UU Lyn is a near-contact binary with an F3V type primary that differs in temperature from the secondary by 1900 K. We present 11 new eclipse times in the V-band which are used together with all previously published eclipse times to show that the period is continuing to decrease at a constant rate and that the orbital distance between the two objects is decreasing.

We acknowledge the Brigham Young University Department of Physics and Astronomy for their support of all research efforts of students and faculty. We wish to thank the student observers who secured observations at the Orson Pratt and West Mountain observatories between the years of 2007 and 2015.

**Author(s):** Leanne Teri Lunsford<sup>1</sup>, Michael D. Joner<sup>1</sup>, Eric G. Hintz<sup>1</sup>

**Institution(s):** 1. Brigham Young University

#### 144.07 – Time Series Photometry of KZ Lacertae

We present BVRI time series photometry of the high amplitude delta Scuti star KZ Lacertae secured using the 0.9-meter telescope located at the Brigham Young University West Mountain Observatory. In addition to the multicolor light curves that are presented, the V data from the last six years of observations are used to plot an O-C diagram in order to determine the ephemeris and evaluate evidence for period change.

We wish to thank the Brigham Young University College of Physical and Mathematical Sciences as well as the Department of Physics and Astronomy for their continued support of the research activities at the West Mountain Observatory.

**Author(s):** Michael D. Joner<sup>1</sup>

**Institution(s):** 1. Brigham Young Univ.

#### 144.08 – Photometric and Spectroscopic Analysis of the delta Scuti Variable V2455 Cygni

V2455 Cygni is a high amplitude delta Scuti variable that has received very little attention. This is surprising given its characteristics of an average magnitude of 8.8, with a full-amplitude of 0.44 in the V filter. Plus it has a published period of 0.09421 days. Finally it has been suggested that this is an SX Phe type variable. We present new photometric and spectroscopic observations of this interesting object. From both sets of observations we demonstrate that V2455 Cyg is part of a binary system with an eccentric orbit. We will present supporting evidence for this binary interpretation, show the best binary model for the system and discuss the stability of the pulsational period of the primary star.

**Author(s):** Marissa Mannard<sup>1</sup>, Eric G. Hintz<sup>1</sup>, Michael D. Joner<sup>1</sup>

**Institution(s):** 1. Brigham Young University

#### 144.09 – KELT RR Lyrae Variable Stars Observed by the NKU Schneider Observatory

In this poster we will discuss our ongoing program to use extant light curves from the Kilodegree Extremely Little Telescope (KELT) survey to find and characterize RR Lyrae (RRL) stars in the disk and inner halo of the Milky Way. RRL stars are of particular interest because they are standard candles and can be used to map out structure in the galaxy. The periods and shape of RRL light curves also contain information about their Oosterhoff type, which can probe galactic formation history, and metallicity respectively. Although there have been several large photometric surveys for RR Lyrae in the nearby galaxy (OGLE, NSVS, ASAS, and MACHO to name a few), they have each been limited in either sky coverage or number of epochs. The KELT survey represents a new generation of surveys that has many epochs over a large portion of the sky. KELT samples over 60% of the sky in both northern and southern hemispheres, and has a long-time-baseline of 4-10 years with a very high cadence rate of less than 20 minutes. This translates into 4,000 to 10,000+ epochs per light curve with completeness out to 3 kpc from the Sun. This poster will present follow-up data taken of RR Lyrae candidate stars found in the KELT survey. These stars were observed using an 11inch telescope at the NKU Schneider Observatory. We will discuss photometric accuracies, cadence, and initial analysis of these stars. We will also discuss the capabilities of our new observatory as well as future follow-up and analysis plans.

**Author(s):** Nathan M. De Lee<sup>3</sup>, Neil Russell<sup>3</sup>, Karen Kinemuchi<sup>1</sup>, Joshua Pepper<sup>2</sup>, Joseph E. Rodriguez<sup>4</sup>, Martin Paegert<sup>4</sup>

**Institution(s):** 1. Apache Point Observatory, 2. Lehigh University, 3. Northern Kentucky University, 4. Vanderbilt University

#### 144.10 – Observing Globular Cluster RR Lyraes with the BYU West Mountain Observatory

We have utilized the 0.9-meter telescope of the Brigham Young

University West Mountain Observatory to secure data on six northern hemisphere globular clusters. Here we present observations of RR Lyrae stars located in these clusters, including light curves. We compare light curves produced using both DAOPHOT and ISIS software packages. Light curve fitting is done with FITLC.

We acknowledge continued support from the Brigham Young University College of Physical and Mathematical sciences for operation of the West Mountain Observatory. Some of the observations included in this presentation were secured within the term of NSF grant AST-0618209.

**Author(s):** Elizabeth Jeffery<sup>1</sup>, Michael D. Joner<sup>1</sup>

**Institution(s):** 1. Brigham Young University

#### 144.11 – A Swift/UVOT Survey of RR Lyrae Stars in the M2 and Omega Centauri Globular Clusters

We present new results from our ongoing Near Ultraviolet (UV) survey of RR Lyrae variable stars in globular clusters using the Swift Ultraviolet Optical Telescope (UVOT). Our previous investigations have shown that RR Lyrae have strong pulsations in the UV. The pulsational parameters show correlations similar to those seen in the optical/IR, including a strong period-shift, period-amplitude relationship and period-temperature relationship. We have also seen a period-luminosity relationship that has a strong dependence on metallicity. We now examine the NUV properties of RR Lyrae in two additional clusters, M2 and Omega Centauri. We show that these two clusters follow the same paradigm and shed new light on the period-luminosity relationship.

**Author(s):** Michael Siegel<sup>1</sup>, Benjamin Balzer<sup>1</sup>

**Institution(s):** 1. Pennsylvania State University

#### 144.12 – Fourier Decomposition and Properties of the Variable Stars in the Globular Cluster NGC 6584

Globular clusters are ideal laboratories for understanding the evolution of stars. By examining the stars within globular clusters, particularly RR Lyrae stars, one can better understand post main sequence evolution of stars and in particular the morphology of the horizontal branch. We present results from observations of the globular cluster NGC 6584 that were gathered using the 0.6 m SARA telescope at CTIO. Nearly 1000 images were obtained in B, V, and I bands from July 2014 through July 2015. This research is a more in depth study of the cluster producing higher quality light curves than those previously done by our group (Toddy et al.) whose main goal was to search for variable stars in NGC6584. Difference image analysis was applied to our images resulting in 77 total variable stars being found in our 13'x13' field of view. Of these 66 were RR Lyrae stars, with 50 being of type RRo and 16 of type RR1. This is 3 more than found in our previous study. 14 of the RRo exhibited the Blazhko Effect. The remainder of the variables were split among 7 long period variables, and 4 eclipsing binaries. The average period of the type RRo variables was found to be 0.54299 days and for type RR1 variables was 0.30610 days. The periods of the RR Lyrae stars and ratio of  $N_I/(N_O+N_I)$  of 0.24 is indicative of an Oosterhoff Type I cluster. Our observations were of high enough quality and phase coverage that we were able to apply Fourier decomposition to the light curves of most of the RR Lyrae stars. By examining the Fourier coefficients of each variable we have determined the absolute magnitude of the variables, the amount of interstellar reddening, the distance to the cluster, the metallicity, as well as other physical parameters of the RR Lyrae stars in NGC 6584.

**Author(s):** Paul T Hettinger<sup>1</sup>, Nathan J Villiger<sup>1</sup>, Brian W. Murphy<sup>1</sup>

**Institution(s):** 1. Butler University

#### 144.13 – K2 and M4: A Unique Opportunity to Unlock the Mysteries of Globular Clusters

One of the most exciting opportunities presented by K2 is the ability to study variable stars in globular clusters (GCs). The K2 observations allow us to perform ensemble asteroseismology of a population that is much older than that in the open clusters in the original Kepler field. This should help us answer long-standing

questions concerning mass loss on the red giant branch and the spread in masses along the horizontal branch. By combining the asteroseismic data with chemical tagging of sub-populations from spectroscopy, we hope to better constrain stellar evolution models and potentially shed some light on the formation history of GCs.

The very crowded nature of stars in GCs poses a challenge, however, due to Kepler's large pixels. M4, observed during K2's campaign 2, presents an excellent opportunity to study GCs with a combination of K2 and ground-based data. M4 is one of the two nearest GCs and thus should appear less crowded and brighter; in fact M4 is likely the only GC whose horizontal branch stars, other than RR Lyraes, will be accessible with K2. We discuss our method of obtaining photometry for the stars in M4 and present sample lightcurves for different classes of oscillating stars in the cluster. We also discuss efforts to use ground-based observations to increase the utility of the K2 dataset.

**Author(s):** Charles A. Kuehn<sup>4</sup>, Dennis Stello<sup>5</sup>, Simon Campbell<sup>2</sup>, Jason Drury<sup>5</sup>, Gayandhi de Silva <sup>1</sup>, Ben Maclean<sup>3</sup>, Timothy R Bedding<sup>5</sup>, Daniel Huber<sup>5</sup>

**Institution(s):** 1. *Australian Astronomical Observatory*, 2. *Max Planck Institute for Astrophysics*, 3. *Monash University*, 4. *University of Northern Colorado*, 5. *University of Sydney*

#### 144.14 – Light Curve Models of Rotationally Distorted, Pulsating Stars

Classical Be stars are a class of active B-type stars, on or near the main-sequence, that have circumstellar disks that are observed via hydrogen Balmer and other line emission. As a population, Be stars are very fast rotators, nearly at the critical point, and rotation introduces significant distortions to the shape of the star. The slightly sub-critical rotation is not sufficient to move material from the stellar surface into the disk, and it is likely that weaker processes such as nonradial pulsations are also required. Here, we present a model of the flux variations of a rotationally distorted stellar surface, perturbed by nonradial pulsations, for comparison to precision time series photometry. We discuss potential applications of our model, such as estimating the flow of mass and angular momentum into the circumstellar disks of Be stars.

We are grateful for support from the National Science Foundation grant AST-1109247.

**Author(s):** M. Virginia McSwain<sup>1</sup>

**Institution(s):** 1. *Lehigh Univ.*

#### 144.15 – RR Lyrae Variables in M33: an analysis of the galaxy's population

RR Lyrae stars are low-mass pulsating variable stars. They can be used as probes to study the properties of stellar populations such as age, metallicity and reddening. M33 is the third most massive spiral galaxy in the Local group with little or no bulge component. Using RR Lyrae stars, we aim to study the early star formation history of M33. We analyze M33 RR Lyrae variables in 7 different fields located at a range of galactocentric distances in M33. The data were taken using the Advanced Camera for Surveys (ACS) and the Wide-Field Planetary Camera 2 (WFPC2) on the Hubble Space Telescope (HST). In order to identify and characterize the variable stars, we use locally written software based on the template light curve fitting technique to determine periods and amplitudes. From the fitted light curves, we can calculate the metallicities and reddenings of the RR Lyrae stars. By combining our results with those from the literature, we are also able to construct the radial density profile of RR Lyraes to investigate whether it is consistent with a halo or disk component

**Author(s):** Nahathai Tanakul<sup>2</sup>, Ata Sarajedini<sup>2</sup>, Soung-Chul Yang<sup>1</sup>

**Institution(s):** 1. *Korean Astronomy and Space Science institute (KASI)*, 2. *University of Florida*

#### 144.16 – The star formation history of DDO210 as probed by its pulsating variable stars

We present the results of our study of the pulsating variable stars in

the isolated Local Group dwarf galaxy, DDO210 (the Aquarius dwarf), using archival ACS/HST imaging in the F475W and F814W passbands. To identify and characterize potential pulsators, we use template fitting to obtain detailed light curve parameters for ~100 bona fide pulsating variable stars. We find both RR Lyrae and Cepheid variables in our sample and use their properties to inform the star formation history of the galaxy and constrain the accretion history of the Milky Way halo through galaxies resembling DDO210.

**Author(s):** Antonio J Ordoñez<sup>1</sup>, Ata Sarajedini<sup>1</sup>

**Institution(s):** 1. *University of Florida*

#### 144.17 – Starspots on LO Pegasi, 2006-2015

LO Pegasi is a rapidly rotating ( $P = 10.154$  hr) young solar analog (spectral class K5-7V) variable star of BY Dra type that exhibits dark starspots on its surface that modulate its brightness as they are carried into and out of view by the star's rotation. Surface maps of the spot distribution were produced based on BVRI photometry obtained at Perkins Observatory from 2006-2015. The maps were generated from the light curves via a non-linear inversion algorithm that uses the differences in the limb darkening through different filter passbands to improve the latitude resolution of the maps. We present an analysis of variations in the size of a polar spot suggested by changes in the average brightness and the amplitude of the rotational modulation from year to year.

**Author(s):** Robert O. Harmon<sup>2</sup>, Mark Chalmers<sup>2</sup>, Robel Geda<sup>3</sup>, Brandi Henry<sup>1</sup>, Viesulas Sliupas<sup>2</sup>

**Institution(s):** 1. *Eastern University*, 2. *Ohio Wesleyan University*, 3. *Rutgers University*

#### 144.18 – Direct Measures of Time-Dependent Diameters and Temperatures of Mira Variables

We examine archival data of the Palomar Testbed Interferometer (PTI) covering a sample of 85 Mira variable stars. The sample contains the three most common types: 65 oxygen-rich (M-type), 11 carbon-rich (C-type) and 9 of the intermediary S-type; periods ranging from 150 to 600 days. The PTI database spans over nine years of data; up to 80 epochs for individual stars, spanning multiple pulsation cycles per star. These interferometric angular sizes, along with ancillary measures of distance and bolometric flux, can be used to determine linear size and effective temperature, respectively. Additionally, the PTI data can be divided into narrowband data across the K-band ( $2.0-2.4 \mu\text{m}$ ), allowing separate analysis of spatially resolved continuum and prominent molecular-bandhead regions of these stars, which typically pulsate out of phase. Preliminary results show average sizes changes of 40% for the stellar radii and 44 % for the molecular envelopes.

**Author(s):** Alma Emilia Ruiz-Velasco<sup>1</sup>, Gerard van Belle<sup>1</sup>, Michelle J. Creech-Eakman<sup>2</sup>

**Institution(s):** 1. *Lowell Observatory*, 2. *New Mexico Institute of Mining and Technology*

#### 144.19 – Cepheid light curve demography via Bayesian functional data analysis

Synoptic time-domain surveys provide astronomers, not simply more data, but a *different kind of data*: large ensembles of multivariate, irregularly and asynchronously sampled light curves. We describe a statistical framework for *light curve demography*—optimal accumulation and extraction of information, not only *along* individual light curves as conventional methods do, but also *across* large ensembles of related light curves. We build the framework using tools from functional data analysis (FDA), a rapidly growing area of statistics that addresses inference from datasets that sample ensembles of related functions. Our Bayesian FDA framework builds hierarchical models that describe light curve ensembles using multiple levels of randomness: upper levels describe the source population, and lower levels describe the observation process, including measurement errors and selection effects. Roughly speaking, a particular object's light curve is modeled as the sum of a parameterized template component (modeling population-averaged behavior) and a peculiar component (modeling variability across the population), subsequently subjected to an observation model. A

functional shrinkage adjustment to individual light curves emerges—an adaptive, functional generalization of the kind of adjustments made for Eddington or Malmquist bias in single-epoch photometric surveys. We describe ongoing work applying the framework to improved estimation of Cepheid variable star luminosities via FDA-based refinement and generalization of the Cepheid period-luminosity relation.

**Author(s):** Thomas J. Loredo<sup>1</sup>, Martin Hendry<sup>3</sup>, Daniel Kowal<sup>2</sup>, David Ruppert<sup>2</sup>

**Institution(s):** 1. Cornell Center for Astrophysics and Planetary Science, 2. Cornell University, 3. University of Glasgow

#### 144.20 – Spitzer mid-IR colors as Cepheid metallicity indicators

Using data from the Warm Spitzer mission, we have found that a significant period-color relation exists for classical Cepheids. This relation is driven by temperature dependent opacity changes in the 4.5 $\mu$ m band. When comparing the PC relations in the MW, LMC and SMC we find that the color feature is metallicity dependent, and can be used as a metallicity indicator, with comparable precision to spectroscopic measurements.

We present the period-metallicity-color relation for Cepheids, and discuss its potential application to larger scale surveys in the era of JWST.

**Author(s):** Victoria Scowcroft<sup>1</sup>, Wendy L. Freedman<sup>4</sup>, Barry Madore<sup>1</sup>, Rachael Beaton<sup>1</sup>, Jeffrey Rich<sup>1</sup>, Mark Seibert<sup>1</sup>, Andy Monson<sup>3</sup>, Jane R. Rigby<sup>2</sup>

**Institution(s):** 1. Carnegie Institution for Science, 2. NASA Goddard, 3. Penn State, 4. University of Chicago

#### 144.21 – The Shocking Truth about Cepheids: The Secret X-ray Lives of Classical Cepheids: Origin of Pulsed FUV and X-Ray Emissions of delta Cep and beta Dor

The Cepheid variable stars (delta Cep) and (beta Dor) have shown FUV spectral emission features from hot (10,000- 300,000 K) plasma that correlate with the phasing of their pulsations. (see Engle et al. 2014). These FUV spectral emissions that include NV 1240, OI 1305, C II 1335A, Si IV 1400A, and He II 1640 show peaks prior to the maximum optical brightness (during the “piston” phase of the pulsation that is observed to be in phase with the stellar pulsations, but the observed X-ray emission occurs near minimum light (near 0.4-0.5P) during the maximum radius and coolest phase of the star. Cepheid stars are an integral part of the cosmic distance ladder, due to their Period-Luminosity relationship (the Leavitt Law). Understanding the dynamics of Cepheid stars, especially with respect to FUV and X-ray emissions, is necessary to be confident in assertions derived from the cosmic distance ladder, including establishing the Hubble Constant to more accurate values.

Presented here is a possible explanation for the pulsation period-related observed UV and X-ray emissions of these Cepheids. Using stellar interior and atmosphere models, conditions found in the ionization zone and outer atmosphere of these stars may be conducive to shocks being formed that are capable of temperatures great enough to produce x-ray emission. The mechanics of these shocks and their propagation in the atmosphere of the stars can potentially explain both the apparent pulsation-phased peaks for the FUV, as well as the pulsation-phase dependent (currently unexplained) X-ray emissions.

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**Author(s):** John Ruby<sup>1</sup>, Scott G. Engle<sup>1</sup>, Edward F. Guinan<sup>1</sup>  
**Institution(s):** 1. Villanova University

#### 144.22 – The Secret Lives of Cepheids: Searching for Evolutionary Changes Using Photoelectric Photometry

Classical Cepheids are pulsating, yellow supergiants and one of the

most important classes of variable stars. They have a direct linear relationship between their period and luminosity and thus serve as crucial “standard candles” for determining the cosmic distance scale and measuring the Hubble Constant. Also, Cepheids play a fundamental role in the calibration of Type Ia supernovae, indicating that the expansion of the Universe is accelerating, and also infer the existence of dark energy. Studies of changes in their pulsation periods and amplitudes reveal evolutionary changes too subtle to detect directly, and understanding these various characteristics of Cepheids is critical to their use as high-precision standard candles. To this end, the Villanova Secret Lives of Cepheids (SLiC) program was created as a comprehensive study of Cepheid behavior, evolution, pulsations, atmospheres, heating dynamics, shocks and winds. As part of the SLiC program, ground-based photometry is being carried out of small sample of bright Cepheids. The observations are being made using the 14-inch reflector telescope at Villanova Campus Observatory. Mounted on the telescope is a SBIG photoelectric photometer equipped with standard Johnson UBVRI filters. Photometry is being carried out of the following stars along with their spectral type, period, and visual mag: X Cyg (F7Ib, ~16.39d, 6.47mag), DT Cyg (F7.5Ib, ~2.5d, 5.82mag), S Sge (G5Ibv, ~8.38d, 5.36mag), FF Aql (F6Ib, ~4.47d, 5.38mag), Eta Aql (F6Iab, ~7.18d, 3.80mag), and Delta Cep (F5Iab, ~5.37d, 3.75mag). The primary scientific objectives are to obtain light curves to investigate possible evolutionary changes from small variations in luminosity, light amplitude and pulsation period. Special emphasis was placed on the classical Cepheid X Cyg due to recent changes in pulsation period, shown by Szabados via a phase jump in X Cyg’s O-C (observed – calculated). X Cyg holds priority in our observations as we attempt to affirm or deny this pulsation period change. We combined the Villanova photometry with complementary B, V and Near-IR photometry conducted from nearby Allentown by Wasatonic.

**Author(s):** Michael Toce<sup>1</sup>, Edward F. Guinan<sup>1</sup>, Scott G. Engle<sup>1</sup>, Richard P. Wasatonic<sup>1</sup>

**Institution(s):** 1. Villanova University

#### 144.23 – Analysis of Kepler Observations of ASAS Variable Stars

We present preliminary results of a study that compares the performance of period-finding algorithms when using data gathered by ground-based telescopes to their performance when using data gathered by space-based telescopes. In order to make this comparison, the periods reported by the All Sky Automated Survey (ASAS) Catalog for Variable Stars in the Kepler Field of View, a study that identified targets for the Kepler Mission before its launch, were compared to periods determined by this study. Only targets that were identified in the ASAS Catalog and later observed by the Kepler Mission were selected for analysis, for a total of 599 targets. The observations gathered by the Kepler Mission were analyzed using three period-finding algorithms: the Lafler-Kinman algorithm, the Analysis of Variance algorithm, and the Conditional Entropy algorithm. These three algorithms analyzed the light curves of each target, and one of the periods produced was selected to be compared to the period found by the ASAS Catalog. The analysis of the two data sets highlights issues with the performance of period finding algorithms with ground-based data, leading to crude period estimates for all targets with periods longer than 10 days. Since the Large Synoptic Scanning Telescope (LSST), due for first light in 2020, will have a similar observation schedule to that of the ASAS survey, similar issues can be expected with the analysis of LSST data for some types of long period variables, like semiregulars, that have periods longer than 10 days. Pezzato was supported by the NOAO/KPNO Research Experiences for Undergraduates (REU) Program which is funded by the National Science Foundation Research Experiences for Undergraduates Program (AST-1262829).

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**Institution(s):** 1. National Optical Astronomy Observatory, 2. Swarthmore College

#### 144.24 – AGB Stars in the Large and Small Magellanic Clouds

Asymptotic giant branch (AGB) stars are evolved, pulsating variable

stars that generate massive outflows of gas and dust, thereby enriching the interstellar medium (ISM) in the products of stellar nucleosynthesis. Recent studies find the dustiest, most extreme AGB stars contribute a disproportionately large amount of matter to their host galaxies; these extreme AGB stars are also the most variable, and they emit most of their energy at mid-infrared wavelengths. Therefore, using the Spitzer Space Telescope, we have imaged several target AGB stars identified in previous surveys of the Large and Small Magellanic Clouds (LMC and SMC, respectively). Our aim is to obtain light curves at 3.6 and 4.5 microns wavelength for these extreme AGB stars. Using multiple epochs of data taken within the last 3 years by our survey and then further comparing this data to past surveys of the SMC and LMC with Spitzer, we were able to generate preliminary light curves for a sample of 30 extreme AGB stars, as well as for other stars found within the image fields. This research project was made possible by the Rochester Institute of Technology Center for Imaging Science Research Experience for Undergraduates program, funded by National Science Foundation grant PHY-1359361 to RIT.

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**Contributing team(s):** The SAGE Team

#### 144.25 – The Pan-STARRS 1 Medium Deep Field Variable Star Catalog

We present the first Pan-STARRS 1 Medium Deep Field Variable Star Catalog (PS1-MDF-VSC). The Pan-STARRS 1 (PS1) telescope is a 1.8 meter survey telescope with a 1.4 Gigapixel camera, located in Haleakala, Hawaii. The Medium Deep survey, which consists of 10 fields located uniformly across the sky, totaling 70 square degrees, is observed each night, in 2-3 filters per field, with 8 exposures per filter, resulting in 3000-4000 data points per star over a time span of 3.5 years. To find the variables, we select objects with > 200 detections, and remove those flagged as saturated. No other cuts are used. There are approximately 2.4 million objects that fit this criteria, with magnitudes between 13th and 24th. These objects are then passed through a lomb-scargle fitting routine to determine periodicity. After a periodicity cut, the candidates are classified by eye into different types of variable stars. We have identified several thousand periodic variable stars, with periods ranging between a few minutes to a few days. We compare our findings to the variable star catalogs within VizieR and AAVSO. In particular, for field MDo2, we recover all the variables that are faint in VizieR, and we find good agreement with the periods reported in VizieR.

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#### 144.26 – Fourier Decomposition and Properties of the Variable Stars in the Globular Cluster NGC 4833

Globular clusters provide an ideal setting to study stellar evolution of stars of similar composition and age. RR Lyrae stars found in globular clusters have a variety of uses in probing the physical characteristics of the stellar population itself and its evolution. Building upon our previous study, we focus on the RR Lyrae stars in the globular cluster NGC 4833. From March through June 2014, we used the Southeastern Association for Research in Astronomy 0.6-meter telescope located at CTIO to collect nearly 1,500 images of NGC 4833 in the B, V, R, and I bands. Using difference image analysis we identified 40 variable stars. Of these, 20 were RR Lyrae stars with 10 being of type RRo, 7 of type RR1, and 3 of type RR2. Additionally, 6 SX Phe, 5 eclipsing binaries, and 9 long period variables were identified. The average period of the type RRo, RR1, and RR2 type variables were 0.69597 days, 0.39547 days, and 0.30654 days, respectively. The periods of the RR Lyrae stars and ratio of  $N_1/(N_0+N_1)$  of 0.41 is indicative of an Oosterhoff Type II cluster. The observations of the RR Lyrae stars were of very high quality and phase coverage allowing us to perform Fourier decomposition of their light curves. From this Fourier decomposition we were able to determine the physical characteristics of the RR Lyrae stars. We found the mean iron abundance to be  $[Fe/H]_{JKZW} = -1.87 \pm 0.06$ , the mean apparent V-magnitude RRo and RR1 type

variables to be  $V_{RR} = 15.51 \pm 0.11$ , a mean absolute V-magnitude of  $M_V = 0.636 \pm 0.053$ ; and an effective temperature for RRo's and RR1's of  $\log_{10} T_{eff} = 3.797$  and  $\log_{10} T_{eff} = 3.855$ , respectively. The multi-band photometry allowed us to determine the reddening of the cluster,  $E(B-V) = 0.342 \pm 0.021$ , which resulted in a distance of  $D(kpc) = 5.91 \pm 0.31$  to NGC 4833.

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### 145 – Stars: Age, Rotation and Activity Poster Session

#### 145.01 – Finding the Orientation of the Stellar Spin Axis

The stellar position angle is defined as the projection of the stellar spin axis on the night sky, as measured from North to East. Measuring the stellar position angle gives information that can be used for stellar spin axis evolution and binary formation theories. Current methods to find this angle use imaging with long baseline interferometry for fast rotating stars. There is a lack of observational techniques to find the orientation of the stellar rotation axis for slow rotating stars, which make up the vast majority of stellar population. We developed a new method for determining the absolute stellar position angle for slow rotating stars using a spectro-astrometric analysis of high resolution long-slit spectra. We used the 2m Thuringer Landessternwarte (TLS) telescope to obtain high resolution spectra ( $R=60,000$ ) with multiple slit orientations to test this method. The stellar rotation causes a tilt in the stellar lines, and the angle of this tilt depends on the stellar position angle and the orientation of the slit. We used a cross-correlation method to compare the subpixel displacements of the position of the photocenter at each slit orientation with telluric lines to obtain the tilt amplitude. We report the results of finding the position angle of the slow rotating K giant Aldebaran and fast rotating reference stars like Vega.

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#### 145.02 – Angular Momentum Evolution of Solar-type Stars and Implications for Gyrochronology

A detailed understanding of the assembly history and rate of chemical enrichment in the Milky Way requires accurate ages for vast numbers of stars. Standard age-dating techniques have significant degeneracies and other limitations, and in any case are mostly limited to the tiny minority of stars in bound clusters.

Data from the Kepler and K2 surveys, along with ground-based studies, show that stellar rotation rates could potentially be exploited to determine ages of field stars since rotation declines with age; this method is called gyrochronology. Several groups have advocated a purely empirical gyrochronology, essentially fitting simple mathematical expressions to rotation/age data, but here we argue that the power of rotation studies lies in their use for calibrating (or rejecting) proposed physical mechanisms for internal angular momentum transport and angular momentum loss through magnetized winds.

We will review the available data and discuss several important selection biases, and will present the results of a detailed Bayesian modeling exercise to show how well a gyrochronology *might* work in the most favorable cases. We will also discuss whether evidence for saturation of wind loss or of internal angular momentum transfer is properly justified in a statistical sense.

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**Institution(s):** 1. Ohio State Univ.

#### 145.03 – Comparative Analysis of Age Indicators in Young M and L dwarfs

Within the nearby solar neighborhood ( $< 100$  pc) there are several collections of stars that share similar space motion and young ages, and are assumed to be coeval. Recently, our team has investigated the kinematic properties of a large sample of low surface gravity brown dwarfs to evaluate their membership probability in these so-called moving groups. We compare spectral properties, optical and infrared gravity measurements, and photometric deviations of brown dwarfs confirmed in groups as well as those that have ambiguous kinematics or which are confirmed non-members of any known association. We analyze these data to determine if the known age indicators for brown dwarfs are consistent with the ages of the proposed moving group affiliations. We also demonstrate the diversity in ambiguous or non-member sources and search for indications of ages for these unaffiliated objects.

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**Contributing team(s):** BDNYC

#### 145.04 – Dating the Stars Next Door: Ages and Coronal X-Ray Activities of Local K-Type Stars

Age is one of the most difficult (but important) basic stellar physical property to determine. One possible means to estimate stellar age is from rotational period; it is known that as cool stars age, they lose angular momentum from magnetic braking and slow-down. Thus, good Rotation-Age relationships exist, which are calibrated with stars possessing reliable ages from: evolutionary tracks and/or memberships in clusters/moving groups or binary star systems. Further, ages of older stars can be estimated from (low) metal abundances and kinematics (high space motions). More recently, age determinations from asteroseismology are also becoming more reliable. Except for the many G, K, M stars in the Kepler/K2 fields, rotational periods are difficult to measure photometrically for older, less active stars since star spots and active regions are smaller & less prominent. Thus measuring the coronal X-ray activity of a star is an appealing alternative. Coronal X-ray emission is generated by the stellar dynamo, and so is directly related to the stars' rotation (and age). Measurement of X-ray fluxes (or upper limits) have been made for most of the nearby stars (within  $\sim 20$  pc) with data available in the HEASARC archives. During the 1990's the ROSAT X-Ray Satellite carried out an all-sky survey of thousands of X-ray sources, including hundreds of nearby stars, producing a large archival database. Using these and other available X-ray data from XMM-Newton & Chandra, we explore the relation between coronal X-ray activity and stellar age of all stars within 10 pc (32.6 LY), with special emphasis on dK and early dM stars that make up  $\sim 85\%$  of the sample. Here we report the progress made in determination the ages these nearby stars. We focused on nearby dK-stars, due to their long lifetimes ( $> 20$  Gyr) and habitable zones that lie  $\sim 0.5$ – $1.5$  AU from their host stars. They appear to be ideal candidates for hosting potentially habitable planets, making them interesting targets. We present a progress report on this project of "dating" nearby stars. This research is supported by grants from NSF/RUI and NASA (Chandra and HST).

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#### 145.05 – Fundamental Parameters of Nearby Red Dwarfs: Stellar Radius as an Indicator of Age

Red dwarfs dominate the Galactic population, yet determining one of their most fundamental characteristics --- age --- has proven difficult. The characterization of red dwarfs in terms of their age is fundamental to mapping the history of star and, ultimately, planet formation in the Milky Way. Here we report on a compelling technique to evaluate the radii of red dwarfs, which can be used to provide leverage in estimating their ages. These radii are also particularly valuable in the cases of transiting exoplanet hosts because accurate stellar radii are required to determine accurate planetary radii.

In this work, we use the BT-Settl models in combination with

Johnson-Kron-Cousins VRI, 2MASS JHK, and WISE All-Sky Release photometry to produce spectral energy distributions (SEDs) to determine the temperatures and bolometric fluxes for 500 red dwarfs, most of which are in the southern sky. The full suites of our photometric and astrometric data (including hundreds of accurate new parallaxes from the RECONS team at the CTIO/SMARTS 0.9m) allow us to also determine the bolometric luminosities and radii. This method of radius determination is validated by a comparison of our measurements to those found using the CHARA Array (Boyajian et al. 2012), which match within a few percent.

In addition to a compilation of red dwarf fundamental parameters, our findings provide a snapshot of relative stellar ages in the solar neighborhood. Of particular interest are the cohorts of very young and very old stars identified within 50 pc. These outliers exemplify the demographic extremes of the nearest stars.

This effort has been supported by the NSF through grants AST-0908402, AST-1109445, and AST-1412026, and via observations made possible by the SMARTS Consortium.

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**Contributing team(s):** RECONS Team

#### 145.06 – Fast Rotators in Kepler 2: An Empirical Method to Determine Spot Lifetime

The Kepler 2 mission is targeting large numbers of relativity nearby ( $d < 100$ pc) G, K, & M dwarfs selected from the SUPERBLINK proper motion survey. Kepler 2 campaigns 0, 1, 2, & 3 monitored a total of 10498 of these cool main-sequence stars. We used the autocorrelation function to search for fast rotators by identifying short-period photometric modulation in the light curves due to star spots. We identified 459 candidate fast rotators with rotation  $< 4d$  that show light curve modulation we believe to be due to star spots. Our autocorrelation analysis identifies two different modes of variability ("stable" and "decaying") which we believe reflect the average lifetime or surface motion rate of individual star spots. We find that the fastest rotators have the shortest spot lifetime. We also note that the decaying rotators tend to be the reddest targets in our sample (early- to mid-M).

**Author(s):** Dicy Ann E. Saylor<sup>1</sup>, Sebastien Lepine<sup>1</sup>, Ian Crossfield<sup>2</sup>, Erik Petigura<sup>4</sup>, Joshua E. Schlieder<sup>3</sup>

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#### 145.07 – A Million Years Young: Determining the Ages of 11 Suspected Young Brown Dwarfs

Brown dwarfs continuously cool and fade with time, so knowing an object's age is necessary in order to estimate its mass. One of the most reliable ways to constrain the age is to identify objects as members of coeval moving groups with reliable ages based on higher mass members. Confirming membership requires knowledge of an object's parallax distance, proper motion, and radial velocity (RV), which requires a high-resolution spectrum. We obtained high-resolution NIRSPEC J-band data and measured radial velocities for a sample of 11 suspected young, nearby M and L dwarfs. We combined these RV values with previously calculated parallax distances and proper motions to determine the likelihood of young moving group membership using the LACeWING code (Riedel et al. 2015). We confirmed memberships in the Argus Association ( $\sim 40$  Myr) and Tucana-Horologium ( $\sim 30$  Myr) with a probability of  $> 66.7\%$  for two of the 11 brown dwarfs. Another one of the dwarfs had a  $> 79.5\%$  probability of membership in both the AB Doradus (110 Myr) and Hercules-Lyra (257 Myr) groups, which will require further inquiry to resolve. We also compare spectra of our 11 brown dwarfs to spectra of established young and field brown dwarfs in order to further understand spectral indicators of youth at high spectral resolution.

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**Contributing team(s):** BDNYC

#### 145.08 – Measuring M Dwarf Rotation in the Pan-STARRS 1 Medium Deep Survey

The rise of large-format CCDs and automated detection methods has greatly increased the tractability of large-scale studies of stellar rotation. Studies of the relationship between stellar rotation and magnetic activity show a strong correlation, supporting the concept of a rotationally-driven dynamo. However, the number of confirmed rotation periods for stars in the fully convective regime, whose magnetic dynamos are less well understood, remains low. Here we report on ongoing work to measure rotation periods for the M dwarf stellar population observed by the Pan-STARRS 1 Medium Deep Survey (PS1/MDS). We refine an initial sample of around 4.3 million sources using color cuts in each of the five Pan-STARRS 1 filters. Of these sources, we estimate there to be around 135,000 sources which are candidate M dwarfs with a spectral type of M1 or higher. We discuss the outcomes of various rotation period detection methods and present preliminary results. This work is supported in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. 1262851 and by the Smithsonian Institution.

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#### 145.09 – Initial K2 results on Pleiades Rotation Rates

The rotation rates of Pleiades members have been studied for years, and, because its age is  $\sim 100$  Myr, it is one of the clusters anchoring many of the models for rotation evolution. With the K2 data, we can probe the rotation rate of more members, to smaller amplitudes, and with a far better cadence, than has even been probed before. We will present our initial results of the mean rotation rate of Pleiades members as determined from K2 data. Nearly 80% of the K2 Pleiades sample has a periodic signal of some sort.

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**Contributing team(s):** K2 Cluster Team

#### 145.10 – Measuring the rotation periods of 4-10 Myr T-Tauri stars in the Orion OB1 association

Most existing studies of young stellar populations have focused on the youngest ( $< 2-3$  Myr) T-Tauri stars, which are usually associated with their natal gas and hence easier to identify. In contrast, older T-Tauri stars ( $\sim 4-10$  Myr), being more difficult to find, have been less studied, even though they hold key insight to understanding evolution of lower-mass ( $0.1-2 M_{\odot}$ ) stars and of protoplanetary discs. We present a study of photometric variability of 1974 confirmed 4-10 Myr old T-Tauri stars in the Orion OB1 association using optical time-series from three different surveys: the Centro de Investigaciones de Astronomía-Quest Equatorial Survey Team (CIDA-QUEST), the Young Exoplanet Transit Initiative (YETI) and from a Kitt Peak National Observatory (KPNO) campaign. We investigated stellar rotation periods according to the type of stars (Classical or Weak-lined T-Tauri stars) and their locations, to look for population-wide trends. We detected 563 periodic variables and 1411 non-periodic variables by investigating the light curves of these stars. We find that  $\sim 30\%$  of Weak-line T-Tauri stars (WTTS) and  $\sim 20\%$  of Classical T-Tauri stars (CTTS) are periodic. Though we did not find any noticeable difference in rotation period between CTTS and WTTS, our study does show a change in the overall rotation periods of stars 4-10 Myr old, consistent with predictions of angular momentum evolution models, an important constraint for theoretical models for an age range for which no similar data existed.

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**Contributing team(s):** YETI

#### 145.12 – Activity and Variability in M Dwarfs

We investigate the connection between activity and variability in a large sample of M Dwarfs for which we have approximately 75 repeat observations. These low luminosity stars have previously been studied using both photometric and spectroscopic data. With a deeper understanding of how variability correlates with magnetic activity, we may be able to determine spectroscopic properties of stars with time domain photometric data alone. We used 9 years of five-band photometric data for over 25,000 spectroscopically observed M dwarfs in the Sloan Digital Sky Survey (SDSS) Stripe 82. Using H-alpha emission as the indicator for magnetic activity strength, we find that activity appears to be a predictor of variability but the relationship changes as a function of spectral type. In early-type M dwarfs (M0-M2), stars with high levels of activity show larger amounts of variability, while in mid-type M dwarfs (M3-M5), we find that as the magnetic activity increases, the variability decreases. We also find that early-type M dwarfs show a larger fraction of possible activity cycles, where their variability changes during the 9 years of observations.

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#### 145.13 – Simulating Starspot Properties as a Function of Stellar Properties When Emergence Rates are High

We wish to explore, under various stellar conditions, how aggregate starspot properties change when spot emergence rates are high. We use a Sun-based model to simulate the emergence, motion and decay of starspots on active stars. The spots are generated with a solar log-normal distribution of areas, and the emergence rate scaled according to the stellar rotation rate. The initial longitude of each spot is generated randomly, and initial latitude is generated with a normal distribution about a changing average, equivalent to the solar butterfly diagram. The spots are then allowed to decay at a rate dependent on the stars' surface turbulence, with a motion determined by the differential rotation and meridional flow. At high emergence rates spots can erupt into old ones, where we will either experience a merger or (partial) destruction, depending on their polarity. We follow this evolution over a magnetic cycle, logging the resulting distribution of spot sizes, latitudes, decay rates and destruction (flare) rates, for varying input parameters and stellar conditions. We compare our results with both stellar observations (including light curves, apparent spot distributions, measured differential rotation and flare rates) and theoretical estimates such as magnetic diffusivities.

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#### 145.14 – GALEX Observes Nearby Cool Stars: Constraints on Ultraviolet Coronal Activity

The GALEX ultraviolet mission (1350-2800Å) has detected many late-type dwarf stars. Numerous M-type dwarf stars exhibit flaring and coronal activity; we use GALEX UV photometry to measure the variability of coronal emission in the GALEX NUV and FUV wavebands.

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### 145.15 – Magnetic Activity of Ultracool Dwarfs

Ultracool dwarfs are very low mass objects that have a temperature below about 2,800K; magnetic activity signatures probe magnetic field behavior in a mass regime intermediate between stars and planets. Very few ultracool dwarfs have detected levels of radio emission, so increasing the sample size is important for the understanding the variety of magnetic processes at work. Because of the dramatic variations in radio and X-ray properties, these probes are best done with simultaneous measurements. We report on a small sample of ultracool dwarfs that have been observed simultaneously with XMM Newton Observatory and the Jansky Very Large Array, for constraints on their coronal plasmas through X-ray and radio observations, respectively; we present the results of the radio reduction, calibration and imaging of our sample. We discuss the implications of upper limits and detections for increasing our understanding of magnetic field behavior in this regime.

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### 145.16 – Determining Stellar Magnetic Fields and Coronal Densities by Radio Spectrum Modeling

Radio emission from active stars provides a sensitive measure of stellar coronal characteristics such as temperature, density and magnetic field strengths. Gyro-synchrotron (GS) emission from mildly relativistic electrons spiraling in magnetic fields is commonly detected in hot coronae of stars with extended magnetospheres, and allows for quantitative estimates of coronal features. Another radiation mechanism, thermal gyro-synchrotron (TGS) radiation, which arises from the thermal electron populations in the high energy tail of a Maxwellian energy distribution, depends strongly on the coronal temperature and strength of the magnetic field. Thus, TGS can potentially provide sensitive constraints on these physical parameters. However, TGS radiation has never been observed. Models predict that TGS should be characterized by an increase in flux, and a corresponding sharp increase in fractional circular polarization at high frequencies. Using the Very Large Array (VLA), we observed eight stars of three different classes: pre-main sequence stars, classical flare stars and close binaries, to determine if their spectral energy distributions (SED's) might display these distinguishing features. The VLA observations were made using 4 GHz wide frequency bands between 15 GHz and 44 GHz, measuring both Stokes I flux and V flux.

For six of the eight stars, the results from VLA are consistent with the SED's we expect for GS, not TGS. For the two pre-main sequence stars, we measured a significant increase in the fractional circular polarization at the higher frequency bands. We are in the process of building detailed modeled fits to determine if we can attribute this to TGS. The development of comprehensive models describing SED's for all of the observed stars will allow us to set upper limits constraining the magnetic field strengths for each source, and, in the case of potential TGS detection, refine TGS models.

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**Institution(s):** 1. University of Iowa

### 145.17 – A Very Bright, Very Hot, and Very Long Flaring Event from the Young Nearby M Dwarf Binary DG CVn

On April 23, 2014, the Swift satellite responded to a hard X-ray transient detected by its Burst Alert Telescope, which turned out to be a stellar flare from a nearby, young M dwarf binary DG-CVn. Observations at X-ray, UV and optical wavelengths of the main impulsive flare and subsequent smaller events reveal a complex pattern of flare events extending over about three weeks. We find that the X-ray spectrum of the primary outburst can be adequately described by either a single very high temperature plasma or a nonthermal thick-target bremsstrahlung model. By evaluating accompanying data of this event and analysis of a second brightening, we argue that the thermal interpretation is more likely on energetic grounds. The primary outburst lasted a few hours and produced the highest temperature thermal plasmas ever seen spectroscopically over the 0.3-100 keV range in a stellar flare, at TX

of 300 MK. The X-ray luminosity of the main flare exceeded the bolometric luminosity of the brighter component ( $L_X > 1.6 L_{bol}$ ) for ~360 seconds. The first event was followed by a comparably energetic event almost a day later, whose coverage at X-ray and optical wavelengths enables inferences about it and the first event. In particular we find evidence for stellar radius-sized coronal loops filled with dense ( $n_e > 10^{12} \text{ cm}^{-3}$ ) coronal plasma. The radiated energy in X-rays and white light reveal these first two events to be some of the most energetic X-ray and white light flares from an M dwarf. These structures require large coronal magnetic field strengths (a few kG for the first event, hundreds of Gauss for the second) to confine the plasma, and we thus predict an extremely high photospheric magnetic field strength of several kiloGauss.

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## 146 – Instrumentation: Ground Based or Airborne Poster Session

### 146.01 – Developing an Interferometer to Measure the Global 21cm Monopole

When radio interferometers observe over very small fields of view, they cannot measure the monopole mode of the sky. However, when the field of view extends to a large region of the sky, it becomes possible to use an measure the monopole with an interferometer. We are currently developing such an interferometer at UC Berkeley's Radio Astronomy Lab (RAL) with the goal of measuring the early stages of the Epoch of Reionization by probing the sky for the global 21cm signal between 50 and 100 MHz, and we have deployed a preliminary version of this experiment in Colorado. We present the current status of the interferometer, the future development plans, and some measurements taken in July of 2015. These measurements demonstrate performance of the analog signal chain of the interferometer as well as the RFI environment of the deployment site in Colorado.

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### 146.02 – The Half Wave Plate Rotator for the BLAST-TNG Balloon-Borne Telescope

The Next Generation Balloon-borne Large Aperture Submillimeter Telescope (BLAST-TNG) is an experiment designed to map magnetic fields in molecular clouds in order to study their role in the star formation process. The telescope will be launched aboard a high-altitude balloon in December 2016 for a 4-week flight from McMurdo station in Antarctica. BLAST-TNG will measure the polarization of submillimeter thermal emission from magnetically aligned interstellar dust grains, using large format arrays of kinetic inductance detectors operating in three bands centered at 250, 350, and 500 microns, with sub-arcminute angular resolution. The optical system includes an achromatic Half Wave Plate (HWP), mounted in a Half Wave Plate rotator (HWPr). The HWP and HWPr will operate at 4 K temperature to reduce thermal noise in our measurements, so it was crucial to account for the effects of thermal contraction at low temperature in the HWPr design. It was also equally important for the design to meet torque requirements while minimizing the power from friction and conduction dissipated at the 4 K stage. We also discuss our plan for cold testing the HWPr using a repurposed cryostat with a Silicon Diode thermometer read out by an EDAS-CE Ethernet data acquisition system.

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**Institution(s):** 1. Cardiff University, 2. Michigan State University, 3. Northwestern University, 4. University of Pennsylvania

### 146.03 – The CCAT 25m-class Submillimeter Telescope

Over cosmic time, half of the radiation emitted by stars has been absorbed by dust and subsequently re-emitted at rest-frame far-infrared to submillimeter wavelengths. A full understanding of the star formation history of the Universe thus requires observations in the submillimeter wavebands. We here give a status update on CCAT, which is envisioned to be a 25-m class submillimeter telescope that will enable a broad range of astronomical studies focused on the origins of stars, galaxies and galaxy clusters. Some of the primary science goals enabled by CCAT will be (1) a detailed measurement of the dust-obscured fraction of the cosmic star formation history back to within the first billion years of cosmic time - by resolving, for the first time, almost the entire far-infrared background light into individual sources, (2) a characterization of the physical mechanisms and energy sources that power the emission from the galaxies involved - such as stellar radiation, shocks, or active galactic nuclei - through spectroscopy, (3) tracing the cycles and components of star formation in the Milky Way and nearby galaxies over large scales at unprecedented spatial and spectral resolution, and in a wide range of different environments, and (4) probing the astrophysical processes in galaxy clusters through multi-band, high resolution studies of the Sunyaev-Zel'dovich effect. Located on a high elevation site in the Atacama Desert of northern Chile (at 5600 meter altitude), CCAT is designed to provide sensitive high angular resolution observations at submillimeter wavelengths (3.5" at 350 micron) over up to a 1 square degree field-of-view. The combination of a large aperture telescope with a precise surface (<17 micron rms wave front error) at a prime observing site, a wide field-of-view (and hence, high mapping speed) utilized through state-of-the-art, large-format cameras and sensitive, multi-object spectrometers makes CCAT an exceptionally powerful discovery instrument.

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**Contributing team(s):** and the CCAT Team

### 146.04 – Development of Kinetic Inductance Detectors for Far-Infrared Spectroscopy

An instrument with high sensitivity and spectral resolution at far-infrared wavelengths could contribute significantly to several currently unanswered questions in astrophysics. Here, we describe a detector system suitable for a spectroscopic experiment at far-infrared wavelengths using kinetic inductance detectors (KIDs). KIDs have the potential to achieve high sensitivity and low noise levels. Specifically, the approach we take uses lumped-element KIDs, which consist of separate capacitive and inductive elements combined to form a microresonator. The inductive element serves as a direct radiation absorber. We describe the design considerations, fabrication process, and readout scheme for a prototype LEKID array of 1600 pixels, along with results from a prototype detector array.

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### 146.05 – FIREhose: Reducing Data from FIRE

Brown dwarfs are stellar objects that do not have enough mass to ignite hydrogen fusion in their core. Their mass is between 0.08 solar masses and the mass of our sun. Brown dwarfs are very bright in the near-infrared wavelength band (0.8- 2.5 microns). We reduced data from the Folded-port InfraRed EchelleTte (FIRE) instrument on the Magellan Telescope at the Las Campanas Observatory. FIRE is a medium-resolution echelle spectrometer, whose data reduction results in a spectrum of a star. When reducing FIRE data, it is important to account for inconsistencies in the data, such as bad

pixels, cosmic rays, and the effects of our atmosphere. Using the FIREhose pipeline, these inconsistencies can be accounted for and corrected using a AO telluric with a known spectrum. After telluric correcting, the data reduction results in a primed spectrum for an object, which can then be used to determine an object's physical properties, such as atmospheric composition, radial velocity, effective temperature and surface gravity.

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**Contributing team(s):** BDNYC

### 146.06 – MIRADAS: The Multi-Object R=22K Near-IR Spectropolarimeter for the 10.4-meter GTC

The Mid-resolution InFRARED Astronomical Spectrograph (MIRADAS), a near-infrared multi-object echelle spectrograph operating at spectral resolution R=22,000 over the 1-2.5 $\mu$ m bandpass, is being developed by an international consortium for the 10.4-meter Gran Telescopio Canarias (GTC). The MIRADAS consortium includes the University of Florida, Universidad de Barcelona, Universidad Complutense de Madrid, Instituto de Astrofísica de Canarias, as well as industrial partners in the US and Europe. MIRADAS completed its Final Design Review in mid-2015, and is currently undergoing fabrication, with planned first light in 2018/2019. In this paper, we review the overall science drivers and system design for MIRADAS, including key technologies such as cryogenic robotic probe arms, macroslicer mini-IFUs, full Stokes polarimetry, and a highly flexible observing configuration.

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**Contributing team(s):** MIRADAS Consortium

### 146.07 – Laboratory Performance and Commissioning of the CHARIS IFS

The Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS) is an integral field spectrograph (IFS) being built for the Subaru telescope. CHARIS will take spectra of brown dwarfs and hot Jovian planets in the coronagraphic image provided by the Subaru Coronagraphic Extreme Adaptive Optics (SCEAO) and AO188 adaptive optics systems. The system is designed to detect objects five orders of magnitude dimmer than their parent star down to an 80 milliarcsecond inner working angle. For characterization, CHARIS has a 'high-resolution' prism providing an average spectral resolution of R82, R69, and R82 in J, H, and K bands respectively. The so-called discovery mode uses a second 'low-resolution' prism with an average spectral resolution of R19 spanning 1.15-2.37 microns (J+H+K bands). This is unique compared to other high contrast IFS designs. It augments low inner working angle performance by reducing the separation at which we can rely on spectral differential imaging. The principal challenge for a high-contrast IFS is quasi-static speckles, which cause undue levels of spectral crosstalk. CHARIS has addressed this through several key design aspects that should constrain crosstalk between adjacent spectral features to be below 1%. Sitting on the Nasmyth platform, the alignment between the lenslet array, prism, and detector will be highly stable, key for the performance of the data pipeline. Nearly every component has arrived and the project is entering its final build phase. Here we review the science case, the resulting design, status of final construction, and lessons learned that are directly applicable to future exoplanet instruments.

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### 146.08 – An Autonomous Ultra-High Frequency

## Satellite Downlink Station for the Arecibo Observatory

Cube-sats, shorthand for “cube satellites,” in the last twelve years have become a very popular way to carry out space-based experiments and studies in low-Earth orbit. Both scientific and commercial groups use the small satellites in efforts ranging from studying the upper atmosphere to imaging the Earth. Due to the Arecibo Observatory’s ideal location at mid-latitude, as well as the growing use of cube-sats for scientific studies that are of interest to the observatory, there is a desire to construct a ground station that will allow the observatory to downlink data from cube-sats in the UHF frequency band. Due to the frequent yet sporadic passes of satellites of interest, the downlink station had a need to be autonomous in tracking and receiving. This poster presents in detail the motivations for constructing an autonomous UHF downlink station at the Arecibo Observatory and where the project is currently, as well as the steps that await completion. The poster also presents an explanation of the downlink station as it will be with complete operational functionality.

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**Institution(s):** 1. Arecibo Observatory

## 146.09 – Steps Toward Real-Time Atmospheric Phase Fluctuation Correction for a High Resolution Radar System

NASA is pursuing a demonstration of coherent uplink arraying at 7.145-7.190 GHz (X-band) and 30-31 GHz (Ka-band) using three 12m diameter COTS antennas separated by 60m at the Kennedy Space Center in Florida, with the goal of a high-power, high-resolution radar array that employs real-time correction for tropospheric phase fluctuation. The major uses for this array will be (a) observations of Near Earth Objects, (b) detection and tracking of orbital debris, (c) high power emergency uplink capability for spacecraft, and (d) radio science experiments.

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**Contributing team(s):** NASA Kennedy Space Center, Jet Propulsion Laboratory, NASA Goddard Space Flight Center, NASA Johnson Space Flight Center, Metropolitan State University of Denver

## 146.10 – Advanced astronomical interference filters from SCHOTT technology

Developing precision interference filters for astronomical radiometry often requires simultaneous solutions to very difficult requirements. SCHOTT’s 80-year legacy methods with interference filters and 9,200-m<sup>2</sup> facility dedicated to filters and optical fabrication bring multiple disciplines together to simultaneously solve requirements that include: narrow-band high-transmission, steep-edge bandpasses, extremely high out-of-band rejection across Si response, sizes accommodating large fields-of-view, precision mechanical filter assemblies and both spectral uniformity and excellent transmitted wavefront across the field. We discuss solutions as satisfied for Spain’s state-of-the-art new fast LOCAL UNIVERSE 3° wide-field survey telescope.

**Author(s):** Anthony B. Hull<sup>4</sup>, Steffen Reichel<sup>2</sup>, Ulf Brauneck<sup>3</sup>, Sebastien Bourquin<sup>3</sup>, Antoni Marin-Franch<sup>1</sup>

**Institution(s):** 1. CEFA, 2. SCHOTT AG, 3. SCHOTT Suisse, 4. University of New Mexico

## 146.11 – The Effects of Commercial Airline Traffic on LSST Observing Efficiency

The Large Synoptic Survey Telescope (LSST) is a ten-year survey that will map the southern sky in six different filters 800 times before the end of its run. In this paper, we explore the primary effect of airline traffic on scheduling the LSST observations in addition to the secondary effect of condensation trails, or contrails, created by the presence of the aircraft. The large national investment being made in LSST implies that small improvements observing efficiency through aircraft and contrail avoidance can result in a significant improvement in the quality of the survey and its science. We have used the Automatic Dependent Surveillance-Broadcast (ADS-B) signals received from commercial aircraft to monitor and record activity over the LSST site. We installed a ADS-B ground station on Cerro Pachón, Chile consisting of a 1090Mhz antenna on the Andes Lidar Observatory feeding a RTL2832U software defined radio. We used *dump1090* to convert the received ADS-B telemetry into Basestation format, where we found that during the busiest time of the night there were only 4 signals being received each minute on average, which will have very small direct effect, if any, on the LSST observing scheduler. As part of future studies we will examine the effects of contrails on LSST observations. Gibson was supported by the NOAO/KPNO Research Experiences for Undergraduates (REU) Program which is funded by the National Science Foundation Research Experience for Undergraduates Program (AST-1262829).

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## 146.12 – Study of Optical Mode Scrambling of Fiber Optics for High Precision Radial Velocity Measurements

Optical Fibers have been used throughout Astronomy for spectroscopy with spectrographs located some distance away from the telescope. This fiber-fed design has greatly increased precision for radial velocity (RV) measurements. However, due to the incomplete fiber illumination mode scrambling in the radial direction, high resolution spectrographs with regular circular fibers have suffered RV uncertainties on the order of a few to tens of m/s with stellar observations, which largely limited their sensitivity in detecting and characterizing low mass planets around stars. At the University of Florida, we studied mode scrambling gain of a few different optical devices, such as three-lens optical double scramblers, octagonal fibers and low numerical aperture fibers with a goal to find an optimal mode scrambling solution for the TOU optical very high resolution spectrograph (R=100,000, 0.38-0.9 microns) and FIRST near infrared high resolution spectrograph (R=60,000, 0.9-1.8 microns) for the on-going Dharma Planet Survey. This presentation will report our lab measurement results and also stellar RV measurements at the observatories.

**Author(s):** Anthony Cassette<sup>1</sup>, Jian Ge<sup>1</sup>, Sarik Jeram<sup>1</sup>, Khaya Klanot<sup>1</sup>, Bo Ma<sup>1</sup>, Frank Varosi<sup>1</sup>

**Institution(s):** 1. University of Florida

## 146.13 – Breaking the 1m/s RV Precision Limit

Existing radial velocity (RV) instruments for planet detection are limited by systematic errors resulting from seeing-limited designs. iLocator, the world’s first diffraction-limited RV instrument, is approved for installation at the Large Binocular Telescope and will utilize a high resolution (R~150,000) spectrograph to search for Earth-like planets orbiting the nearest stars. Instrument commissioning is scheduled for 2018 will coincide with science operations of the Transiting Exoplanet Surveying Satellite (TESS).

iLocator utilizes the “extreme” adaptive optics (AO) system of the LBT to reduce spatial variations of light caused by atmospheric turbulence (Esposito et al. 2011). This corrected light will be coupled into single-mode fibers to overcome modal-noise before being fed into an ultra-stable cryogenic Y- and J-band spectrograph (0.958-1.339µm), optimized for detecting terrestrial planets around late-type stars.

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#### **146.14 – Verification of Absolute Calibration of Quantum Efficiency for LSST CCDs**

We describe a system to measure the Quantum Efficiency in the wavelength range of 300nm to 1100nm of 40x40 mm n-channel CCD sensors for the construction of the 3.2 gigapixel LSST focal plane. The technique uses a series of instruments to create a very uniform flux of photons of controllable intensity in the wavelength range of interest across the face of the sensor. This allows the absolute Quantum Efficiency to be measured with an accuracy in the 1% range. This system will be part of a production facility at Brookhaven National Lab for the basic components of the LSST camera.

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**Institution(s):** 1. Brookhaven National Laboratory, 2. Harvard, 3. Purdue University, 4. SLAC National Accelerator Laboratory, 5. Wayne State University

#### **146.15 – An Investigation of CCD Charge Transfer and Detector Anomalies for a Low Light Level Application**

The SuperNova Integral Field Spectrograph (SNIFS) is used to obtain spectra of nearby Type Ia supernovae as part of the Nearby Supernova Factory. Charge transfer inefficiency (CTI) in the CCD detectors used on SNIFS has the potential to cause distortions to spectra and increase noise. We present a study of the CTI in the SNIFS CCDs using trails from cosmic rays in dark frames. This study shows that the effect of CTI on supernova spectra is minimal, and additionally reveals a detector anomaly, a 1 e<sup>-</sup> undershoot, that is correlated with lower temperatures of the SDSU ARC electronics. We will also present plans for the characterization of new, lower noise, faster readout CCDs from Lawrence Berkeley National Laboratory as part of an upgrade of SNIFS.

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**Institution(s):** 1. Lawrence Berkeley National Laboratory, 2. University of California, Berkeley

#### **146.16 – The Renovation and Future Capabilities of the Thacher Observatory**

The Thacher School is in the process of renovating the campus observatory with a new meter class telescope and full automation capabilities for the purpose of scientific research and education. New equipment on site has provided a preliminary site characterization including seeing and V-band sky brightness measurements. These data, along with commissioning data from the MINERVA project (which uses comparable hardware) are used to estimate the capabilities of the observatory once renovation is complete. Our V-band limiting magnitude is expected to be better than 21.3 for a one minute integration time, and we estimate that milli-magnitude precision photometry will be possible for a V=14.5 point source over approximately 5 min timescales. The quick response, autonomous operation, and multi-band photometric capabilities of the renovated observatory will make it a powerful follow-up science facility for exoplanets, eclipsing binaries, near-Earth objects, stellar variability, and supernovae.

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**Institution(s):** 1. The Thacher School

#### **146.17 – Astronomy Legacy Project – Pisgah Astronomical Research Institute**

Pisgah Astronomical Research Institute (PARI) is a not-for-profit public foundation in North Carolina dedicated to providing hands-on educational and research opportunities for a broad cross-section of users in science, technology, engineering and math (STEM) disciplines. In November 2007 a Workshop on a National Plan for Preserving Astronomical Photographic Data (2009ASPC,410,33O, Osborn, W. & Robbins, L) was held at PARI. The result was the establishment of the Astronomical Photographic Data Archive

(APDA) at PARI. In late 2013 PARI began ALP (Astronomy Legacy Project). ALP's purpose is to digitize an extensive set of twentieth century photographic astronomical data housed in APDA. Because of the wide range of types of plates, plate dimensions and emulsions found among the 40+ collections, plate digitization will require a versatile set of scanners and digitizing instruments. Internet crowdfunding was used to assist in the purchase of additional digitization equipment that were described at AstroPlate2014 Plate Preservation Workshop (www.astroplate.cz) held in Prague, CZ, March, 2014. Equipment purchased included an Epson Expression 11000XL scanner and two Nikon D800E cameras. These digital instruments will compliment a STScI GAMMA scanner now located in APDA. GAMMA will be adapted to use an electroluminescence light source and a digital camera with a telecentric lens to achieve high-speed high-resolution scanning. The 1 $\mu$ m precision XY stage of GAMMA will allow very precise positioning of the plate stage. Multiple overlapping CCD images of small sections of each plate, tiles, will be combined using a photo-mosaic process similar to one used in Harvard's DASCH project. Implementation of a software pipeline for the creation of a SQL database containing plate images and metadata will be based upon APPLAUSE as described by Tuvikene at AstroPlate2014 (www.astroplate.cz/programs/).

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**Institution(s):** 1. Brevard College, 2. Pisgah Astronomical Research Institute

#### **146.18 – Detection Limit for the Globally Distributed Falcon Telescope Network and Viability for Exoplanet Detection**

The Falcon Telescope Network (FTN) is a globally distributed system of twelve 20-inch robotic telescopes that will be centrally controlled from the Cadet Space Operations Center (CSOC) at the U.S. Air Force Academy in Colorado Springs, CO. In an effort to explore the viability of using the FTN for an exoplanet survey, each site will be characterized to demonstrate the ability to detect and collect accurate photometry on a variety of targets, specifically on nearby (< 25 pc) late-type M Dwarf stars. Values for the limiting magnitude of the optical system using the Sloan Digital Sky Survey *i'* and *z'* filters were estimated through a radiative transport approach and validated through a parallel observing campaign. The results of this campaign are presented and will be used as constraints on future projects in exoplanet research, studies in Space Situational Awareness (SSA), and detection and tracking of near-earth objects.

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**Institution(s):** 1. US Air Force Academy

#### **146.19 – LRS2: A New Integral Field Spectrograph for the HET**

Here we present LRS2 (Low Resolution Spectrograph) and highlight early science opportunities with the newly upgraded Hobby Eberly telescope (HET). LRS2 is a four-channel optical wavelength (370nm – 1micron) spectrograph based on two VIRUS unit spectrographs. This fiber-fed integral field spectrograph covers a 12" x 6" field of view, switched between the two units (one blue, and one red) at R~2000. We highlight design elements, including the fundamental modification to grisms (from VPH gratings in VIRUS) to access the higher resolution. We discuss early science opportunities, including investigating nearby "blue-bulge" spiral galaxies and their anomalous star formation distribution.

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**Institution(s):** 1. Carnegie Observatories, 2. University of Texas at Austin

#### **146.20 – Magdalena Ridge Observatory Interferometer – New Path to First Light**

The Magdalena Ridge Observatory Interferometer (MROI), a 10-telescope optical/near-IR interferometer with baselines ranging from 7.8 to 343 meters, has been conceived to be the most ambitious

optical/NIR interferometric array under construction to date. U.S. Congressional, N.M. State and university funding (from NM Tech and partner funding at the University of Cambridge) attained from 2000-13 provided for a nearly complete system design, installation of a large portion of the physical infrastructure at the Magdalena Ridge, the first telescope, delay line, fringe tracker and many other necessary sub-systems. New funding has recently been obtained under a cooperative agreement between NM Tech and the Air Force Research Lab (AFRL) to bring the facility to three fully operational telescopes and associated hardware such that first fringes and closure phase will be realized within 5 years. The completed facility will be able to provide support for observing geosynchronous satellites as well as many exciting observations of astronomical targets. An update on the MROI status, plans moving forward for the next 5 years, and some examples of observational applications feasible at different phases of the array's completion will be presented.

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**Contributing team(s):** Magdalena Ridge Observatory Interferometer team

#### **146.21 – Bringing Perfect Vision to the Daniel K. Inouye Solar Telescope**

The world's largest ground-based solar telescope is one step closer to operation with the acceptance of the deformable mirror engineered by AOA Xinetics, a Northrop Grumman Corporation company. The Daniel K. Inouye Solar Telescope (DKIST), currently under construction in Haleakala, Hawaii, will offer unprecedented high-resolution images of the sun using the latest adaptive optics technology to provide its distortion-free imaging.

Led by the National Solar Observatory (NSO) and the Association of Universities for Research in Astronomy (AURA), the Inouye Solar Telescope will help scientists better understand how magnetic fields affect the physical properties of the Sun, what roles they play in our solar system and how they affect Earth. Ground-based telescopes, whether observing the sun or the night sky must contend with atmospheric turbulence that acts as a flexible lens, constantly reshaping observed images. This turbulence makes research on solar activity difficult and drives the need for the latest adaptive optics technology.

To provide DKIST with the distortion-free imaging it requires, AOA Xinetics designed a deformable mirror with 1,600 actuators, four times the normal actuator density. This deformable mirror (DM) is instrumental in removing all of the atmospheric blurriness that would otherwise limit the telescope's performance. The mirror also has an internal thermal management system to handle the intense solar energy coming from DKIST's telescope. This poster provides the history behind this incredible success story.

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**Institution(s):** 1. *National Solar Observatory*, 2. *Northrop Grumman*  
**Contributing team(s):** National Solar Observatory

#### **146.22 – Characterization of Silicon Moth-Eye Antireflection Coatings for Astronomical Applications in the Infrared**

Silicon moth-eye antireflective structures have emerged to be an excellent approach for reducing the amount of light that is lost upon incidence on a given surface of optics made of silicon. This property has been exploited for a wide variety of products ranging from eyeglasses and flat-panel displays to solar panels. These materials typically come in the form of coatings that are applied to an optical substrate such as glass. Moth-eye coatings, made of a periodic array of subwavelength pillars on silicon substrates or other substrates, can produce the desired antireflection (AR) performance for a broad wavelength range and over a wide range of incident angles. In the field of astronomy, every photon striking a detector is significant –

and thus, losses from reflectivity at the various optical interfaces before a detector can have significant implications to the science at hand. Moth-eye AR coatings on these optical interfaces may minimize their reflection losses while maximizing light throughput for a multitude of different astronomical instruments. In addition, moth-eye AR coatings, which are patterned directly on silicon surfaces, can significantly enhance the coating durability. At the University of Florida, we tested two moth-eye filters designed for use in the near-infrared regime at 1-8 microns by examining their optical properties, such as transmission, the scattered light, and wavefront quality, and testing the coatings at cryogenic temperatures to characterize their viability for use in both ground- and space-based infrared instruments. This presentation will report our lab evaluation results.

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**Institution(s):** 1. *University of Florida*

### **147 – Instrumentation: Space Missions Poster Session**

#### **147.01 – SPHEREx: An All-Sky Spectral Survey**

SPHEREx, a mission in NASA's Small Explorer (SMEX) program that was selected for Phase A in July 2015, is an all-sky survey satellite designed to address all three science goals in NASA's astrophysics division, in a single survey, with a single instrument. We will probe the physics of inflation by measuring non-Gaussianity by studying large-scale structure, surveying a large cosmological volume at low redshifts, complementing high-z surveys optimized to constrain dark energy. The origin of water and biogenic molecules will be investigated in all phases of planetary system formation - from molecular clouds to young stellar systems with protoplanetary disks - by measuring ice absorption spectra. We will chart the origin and history of galaxy formation through a deep survey mapping large-scale spatial power. Finally, SPHEREx will be the first all-sky near-infrared spectral survey, creating a legacy archive of spectra (0.75 - 4.8  $\mu\text{m}$  at  $R = 41.5$  and 150) with high sensitivity using a cooled telescope with large mapping speed.

SPHEREx will observe from a sun-synchronous low-earth orbit, covering the entire sky in a manner similar to IRAS, COBE and WISE. During its two-year mission, SPHEREx will produce four complete all-sky maps for constraining the physics of inflation. These same maps contain numerous high signal-to-noise absorption spectra to study water and biogenic ices. The orbit naturally covers two deep regions at the celestial poles, which we use for studying galaxy evolution. All aspects of the SPHEREx instrument and spacecraft have high heritage. SPHEREx requires no new technologies and carries large technical and resource margins on every aspect of the design. The projected instrument sensitivity, based on conservative performance estimates, meets the driving point source sensitivity requirement with 300 % margin.

SPHEREx is a partnership between Caltech and JPL, following the successful management structure of the NuSTAR and GALEX SMEX missions. The spacecraft will be supplied by Ball Aerospace, based on the demonstrated low-cost BCP 100 bus. The Korea Astronomy and Space Science Institute will contribute hardware and scientific analysis based on two similar space infrared astronomy instruments.

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**Contributing team(s):** SPHEREx Science Team

#### **147.02 – Probing the Origin and Evolution of Interstellar and Protoplanetary Biogenic Molecules: A Comprehensive Survey of Interstellar Ices with SPHEREx**

Many of the most important building blocks of life are locked in interstellar and protoplanetary ices. Examples include  $\text{H}_2\text{O}$ ,  $\text{CO}$ ,  $\text{CO}_2$ , and  $\text{CH}_3\text{OH}$ , among others. There is growing evidence that in some environments, such as within the cores of dense molecular clouds and the mid-plane of protoplanetary disks, the amounts of

these species in ices far exceeds that in the gas phase. As a result, collisions between ice-bearing bodies and newly forming planets are thought to be a major means of delivering these key species to young planets. There currently exist fewer than 250 ice absorption spectra toward Galactic molecular clouds, which is insufficient to reliably trace the ice content of clouds through the various stages of collapse to star and planet formation, or assess the effects of their environments and physical conditions, such as cloud density, internal temperature, presence or absence of embedded sources, external UV and X-ray radiation, gas-phase composition, or cosmic-ray ionization rate, on the ice composition for clouds at similar evolutionary stages. Ultimately, our goal is to understand how these findings connect to our own Solar System.

SPHEREx, which is a mission in NASA's Small Explorer (SMEX) program that was selected for a Phase A study in July 2015, will be a game changer for the study of interstellar, circumstellar, and protoplanetary disk ices. SPHEREx will obtain spectra over the entire sky in the optical and near-IR, including the 2.5 to 4.8 micron region, which contains the above biogenic ice features. SPHEREx will detect millions of potential background continuum point sources already catalogued by NASA's Wide-field Infrared Survey Explorer (WISE) at 3.4 and 4.6 microns for which there is evidence for intervening gas and dust based on the 2MASS+WISE colors with sufficient sensitivity to yield ice absorption spectra with  $\text{SNR} \geq 100$  per spectral resolution element. The resulting  $> 100$ -fold increase in the number of high-quality ice absorption spectra toward a wide variety of regions distributed throughout the Galaxy will reveal correlations between ice content and environment not possible with current spectra. Finally, SPHEREx will provide JWST with an ice source catalog for follow-up.

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#### 147.03 – SPHEREx: Probing the Physics of Inflation

SPHEREx, a mission in NASA's Small Explorer (SMEX) program that was selected for Phase A in July 2015, is an all-sky survey satellite designed to address all three science goals in NASA's astrophysics division: probe the origin and destiny of our Universe; explore whether planets around other stars could harbor life; and explore the origin and evolution of galaxies. These themes are addressed by a single survey, with a single instrument.

In this poster, we describe how SPHEREx can probe the physics of inflationary non-Gaussianity by measuring large-scale structure with galaxy redshifts over a large cosmological volume at low redshifts, complementing high-redshift surveys optimized to constrain dark energy.

SPHEREx will be the first all-sky near-infrared spectral survey, creating a legacy archive of spectra. In particular, it will measure the redshifts of over 500 million galaxies of all types, an unprecedented dataset. Using this catalog, SPHEREx will reduce the uncertainty in  $f_{\text{NL}}$  -- a parameter describing the inflationary initial conditions -- by a factor of more than 10 compared with CMB measurements. At the same time, this catalog will enable strong scientific synergies with Euclid and WFIRST.

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#### 147.04 – SPHEREx: Understanding the Origin and Evolution of Galaxies Through the Extragalactic Background Light

The near IR extragalactic background light (EBL) encodes the integrated light production over cosmic history, so traces the total emission from all galaxies along the line of sight up to ancient first-light objects present during the epoch of reionization (EOR). The EBL can be constrained both through direct photometric measurements and through measurements of anisotropies in the EBL which take advantage of the fact that extragalactic populations produce fluctuations with distinct spatial and spectral characteristics from local foregrounds. Because the amplitude of the linear

clustering signal is proportional to the total photon emission, large-scale EBL anisotropies are an important tracer of star formation history. In particular, EBL anisotropies trace the underlying clustering of faint emission sources, such as low mass objects present during the EOR, dwarf galaxies, and intra-halo light (IHL), all of which are components not readily detected in point source surveys. The fluctuation amplitude measured independently by a number of recent experiments exceeds that expected from the large-scale clustering of known galaxy populations, indicating the presence of a large integrated brightness from these faint and diffuse components.

SPHEREx, a mission in NASA's Small Explorer (SMEX) program that was selected for Phase A in July 2015, is an all-sky survey satellite designed to address all three science goals in NASA's astrophysics division: to probe the origin and destiny of our Universe; to explore whether planets around other stars could harbor life; and to explore the origin and evolution of galaxies. SPHEREx will produce extremely deep maps of the  $\sim 200$  square degrees around the celestial poles in  $\lambda/\Delta\lambda \sim 40$  bins. These will be ideal for EBL anisotropy measurements, either by averaging into broad spectral bands, or as a possible science enhancement option, by performing tomography of cosmic large scale structure using line tracers such as Ly $\alpha$ , H $\alpha$ , H $\beta$ , O[II] and O[III]. SPHEREx is an ideal intensity mapping machine, and has the sensitivity to determine the origin and history of the light production associated with EBL fluctuations, and search for an EOR component its to minimum required level.

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**Contributing team(s):** SPHEREx Science Team

#### 147.05 – SPHEREx: Science Opportunities for the Astronomical Community

SPHEREx, a mission in NASA's Small Explorer (SMEX) program that was selected for Phase A study in July 2015, will perform an all-sky near-infrared spectral survey between 0.75 - 4.8 microns, reaching 19th mag (5 $\sigma$ ) in narrow  $R=40$  filters. The key science topics of the SPHEREx team are: (a) primordial non-Gaussianity through 3-dimensional galaxy clustering; (b) extragalactic background light fluctuations; and (c) ices and biogenic molecules in the interstellar medium and towards protoplanetary environments.

The large legacy dataset of SPHEREx will enable a large number of scientific studies and find interesting targets for follow-up observations with Hubble, JWST, ALMA, among other facilities. The SPHEREx catalog will include 1.5 billion galaxies with redshifts secured for more than 10 and 120 million with fractional accuracies in error/(1+z) better than 0.3% and 3%, respectively. The spectral coverage and resolution provided by SPHEREx are adequate to determine redshifts for all WISE-detected sources with an accuracy better than 3%. The catalog will contain close to 1.5 million quasars including several hundred bright QSOs seen during the epoch of reionization. The catalog will be adequate to obtain redshifts for all 25,000 galaxy clusters expected to be detected in X-rays with e-Rosita. SPHEREx could also produce all-sky maps of the Galactic emission lines, including hydrocarbon emission around 3 microns.

In this poster, we will discuss the data release schedule and some example science studies the broader astronomical community will be able to lead using the SPHEREx database. We will also outline existing plans within the SPHEREx team to develop software tools to enable easy access to the data and to conduct catalog searches, and ways in which the community can provide input to the SPHEREx Science Team on scientific studies and data/software requirements for those studies. The team is eager to develop best software tools and facilitate easy access on a timely schedule to allow a large number of scientific applications and for target selection for JWST observations.

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**Contributing team(s):** SPHEREx Science Team

## 147.06 – SPHEREx: Instrument design and implementation

SPHEREx, a mission in NASA's Small Explorer (SMEX) program that was selected for Phase A in July 2015, is an all-sky survey satellite designed to address all three science goals in NASA's astrophysics division: probe the origin and destiny of our Universe; explore whether planets around other stars could harbor life; and explore the origin and evolution of galaxies.

SPHEREx has a simple, high heritage design with large optical throughput to maximize spectral mapping speed, ideal for an all-sky spectral survey. The 20 cm telescope is based on a wide-field off-axis three-mirror astigmat. With an instantaneous field of view of  $3.5 \times 7.0$  degrees imaged by four H2RG focal plane arrays of 6.2 arcsecond pixels, SPHEREx produces spectra without the use of any dispersive elements. Instead, it uses four linear variable filters (LVFs) placed above the detectors to yield  $R=41.5$  and  $R=150$  spectra covering wavelengths 0.75 to 4.8  $\mu\text{m}$ . Spectra are constructed by stepping the telescope boresight across the sky, modulating the location of an object within the FOV and varying the observation wavelength in each image. Each pointing provides a long  $> 96$  s integration so that the detectors realize background-limited sensitivity. The telescope is cooled by a series of three deployable thermal shields with V-groove radiators to  $< 80\text{K}$ , with the two long-wavelength focal planes to  $< 55\text{K}$ . The design has ample technical margins on detector, optical, thermal, and pointing performance, and carries an additional large margin on point source sensitivity.

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## 147.07 – WFC3/UVIS 2.0

WFC3 UVIS data processing pipeline has been improved to provide better precision by implementing chip dependent photometry and cte corrections. The two UVIS CCDs have different characteristics, different QE and different wavelength dependent response functions. Therefore, to improve the photometric precision, new flat fields, zero points, encircled energy curves and aperture corrections were generated. In this presentation we describe these changes, and their effects on data analysis, including using AstroDrizzle. CTE corrections are presented by S. Baggett at this meeting.

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**Contributing team(s):** and the WFC3/UVIS2.0 Team

## 147.08 – HST WFC3/UVIS: charge transfer efficiency monitoring and mitigation

The harsh low-earth orbit environment is known to damage CCD devices and the HST WFC3/UVIS camera is no exception. One consequence of the radiation damage is charge-transfer efficiency (CTE) loss over time. We summarize the level of the CTE losses, the effect on science data, and the pre- and post-observation mitigation options available. Among them is the pixel-based CTE correction, which has been incorporated into the HST automatic data processing pipeline. The pipeline now provides both standard and CTE-corrected data products; observers with older data can re-retrieve their images via the Mikulski Archive for Space Telescopes (MAST) to obtain the new products.

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**Contributing team(s):** WFC3 Team

## 147.09 – HST WFC3/IR Calibration Updates

We report on several improvements to the characterization, monitoring, and calibration of the HST WFC3/IR detector. The detector performance has remained overall stable since its installation during HST Servicing Mission 4 in 2009. We present an

updated persistence model that takes into account effects of exposure time and spatial variations in persistence across the detector, new grism wavelength solutions and master sky images, and a new SPARS sample sequence. We also discuss the stability of the IR gain, the time evolution and photometric properties of IR "snowballs," and the effect of IR "blobs" on point-source photometry.

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**Contributing team(s):** HST WFC3 Team

## 147.10 – HST WFC3: Instrument Status and Advice for Cycle 24 Proposers

The Wide Field Camera 3 on-board of the Hubble Space Telescope provides astronomers with powerful imaging and slitless spectroscopic capabilities from the near-ultraviolet (200 nm) to the near-infrared (1700 nm). We summarize the basic characteristics and performances of WFC3, highlight changes in the calibration pipeline, summarize the calibration program for Cycle 23, and provide new information useful for observers planning to apply for future science investigations.

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**Contributing team(s):** WFC3 Team

## 147.11 – Updates on the Performance and Calibration of HST/STIS

The Space Telescope Imaging Spectrograph (STIS) on the Hubble Space Telescope (HST) has been on orbit for almost 19 years and continues to produce high quality scientific results using a diverse complement of operating modes. These include spatially resolved spectroscopy in the UV and optical, high spatial resolution echelle spectroscopy in the UV, and solar-blind imaging in the UV. In addition, STIS possesses unique visible-light coronagraphic modes that keep the instrument at the forefront of exoplanet and debris-disk research. As the instrument's characteristics evolve over the instrument's lifetime, the instrument team at Space Telescope Science Institute monitors its performance and works towards improving the quality of its products. Here we present updates on the status of the STIS CCD and FUV & NUV MAMA detectors, as well as changes to the CalSTIS reduction pipeline and available instrument modes. We present on-going work to calibrate the BAR5 occulter, as well as calibration improvements for the echelle gratings.

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## 147.12 – Pixel-Based CTI Corrections for HST/STIS CCD Data

The Space Telescope Imaging Spectrograph (STIS) team at STScI has created stand-alone automated software to apply Charge Transfer Inefficiency (CTI) corrections to STIS CCD data. CTI results from radiation damage to the CCD detector during its many years in the space environment on-board the Hubble Space Telescope (HST). The software will remove trails and other image artifacts caused by CTI, and will help correct target fluxes and positions to their proper values. The software script (stis\_cti v1.0) uses a pixel-based correction algorithm, and will correct both images and spectra. It automatically generates CTI corrected dark reference files, applies CTI corrections to the science data, and outputs the usual CALSTIS products with CTI corrections applied. Currently only the most common observation modes are supported -- full-frame, non-binned data, taken with the default CCD amplifier; future enhancements may include sub-array data. It is available free to the community for download and use. Further information can be found at

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### 147.13 – The Future of Flats Onboard JWST with the Near Infrared Camera

The Near Infrared Camera (NIRCam) onboard the James Webb Space Telescope (JWST) is the primary imager of JWST with observing wavelengths covering 0.6 to 5.0  $\mu\text{m}$ . A dichroic beam splitter reflects short wavelengths (0.6–2.3  $\mu\text{m}$ ) into one channel and transmits long wavelengths (2.4–5.0  $\mu\text{m}$ ) into another. A selection of wide, medium and narrowband filters are available. Obtaining in-orbit flats with NIRCam will be a challenge since NIRCam will not have on-board illumination lamps. Instead, we will utilize the external zodiacal light, preferentially observing along the longitudinal ecliptic plane for maximum brightness. Sky flats will allow us to verify the accuracy and stability of our ground flat fields, and they also allow us to monitor flat field properties with time. Due to the faintness of the sky, however, high signal-to-noise ratios can only be obtained within a reasonable integration time through the broad and a few of the medium-band filters. We have obtained flat-field exposures in ground testing through all filters, including narrow-band filters. Here we analyze the similarity of flats through narrow-band and medium-band filters lying within the wavelength range of broad-band filters. Proving that these flats are indistinguishable with respect to the broad-band filter will allow easier calibration and monitoring once NIRCam is in orbit.

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**Contributing team(s):** NIRCam Team

### 147.14 – Observer's Interface for JWST Observation Specifications

In support of the launch of the James Webb Space Telescope, various teams at STScI (the Space Telescope Science Institute) have collaborated on how to re-structure the view of an observing program within the Astronomer's Proposal Tool (APT) to accommodate for the differences between HST and JWST. For HST APT programs, the structure is visit-dominant, and there is one generic form for entering observing information that spans all instruments with their required fields and options. This can result in sometimes showing irrelevant fields to the user for a given observing goal. Also, the generation of mosaicked observations in HST requires the user to manually calculate the position of each tile within the mosaic, accounting for positional offsets and the roll of the telescope, which is a time consuming process. Now, for JWST programs in APT, the description of the observations has been segregated by instrument and mode into discrete observing templates. Each template's form allows instrument specific choices and displays of relevant information. APT will manually manage the number of visits needed to perform the observation. This is particularly useful for mosaics and dithering with JWST. For example, users will select how they would like a mosaic to be tiled at the observation level, and the visits are automatically created. In this, visits have been re-structured to be purely informational; all editing is done at the observation level. These options and concepts are illustrated to future users via the corresponding poster.

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### 147.15 – JWST/MIRI Data Reduction Pipeline

The James Webb Space Telescope (JWST) will launch in 2018 and will carry four science instruments: NIRISS, NIRSpec, NIRCam and MIRI. MIRI (the Mid-Infrared Instrument) will observe the sky at 5 to 28.5 microns and provides four observing modes: imaging, low-resolution spectroscopy (LRS), medium-resolution spectroscopy (MRS) via an integral field unit, and coronagraphy.

The MIRI data reduction pipeline is based on extensive testing of the

instrument and will provide not only basic calibrated data, but also higher level science products. The pipeline is split into three stages: first, the raw data is processed into an uncalibrated slope image; second, each slope image is calibrated; and third, slope images from multiple exposures are combined and processed to produce the final data product. The final data products include: calibrated mosaics and catalogs of point sources for imaging observations; extracted spectra for LRS observations; PSF subtracted images for coronagraph observations; and spectral cubes for MRS observations. The overall goal of the MIRI pipeline is to provide well-calibrated, high level data products that maximize the scientific return from the instrument.

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**Contributing team(s):** JWST/MIRI Team

### 147.16 – Relationship of Science Return to Potential Architectures for WFIRST

The potential move of WFIRST to an L2 orbit opens many exciting possibilities for this important mission. This poster explores options for mission architecture for WFIRST and the effect of those choices on potential science return and the ability to respond to scientifically important but not yet formulated requirements. For each architectural option the marginal return in science performance is presented. We also examine these architectural choices for their cost, cost risk, technical maturity and ability to advance the launch date.

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### 147.17 – Post-processing images from the WFIRST-AFTA coronagraph testbed

The concept for the exoplanet imaging instrument on WFIRST-AFTA relies on the development of mission-specific data processing tools to reduce the speckle noise floor. No instruments have yet functioned on the sky in the planet-to-star contrast regime of the proposed coronagraph (1E-8). Therefore, starlight subtraction algorithms must be tested on a combination of simulated and laboratory data sets to give confidence that the scientific goals can be reached. The High Contrast Imaging Testbed (HCIT) at Jet Propulsion Lab has carried out several technology demonstrations for the instrument concept, demonstrating 1E-8 raw (absolute) contrast. Here, we have applied a mock reference differential imaging strategy to HCIT data sets, treating one subset of images as a reference star observation and another subset as a science target observation. We show that algorithms like KLIP (Karhunen-Loève Image Projection), by suppressing residual speckles, enable the recovery of exoplanet signals at contrast of order 2E-9.

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### 147.18 – PSF subtraction for the WFIRST-AFTA coronagraph

Direct detection and characterization of mature giant or sub-Neptunes exoplanets in the visible require space-based instruments optimized for high-contrast imaging with contrasts of 1e-9. In this context, the Wide-Field Infrared Survey Telescope - Astrophysics Focused Telescope Assets (WFIRST-AFTA) will reach raw contrasts of about 1e-9 to 8e-9 using state-of-the-art starlight suppression and wavefront control techniques. A ten-fold contrast improvement is therefore expected using post-processing techniques to reduce the speckle noise level to a factor of at least 10 lower in order to distinguish 1e-9 planets from speckles. Point spread function (PSF) subtractions on both ground-based and space-based instruments have not yet been demonstrated at such high-contrast levels and we explore new ways of implementing these techniques on AFTA-like simulated images in the presence of deformable mirrors, coronagraph and integral field spectrograph (IFS). In this communication, we cover both the problems of planet detection

(investigating new metrics such as the False Positive Probability), and planet characterization (demonstrating accurate spectrum extraction even in the presence of speckles).

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#### 147.19 – Multiple Gigabit-per-Second Class Data Link Enabling WFIRST at L2

NASA's Wide-Field Infrared Survey Telescope (WFIRST) will be the first of a new generation of missions, expected to generate amounts of data unprecedented in astrophysics from space. This trend is driven by the availability of high resolution, large area detectors, commonly generating simultaneously spatial and spectral information, and the desire to have access to data in the least processed form. Although this increase in data volume is new for astrophysics missions, the data volume and associated rates are well within the realm of Earth science and other space missions. While NASA currently plans to launch WFIRST into a geosynchronous orbit, there are many advantages to placing future observatories outside of Earth's orbit at locations such as the Sun-Earth libration point L2. These advantages include a more benign radiation environment due to the absence of trapped electrons, eclipse-free Sun illumination for power generation and a stable thermal environment because of the much more slowly varying Sun angle. More importantly, a Sun-Earth libration point L2 orbit will allow for longer integration times thereby enhancing many of the WFIRST mission science cases. These advantages can be realized, if a cost effective, high capacity downlink solution is available. Here, we outline our approach to providing link capacities from L2 in excess of 3 Gbps ( $3 \times 10^9$  bits/s) based on existing, flight proven components. At these rates, even very large data sets can be transmitted in short data bursts, an approach that allows highly efficient scheduling of ground stations.

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#### 147.20 – The Space Infrared Telescope for Cosmology and Astrophysics (SPICA) in the New Framework

SPICA is a cryogenic space-borne observatory designed for optimal sensitivity in the mid-infrared through submillimeter range: 17-230 microns. The mission is an ESA / JAXA collaboration, now considered for the ESA Cosmic Visions M5 opportunity. SPICA will feature a 2.5-meter telescope cooled to below 8K, this offers the potential for 100-1000-fold advances in sensitivity beyond that obtained with Herschel and SOFIA in the far-IR. With a line sensitivity of  $\sim 5 \times 10^{-20}$  W/m<sup>2</sup> (1 h, 5 sigma), SPICA will be a complement to JWST and ALMA for deep spectroscopic observations.

Integrated over cosmic history, star formation has occurred predominantly in dust-obscured regions which are inaccessible in the rest-frame UV and optical. Both the luminosity history and the detailed physics that govern it can only be directly measured in the mid-IR-submillimeter. Similarly, forming stars and planetary systems cool primarily through the far-IR. By taking advantage of the low-background platform, the SPICA instruments are designed for these topics. The SPICA mid-IR instrument (SMI) will provide R~50 imaging spectroscopy and R~1,000 full-band slit-fed spectroscopy from 17 to 36 microns, with a high-resolution (R=25,000) capability from 12-18 microns. The SPICA far-IR instrument (SAFARI) will cover 34 to at least 230 microns with multiple R~300 wide-band grating spectrometer modules coupling to high-sensitivity far-IR detectors. A R~3,000 scanned-etalon module will also be available for Galactic targets with bright continua and/or dense line spectra.

SPICA has emerged with a new ESA-JAXA collaborative framework. In the current division of responsibilities, ESA will take the lead role, provide the telescope, the fine-attitude sensor, and the spacecraft bus. JAXA will provide the cryogenic system, the SMI instrument, integrate the telescope and instruments, and provide the launch

vehicle. The SAFARI instrument will be provided by a consortium funded by the European national agencies led by SRON. Key detector and spectrometer contributions to SAFARI are under consideration in the US. The mission timeline is set by the Cosmic Visions M5 schedule, which has final approval in 2018-19, and launch in the late 2020s.

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**Contributing team(s):** The SPICA Consortium, the SAFARI Consortium

#### 147.21 – The Guest Investigator Program for the Transiting Exoplanet Survey Satellite (TESS)

Over the summer of 2015, NASA HQ approved the establishment of a Guest Investigator (GI) Program for the Transiting Exoplanet Survey Satellite (TESS). This office, being established at NASA's Goddard Space Flight Center, will provide support to the Astronomical Community for working with data from the TESS mission. In this presentation, we discuss the overall structure and plan for the GI program, and show the schedule for Community involvement.

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**Institution(s):** 1. MIT, 2. NASA's GSFC, 3. SAO

#### 147.22 – LUVOIR and HabEx mission concepts enabled by NASA's Space Launch System

NASA Marshall Space Flight Center has developed candidate concepts for the 'decadal' LUVOIR and HabEx missions. ATLAST-12 is a 12.7 meter diameter on-axis telescope designed to meet the science objectives of the AURA Cosmic Earth to Living Earth report. HabEx-4 is a 4.0 meter diameter off-axis telescope designed to both search for habitable planets and perform general astrophysics observations. These mission concepts take advantage of the payload mass and volume capacity enabled by NASA Space Launch System to make the design architectures as simple as possible. Simplicity is important because complexity is a significant contributor to mission risk and cost. This poster summarizes the two mission concepts.

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**Institution(s):** 1. NASA

**Contributing team(s):** MSFC Advanced Concept Office

#### 147.23 – An Engineering Design Reference Mission for a Future Large-Aperture UVOIR Space Observatory

From the 2010 NRC Decadal Survey and the NASA Thirty-Year Roadmap, *Enduring Quests, Daring Visions*, to the recent AURA report, *From Cosmic Birth to Living Earths*, multiple community assessments have recommended development of a large-aperture UVOIR space observatory capable of achieving a broad range of compelling scientific goals. Of these priority science goals, the most technically challenging is the search for spectroscopic biomarkers in the atmospheres of exoplanets in the solar neighborhood. Here we present an engineering design reference mission (EDRM) for the Advanced Technology Large-Aperture Space Telescope (ATLAST), which was conceived from the start as capable of breakthrough science paired with an emphasis on cost control and cost effectiveness. An EDRM allows the engineering design trade space to be explored in depth to determine what are the most demanding requirements and where there are opportunities for margin against requirements. Our joint NASA GSFC/JPL/MSFC/STScI study team has used community-provided science goals to derive mission needs, requirements, and candidate mission architectures for a future large-aperture, non-cryogenic UVOIR space observatory. The ATLAST observatory is designed to operate at a Sun-Earth L2 orbit, which provides a stable thermal environment and excellent field of regard. Our reference designs have emphasized a serviceable 36-segment 9.2 m aperture telescope that stows within a five-meter diameter launch vehicle fairing. As part of our cost-management effort, this particular reference mission builds upon the engineering design for JWST. Moreover, it is scalable to a variety of launch vehicle fairings. Performance needs developed under the study are traceable to a

variety of additional reference designs, including options for a monolithic primary mirror.

**Author(s):** Harley A. Thronson<sup>1</sup>, Matthew R Bolcar<sup>1</sup>, Mark Clampin<sup>1</sup>, Julie A. Crooke<sup>1</sup>, David Redding<sup>2</sup>, Norman Rioux<sup>1</sup>, H. Philip Stahl<sup>3</sup>

**Institution(s):** 1. NASA GSFC, 2. NASA JPL, 3. NASA MSFC

#### **147.24 – Life Finder Detectors; Detector Needs and Status for Spectroscopic Biosignature Characterization**

The search for life on other worlds looms large in NASA's future. Outside our solar system, direct spectroscopic biosignature characterization using very large UV-Optical-IR telescopes with coronagraphs or starshades is a core technique to both AURA's High Definition Space Telescope (HDST) concept and NASA's 30-year strategic plan. These giant space observatories require technological advancements in several areas, one of which is detectors. In this presentation, we review the detector requirements for spectroscopic biosignature characterization and discuss the status of some existing and proposed detector technologies for meeting them.

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**Institution(s):** 1. NASA's GSFC, 2. Space Telescope Science Institute

#### **147.25 – Modular Orbital Demonstration of an Evolvable Space Telescope (MODEST)**

The "Search for Life" via imaging of exoplanets is a mission that requires extremely stable telescopes with apertures in the 10 m to 20 m range. The High Definition Space Telescope (HDST) envisioned for this mission would have an aperture >10 m, which is a larger payload than what can be delivered to space using a single launch vehicle. Building and assembling the mirror segments enabling large telescopes will likely require multiple launches and assembly in space. Space-based telescopes with large apertures will require major changes to system architectures.

The Optical Telescope Assembly (OTA) for HDST is a primary mission cost driver. Enabling and affordable solutions for this next generation of large aperture space-based telescope are needed. This paper reports on the concept for the Modular Orbital Demonstration of an Evolvable Space Telescope (MODEST), which demonstrates on-orbit robotic and/or astronaut assembly of a precision optical telescope in space. It will also facilitate demonstration of active correction of phase and mirror shape. MODEST is proposed to be delivered to the ISS using standard Express Logistics Carriers (ELCs) and can be mounted to one of a variety of ISS pallets. Post-assembly value includes space, ground, and environmental studies, and a testbed for new instruments. This demonstration program for next generation mirror technology provides significant risk reduction and demonstrates the technology in a six-mirror phased telescope. Other key features of the demonstration include the use of an active primary optical surface with wavefront feedback control that allows on-orbit optimization and demonstration of precise surface control to meet optical system wavefront and stability requirements.

MODEST will also be used to evaluate advances in lightweight mirror and metering structure materials such as SiC or Carbon Fiber Reinforced Polymer that have excellent mechanical and thermal properties, e.g. high stiffness, high modulus, high thermal conductivity, and low thermal expansion. It has been demonstrated that mirrors built from these materials can be rapidly replicated in a highly cost effective manner, making these materials excellent candidates for a low cost, high performance OTA.

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**Institution(s):** 1. Northrop Grumman Corporation

#### **147.26 – BurstCube: A CubeSat for Gravitational Wave Counterparts**

We present BurstCube, a novel CubeSat that will detect and localize Gamma-ray Bursts (GRBs). BurstCube will detect both long GRBs attributed to the collapse of massive stars, and short GRBs that are the result of a binary neutron star merger, which are also predicted to be the counterparts of gravitational wave sources soon to be detectable by advanced LIGO/Virgo, as well as other gamma-ray (10-1000 keV) transients. BurstCube contains 4 CsI scintillators coupled with arrays of compact low-power Silicon photomultipliers (SiPMs) on a 6U CubeSat incorporating in-house front-end electronics for large-area arrays of SiPMs, off-the-shelf spacecraft components and a straightforward design and implementation. BurstCube will potentially complement existing facilities such as Swift and Fermi in the short term, and provide a means for GRB detection, localization, and characterization in the interim time before the next generation future gamma-ray mission flies, as well as space-qualify SiPMs and test technologies that may be used on the next generation gamma-ray probe or flagship. The ultimate configuration of BurstCube is to have a set of ~10 BurstCubes to provide all-sky coverage to GRBs for substantially lower cost than a full-scale mission.

**Author(s):** Judith L. Racusin<sup>1</sup>, Jeremy S Perkins<sup>1</sup>, Michael Stephen Briggs<sup>2</sup>, Georgia De Nolfo<sup>1</sup>, John Krizmanic<sup>1</sup>, Valerie Connaughton<sup>3</sup>, Julie E. McEnery<sup>1</sup>

**Institution(s):** 1. NASA/GSFC, 2. University of Alabama Huntsville, 3. USRA

#### **147.27 – The Astro-H In-Flight Calibration Plan**

We present the in-flight calibration plan for the scientific payload onboard the Japanese-U.S. X-ray satellite Astro-H (Takahashi et al., 2013), planned for launch in February 2016. Target viability has been assessed using simulations in order to determine the optimal exposure time necessary to achieve the uncertainty requirement and goal on each parameter of interest, with an emphasis on finding sources that can be used for multiple instruments and to address multiple calibration goals. The majority of the calibration observations will be performed within the first three months of the mission.

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**Institution(s):** 1. Smithsonian Astrophysical Observatory

**Contributing team(s):** The Astro-H Team

#### **147.28 – Arcus: An X-ray Grating Spectroscopy Mission**

We present the design and scientific motivation for Arcus, an X-ray grating spectrometer mission to be proposed to NASA as a MIDE-X in 2016. This mission will observe structure formation at and beyond the edges of clusters and galaxies, feedback from supermassive black holes, the structure of the interstellar medium and the formation and evolution of stars. Key mission design parameters are R~3000 and >700 cm<sup>2</sup> of effective area at the crucial O VII and O VIII lines, with the full bandpass going from ~10-50Å. Arcus will use the silicon pore optics proposed for ESA's Athena mission, paired with off-plane gratings being developed at the University of Iowa and combined with MIT/Lincoln Labs CCDs.

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**Institution(s):** 1. Smithsonian Astrophysical Observatory

**Contributing team(s):** The Arcus Collaboration

#### **147.29 – Data Collection and Recording on the Wisconsin/GSFC X-ray Quantum Calorimeter**

The Wisconsin/GSFC X-ray Quantum Calorimeter (XQC) is an astronomical X-ray sounding rocket payload which uses a micro-calorimeter array to detect low (less than 1keV) X-rays. Three different devices were evaluated to upgrade XQC's data collection and recording system. The system takes incoming data from XQC's pixel sensors and stores it to a memory card. The upgrade is a much smaller board and much more compact storage device. The Terasic DEO-Nano, Terasic DEO-Nano SoC, and the BeagleBone Black were tested to determine which would suit the needs of XQC best. The device needed to take incoming data, store it to an SD card, and be able to output it through a USB connection. The Terasic DEO-Nano is

a simple FPGA, but needed some peripheral additions for an SD card slot and USB readout. The Terasic DEO-Nano SoC was a powerful FPGA and hard processor running Linux combined. It was able to do what was needed, but pulled too much power in the process. The BeagleBone Black had a microcontroller and also ran Linux. This last device ended up being the best choice, as it did not require too much power and had a very easy system already in place for USB readout. The only difficulty to deal with was programming the microcontroller in assembly language. This device is necessary due to the telemetry on XQC not being able to send all of the data down during the flight. It records valuable data about low energy X-rays so that the X-ray Astrophysics Groups at the University of Wisconsin-Madison and Goddard Space Flight Center can analyze and resolve the spectrum of the soft X-ray background.

Later, using the digital logic on a Terasic DEO-Nano FPGA, a data simulator for the BeagleBone Black data collection and recording device was created. Programmed with Quartus II, the simulator uses basic digital logic components to fabricate trackable data signals and related timing signals to send to the data management device, as well as other timing signals that are asynchronous to the rest of the circuit, a failsafe enable for outputs, and several user feedback components

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**Institution(s):** 1. University of Miami

**Contributing team(s):** X-ray Astrophysics Group at the University of Wisconsin-Madison

### 147.30 – Here There Be Dragons: Characterization of ACS/WFC Scattered Light Anomalies

We present a study characterizing scattered light anomalies that occur around the edge of the Advanced Camera for Surveys (ACS) Wide Field Channel (WFC). The study is based on all full-frame WFC raw images ever produced by ACS. Using the 2MASS catalog, we identified stars outside of the ACS/WFC field of view which cause two particular scattered light artifacts known as "dragon's breath" and edge glow. We determined which regions around the chip the stars must fall in to cause dragons breath to occur and characterized the amount of stellar flux received during an integration (expressed in instrumental magnitudes) needed to cause scattering. We have completed this study for the ACS F606W and F814W filters. We provide a map of risky areas around the ACS chips and an upper limit of magnitudes to be concerned about. We will use these results to develop interactive tools that will aid the astronomical community in the proposal process for ACS/WFC.

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**Institution(s):** 1. Space Telescope Science Institute

**Contributing team(s):** ACS

### 147.31 – Focal plane actuation for the development of a high resolution suborbital telescope

We present a hexapod stabilized focal plane as the key instrument for a proposed suborbital balloon mission. Balloon gondolas currently achieve 1-2 arcsecond pointing error, but cannot correct for unavoidable jitter movements (~50µm at 20hz) caused by wind rushing over balloon surfaces, thermal variations, cryocoolers, and reaction wheels. The jitter causes image blur during exposures and is the limiting resolution of the system. To solve this, the hexapod system actuates the focal plane to counteract the jitter through real-time closed loop feedback from star-trackers. Removal of this final jitter term decreases pointing error by an order of magnitude and allows for true diffraction-limited observation. This boost in resolution will allow for Hubble-quality imaging for a fraction of the cost. Tip-tilt pointing systems have been used for these purposes in the past, but require additional optics and introduce multiple reflections. The hexapod system, rather, is compact and can be plugged into the focal point of nearly any configuration. The design also thermally isolates the hexapod from the cryogenic focal plane enabling the use of well-established non-cryogenic hexapod technology. High-resolution time domain multispectral imaging of the gas giant outer planets, especially in the UV range, is of particular interest to the planetary community, and a suborbital telescope with the hexapod stabilization in place would provide a wealth of new data. On an Antarctic ~100-day Long-Duration-Balloon mission the

continued high-resolution imaging of gas giant storm systems would provide cloud formation and evolution data second to only a Flagship orbiter.

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**Institution(s):** 1. Arizona State University, 2. NASA Goddard

### 147.32 – ACCESS Sub-system Performance

ACCESS: Absolute Color Calibration Experiment for Standard Stars is a series of rocket-borne sub-orbital missions and ground-based experiments designed to leverage significant technological advances in detectors, instruments, and the precision of the fundamental laboratory standards used to calibrate these instruments to enable improvements in the precision of the astrophysical flux scale through the transfer of laboratory absolute detector standards from the National Institute of Standards and Technology (NIST) to a network of stellar standards with a calibration accuracy of 1% and a spectral resolving power of 500 across the 0.35 to 1.7 micron bandpass.

A cross wavelength calibration of the astrophysical flux scale to this level of precision over this broad a bandpass is relevant for the data used to probe fundamental astrophysical problems such as the SNeIa photometry based measurements used to constrain dark energy theories.

We will describe the strategy for achieving this level of precision, the payload and calibration configuration, present sub-system test data, and the status and preliminary performance of the integration and test of the spectrograph and telescope. NASA APRA sounding rocket grant NNX14AH48G supports this work.

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### 147.33 – Observer's Interface for Solar System Target Specification

When observing an asteroid or comet with HST, it has been necessary for the observer to manually enter the target's orbital elements into the Astronomer's Proposal Tool (APT). This allowed possible copy/paste transcription errors from the observer's source of orbital elements data. In order to address this issue, APT has now been improved with the capability to identify targets in and then download orbital elements from JPL Horizons. The observer will first use a target name resolver to choose the intended target from the Horizons database, and then download the orbital elements from Horizons directly into APT. A manual entry option is also still retained if the observer does not wish to use elements from Horizons. This new capability is available for HST observing, and it will also be supported for JWST observing. The poster shows examples of this new interface.

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**Institution(s):** 1. Space Telescope Science Institute

## 148 – Astronomy and Society Poster Session

### 148.01 – Child Care Gifts to Bolster Astronomy

Caring for children should not derail potentially excellent future astronomers. It is therefore suggested that a mechanism be created for established astronomers to voluntarily will 10 percent of their estate to a fund that helps aspiring astronomers reduce child care costs. Statistics indicate that many scientists delay child rearing until

they have secure jobs. This delay appears to be based on the early relative cost of child care and the perception that time spent raising children negatively impacts job performance and future employability. Having even a portion of child care expenses covered may increase the efficiency of early-career education and productivity of early-career scientific research. It is hoped that some established astronomers may be inspired to contribute by remembering their own lives as aspiring astronomers, while also wishing to add to their legacy. Only an expression of interest is requested here, both from established astronomers who might be interested in taking such a donation pledge, and from aspiring astronomers who feel their careers would be helped by child care assistance.

**Author(s): Robert J. Nemiroff<sup>2</sup>, Alice Allen<sup>1</sup>**

**Institution(s):** 1. *Astrophysics Source Code Library*, 2. *Michigan Technological Univ.*

## 148.02 – Astronomy Allies

Imagine you are a grad student, at your first conference, and a prominent senior scientist shows interest in your work, and he makes things get way too personal? What would you do? Would you report it? Or would you decide, after a few other instances of harassment, that maybe you shouldn't pursue astronomy? Harassment is under-reported, the policies can be difficult to understand or hard to find, and it can be very intimidating as a young scientist to report it to the proper individuals. The Astronomy Allies Program is designed to help you with these sorts of problems. We are a group of volunteers that will help by doing the following: provide safe walks home during the conference, someone to talk to confidentially, as an intervener, as a resource to report harassment. The Allies are a diverse group of scientists committed to acting as mentors, advocates, and liaisons. The Winter 2015 AAS meeting was the first meeting that had Astronomy Allies, and Astronomy Allies provided a website for information, as well as a twitter, email, and phone number for anyone who needs our help or would like more information. We posted about the Astronomy Allies on the Women In Astronomy blog, and this program resonates with many people: either they want to help, or they have experienced harassment in the past and don't want to see it in the future. Harassment may not happen to most conference participants, but it's wrong, it's against the AAS anti-harassment policy ( <http://aas.org/policies/anti-harassment-policy> ), it can be very damaging, and if it happens to even one person, that is unacceptable. We intend to improve the culture at conferences to make it so that harassers feel they can't get away with their unprofessional behavior.

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**Institution(s):** 1. *The Carnegie Observatories*, 2. *University of Hawaii*

## 202 – Galaxy Evolution in the Cluster Environment

### 202.01 – Disentangling the ICL with the CHEFs in the Pandora galaxy cluster

The intracluster light (ICL) is important for understanding the metal enrichment of the intracluster gas and constraining cosmological parameters independently of the other methods. However, its measurement it is not trivial due to the necessity of disentangling the light of stars locked up in galaxies from the proper ICL. Currently, there is no standard method to efficiently measure the ICL (Rudick et al. 2011, ApJ, 732, 48), and different approaches relying on the binding energy of the cluster galaxies, the density of the material, or the surface brightness distribution, have been tried. Moreover, a suitable way to disentangle the limits of the brightest cluster galaxy (BCG) and the ICL still has not been developed. The CHEFs (from Chebyshev-Fourier bases, Jiménez-Teja & Benítez 2012, ApJ, 745, 150) are a mathematical tool especially designed to model the two-dimensional light distribution of galaxies. We use the CHEFs and tools from differential geometry to infer the light contribution of the ICL to the total brightness, without imposing any artificial thresholds and avoiding the ambiguity introduced by free parameters

that are usually set in these studies (Rudick et al. 2011). We use the extremely deep optical images from Abell 2744, the Pandora cluster, a multi-cluster merger, observed by the Hubble Frontier Fields project to show the efficiency of this new method. The CHEFs can accurately fit and remove all the galaxies close to the cluster center, including the BCG. The limits of the BCG are marked out by determining the points where the surface curvature changes, thus disentangling the ICL from the BCG light in a completely natural way. Once we have the residual image just containing ICL and background, we extrapolate the value of this latter from images of individual pointings close to the main Pandora field. We finally estimate the ICL to be ~24% of the total light, which is very consistent with the predictions from numerical simulations (Montes & Trujillo 2014, ApJ, 794, 137). We emphasize we obtain this result without relying on any assumption on neither the morphology nor the surface distribution of the ICL.

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**Institution(s):** 1. *National Observatory*, 2. *University of Michigan/Eureka Scientific*

### 202.02 – Investigating star formation properties of galaxies in massive clusters with Herschel and ALMA

I will present results from an investigation of star formation properties of galaxies residing in two massive  $z \sim 1$  clusters (including the 'El Gordo' merger) that were initially selected via their Sunyaev-Zeldovich decrements by the Atacama Cosmology Telescope (ACT) southern survey. This study uses new Herschel Space Observatory and Atacama Large Millimeter/submillimeter Array (ALMA) Cycle 2 observations, which provide information about the dust and cold gas content of galaxies in our targeted clusters. We have detected CO (4-3) and [CI] in individual star-forming cluster galaxies, and also measured stacked continuum and spectral line fluxes at long (e.g., far-infrared, submillimeter, and radio) wavelengths. We use these results to explore the relations between star formation and local environment and cluster dynamical state.

This work has been supported by (i) an award issued by JPL/Caltech in association with Herschel, which is a European Space Agency Cornerstone Mission with significant participation by NASA, and (ii) the National Science Foundation through award GSSP SOSPA2-018 from the National Radio Astronomy Observatory, which is operated under cooperative agreement by Associated Universities, Inc.

**Author(s): John F. Wu<sup>7</sup>, Andrew J. Baker<sup>7</sup>, Paula Aguirre<sup>6</sup>, D. Barkats<sup>2</sup>, Mark Halpern<sup>8</sup>, Matt Hilton<sup>10</sup>, John Patrick Hughes<sup>7</sup>, Leopoldo Infante<sup>6</sup>, Robert Lindner<sup>1</sup>, Tobias Marriage<sup>3</sup>, Felipe Menanteau<sup>9</sup>, Cristobal Sifon<sup>4</sup>, Axel Weiss<sup>5</sup>**

**Institution(s):** 1. *Earthling Interactive*, 2. *European Southern Observatory*, 3. *Johns Hopkins University*, 4. *Leiden University*, 5. *Max Planck Institute for Radio Astronomy*, 6. *Pontificia Universidad Católica de Chile*, 7. *Rutgers University*, The State University of New Jersey, 8. *University of British Columbia*, 9. *University of Illinois, Urbana-Champaign*, 10. *University of Kwazulu-Natal*

**Contributing team(s):** ACT Collaboration

### 202.03 – Exploring the $z \sim 1$ Sky with the Massive and Distant Clusters of WISE Survey

The Massive and Distant Clusters of WISE Survey (MaDCoWS) is a comprehensive program to detect and characterize the most massive galaxy clusters in the Universe at  $z \sim 1$  over the full extragalactic sky. The survey employs color-selection of WISE sources coupled with a wavelet smoothing algorithm to identify overdensities at this epoch. I will present an overview of the survey and present the status of our search within the PanSTARRS footprint, which has yielded several thousand cluster candidates. MaDCoWS is efficiently isolating the cluster population at this epoch, and I will show recent results from targeted follow-up observations, including confirmation of a  $10^{15}$  solar mass cluster at  $z=1.19$ .

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**Institution(s):** 1. *Univ. of Florida*

**Contributing team(s):** MaDCoWS Team

## **202.04 – Massive and Distant Clusters of WISE Survey (MaDCoWS): Stellar Mass Fraction in IR-Selected Clusters at $z \sim 1$**

Galaxy clusters are the largest gravitationally bound objects in the universe. In addition to being interesting objects to study in their own right, they are excellent laboratories in which to study galaxy evolution. Furthermore, the properties and abundance of galaxy clusters provide important tests for cosmology. Currently the South Pole Telescope (SPT) provides the largest catalog of high-redshift clusters selected through the Sunyaev-Zel'dovich (SZ) effect, which measures the pressure of the intracluster medium (ICM). The complementary Massive and Distant Clusters of WISE Survey (MaDCoWS) selects galaxy clusters on their stellar mass by identifying overdensities in the Wide Field Infrared Explorer (WISE) All-Sky Data release, which provides a selection independent to that of the SPT. We have followed up the most promising cluster candidates identified from MaDCoWS with Spitzer and the Combined Array for Research in Millimeter-wave Astronomy (CARMA) to get rest-frame H-band luminosities and radio observations of the SZ effect, respectively. Twelve clusters were robustly detected with CARMA with redshifts in the range  $0.8 < z < 1.3$  and total masses ranging from  $2 \times 10^{14}$  solar masses. Combining CARMA masses measured from the SZ observations with Spitzer/IRAC stellar masses, we determine the stellar mass fraction of the MaDCoWS sample of IR-selected clusters and compare with similar ICM-selected clusters from the SPT.

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**Institution(s):** 1. University of Missouri -- Kansas City

## **202.05 – Crowded Field Photometry in the CLASH Clusters: Measuring the Red Sequence of Cluster Galaxies with Robust Photometry**

The Cluster Lensing And Supernova survey with Hubble (CLASH) is an HST multi-cycle treasury program investigating 25 massive clusters of galaxies with X-ray gas  $T_x > 5$  keV, spanning  $\sim 5$  to  $\sim 30 \times 10^{14}$  solar masses, and a redshift range of  $0.15 < z < 0.9$ . With 500 orbits of HST time and 16-filter, ultraviolet to infrared photometry of each cluster, this survey offers an unprecedented dataset for cluster galaxy photometry across a span of age and mass, but obtaining robust photometry for the cluster members has been hampered by the crowded field. We have developed a new technique to detect and define objects despite the presence of overlapping light profiles and to measure photometry of galaxies overlapping the extended haloes of massive galaxies. Utilizing spectral energy distribution fitting, we infer the properties of the detected galaxies, including their abundances and the time since their first star formation. Here we will discuss our technique and results, including the role metallicity and age play in shaping the red sequence of cluster galaxies.

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**Contributing team(s):** CLASH Team

## **202.06 – The Phase Space of $z=1.2$ Clusters: Probing Dust Temperature and Star Formation Rate as a Function of Environment and Accretion History**

Understanding the influence of environment is a fundamental goal in studies of galaxy formation and evolution, and galaxy clusters offer ideal laboratories with which to examine environmental effects on their constituent members. Clusters continually evolve and build up mass through the accumulation of galaxies and groups, resulting in distinct galaxy populations based on their accretion history. In Noble et al. 2013, we presented a novel definition for environment using the phase space of line-of-sight velocity and clustercentric radius, which probes the time-averaged density to which a galaxy has been exposed and traces out accretion histories. Using this dynamical definition of environment reveals a decline in specific star formation towards the cluster core in the earliest accreted galaxies, and was further shown to isolate post-starburst galaxies within clusters (Muzzin et al. 2014). We have now extended this work to higher-redshift clusters at  $z=1.2$

using deep Herschel-PACS and -SPIRE data. With a sample of 120 spectroscopically-confirmed cluster members, we investigate various galaxy properties as a function of phase-space environment. Specifically, we use 5-band Herschel photometry to estimate the dust temperature and star formation rate for dynamically distinct galaxy populations, namely recent infalls and those that were accreted into the cluster at an earlier epoch (Noble et al. submitted). These properties are then compared to a field sample of star-forming galaxies at  $1.1 < z < 1.2$  to shed light on cluster-specific processes in galaxy evolution. In this talk I will discuss the various implications of a phase-space definition for environment, and present our most recent results, focusing on how this accretion-based definition aids our understanding of quenching mechanisms within  $z=1.2$  galaxies.

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**Institution(s):** 1. University of Toronto  
**Contributing team(s):** the SpARCS Collaboration

## **202.07 – ALMA Reveals a Galaxy-Scale Fountain of Cold Molecular Gas Pumped by a Black Hole**

A new ALMA observation of the cool core brightest cluster galaxy in Abell 2597 reveals that a supermassive black hole can act much like a mechanical pump in a water fountain, driving a convective flow of molecular gas that drains into the black hole accretion reservoir, only to be pushed outward again in a jet-driven outflow that then rains back toward the galaxy center from which it came. The ALMA data reveal "shadows" cast by giant molecular clouds falling on ballistic trajectories towards the black hole in the innermost 500 parsecs of the galaxy, manifesting as deep redshifted continuum absorption features. The black hole accretion reservoir, fueled by these infalling cold clouds, powers an AGN that drives a jet-driven molecular outflow in the form of a 10 kpc-scale, billion solar mass expanding molecular bubble or plume. The molecular shell is permeated with young stars, perhaps triggered in situ by the jet. Buoyant X-ray cavities excavated by the propagating radio source may further uplift the molecular filaments, which are observed to fall inward toward the center of the galaxy from which they came, presumably keeping the fountain long-lived. The results show that cold molecular gas can couple to black hole growth via both feedback and feeding, in alignment with "cold chaotic accretion" models for the regulation of star formation in galaxies.

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**Institution(s):** 1. Yale University

## **202.08 – A very Deep Chandra Observation of NGC 1404: the Best Constraints on the Transport Processes in the Intracluster Medium**

The intracluster medium (ICM), as a magnetized and highly ionized fluid, provides an ideal laboratory to study plasma physics. We present results from the Chandra X-ray observation of NGC 1404, a bright elliptical galaxy falling through the ICM of the Fornax Cluster. The hot, gaseous corona surrounding NGC 1404 is characterized by a sharp upstream edge, 8 kpc from the galaxy center, and a downstream gaseous tail, extending 15 kpc behind the galaxy center. We resolve the scales of contact discontinuities down to an unprecedented level due to the combination of the proximity of NGC 1404, the superb spatial resolution of Chandra, and a very deep (670 ksec) exposure. In particular, we measure a temperature discontinuity over a spatial scale of  $\sim 300$  pc ( $1.5''$ ) across the upstream front. We also observe mixing of the downstream tail with the surrounding ICM. We will discuss the implications for ICM transport processes and the interplay between the dynamic motion of the ICM flows and the magnetic fields. Our simulation, tailored to the specific scenario, will provide further insight into the details of the merger process.

**Author(s):** Yuanyuan Su<sup>1</sup>, Ralph P. Kraft<sup>1</sup>, Elke Roediger<sup>3</sup>, Paul Nulsen<sup>1</sup>, William R. Forman<sup>1</sup>, Eugene Churazov<sup>2</sup>, Christine Jones<sup>1</sup>, Marie E. Machacek<sup>1</sup>, Scott W. Randall<sup>1</sup>  
**Institution(s):** 1. Harvard-Smithsonian Center for Astrophysics, 2. Max Planck Institute for Astrophysics, 3. University of Hull

## **202.09 – Evidence for particle re-acceleration in the**

## binary merging galaxy cluster A3411-3412 ?

Radio relics are large extended polarized sources located in the outskirts of galaxy clusters. There is substantial evidence that these radio relics trace particles accelerated at cluster merger shocks. However, cluster merger shocks typically have a low Mach number and it is therefore still unclear how these shocks are able to accelerate particles so efficiently, as inferred by the luminosity of these radio relics. A proposed solution to resolve this apparent discrepancy is that cluster shocks re-accelerate a population of fossil relativistic electrons. A likely source for this fossil plasma could be the disturbed tailed radio galaxies that are commonly found in merging galaxy clusters.

We present new GMRT and JVLA radio observations of the binary merging galaxy cluster A3411-3412. Combining these observations with deep Chandra data, we find evidence for a surface brightness discontinuity that likely traces a low-Mach number shock. At this location, we observe the presence of a radio relic. Most interestingly, this relic seems to be connected to a nearby radio galaxy. This suggests that electrons from the lobes of this AGN are re-accelerated by a low-Mach number merger shock. This result highlights the importance of understanding the interaction between radio galaxies and cluster shocks in the dilute outskirts of galaxy clusters.

**Author(s):** Reinout J. Van Weeren<sup>4</sup>, Felipe Andrade-Santos<sup>4</sup>, William Dawson<sup>2</sup>, Dharam Vir Lal<sup>3</sup>, Georgiana A Ogrea<sup>4</sup>, Nathan Golovich<sup>5</sup>, Marcus Brüggen<sup>1</sup>, Christine Jones<sup>4</sup>, William R. Forman<sup>4</sup>  
**Institution(s):** 1. *Hamburger Sternwarte*, 2. *Lawrence Livermore National Lab*, 3. *NCRA*, 4. *Smithsonian Astrophysical Observatory*, 5. *UC Davis*

## 203 – Black Holes I: Models and Simulations

### 203.01 – General Relativistic Mini-Disk Dynamics during Black Hole Binary Inspiral

During galaxy mergers, as a result of dynamical friction (stars, gas, etc.) and gravitational slingshot, the supermassive black holes (SMBHs) from each galaxy will become gravitationally bound and eventually merge due to gravitational radiation. It is expected that gas will form a circumbinary accretion disk around the SMBH binary that will persistently feed individual “mini-disks” via dense streams out to their tidal truncation radii. However, these radii are not well known during the late stages of inspiral and merger. We present general relativistic hydrodynamic simulations aimed at resolving this uncertainty and producing templates of unique electromagnetic (EM) signatures for such systems to assist in direct observational detection with currently available observatories. We place particular emphasis on the dynamics of the individual “mini-disks” where violent shocks via disk-disk and disk-stream interactions will likely produce intense EM emission.

**Author(s):** Dennis Bowen<sup>1</sup>  
**Institution(s):** 1. *RIT*

### 203.02D – Thin Disk Accretion in the Magnetically-Arrested State

Shakura-Sunyaev thin disk theory is fundamental to black hole astrophysics. Though applications of the theory are wide-spread and powerful tools for explaining observations, such as Soltan's argument using quasar power, broadened iron line measurements, continuum fitting, and recently reverberation mapping, a significant large-scale magnetic field causes substantial deviations from standard thin disk behavior. We have used fully 3D general relativistic MHD simulations with cooling to explore the thin ( $H/R \sim 0.1$ ) magnetically arrested disk (MAD) state and quantify these deviations. This work demonstrates that accumulation of large-scale magnetic flux into the MAD state is possible, and then extends prior numerical studies of thicker disks, allowing us to measure how jet power scales with the disk state, providing a natural explanation of phenomena like jet quenching in the high-soft state of X-ray binaries. We have also simulated thin MAD disks with a misaligned black hole spin axis in order to understand further deviations from thin disk theory that may significantly affect observations.

**Author(s):** Mark J. Avara<sup>1</sup>, Jonathan McKinney<sup>1</sup>, Christopher S. Reynolds<sup>1</sup>

**Institution(s):** 1. *University of Maryland*

### 203.03D – Predicting Observational Signatures of Gas Disks Around Massive Black Hole Binaries

I will discuss theoretical work on modeling the interaction of a binary and a gas disk. Such systems are manifested astrophysically during the formation of planetary systems and in the nuclei of galaxies which harbor massive black hole binaries (MBHBs). I will demonstrate the existence of transitions in circumbinary disk solutions which delineate values of the binary mass ratio for which distinct modes of variable accretion occur. Finally, I will present Implications for planetary and MBHB systems along with recent applications of such circumbinary disk models to observations of MBHB candidates.

**Author(s):** Daniel J. D'Orazio<sup>1</sup>, Zoltan Haiman<sup>1</sup>, Andrew MacFadyen<sup>2</sup>, Paul Duffell<sup>3</sup>, Brian Farris<sup>1</sup>, David Schiminovich<sup>1</sup>  
**Institution(s):** 1. *Columbia University*, 2. *New York University*, 3. *University of California Berkeley*

### 203.04D – Radiative Transfer Models of Tidal Disruption Events: What Sets their Emission Line Strengths and Total Optical Flux?

Given the recent influx of observational data and theoretical investigation into the nature of the tidal disruption of stars by supermassive black holes (TDEs), a full radiative transfer calculation applicable to an optically thick, electron scattering-dominated reprocessing region can provide valuable insight. Such a calculation can help address puzzles such as the lack of hydrogen emission lines in the optical spectra some TDEs, the origin of the optical and UV flux, and the simultaneous observation of x-rays along with the optical emission. In this talk I will discuss such a calculation performed with my collaborators as part of my dissertation. We track the reprocessing of accretion luminosity from a supermassive black hole as the light travels through an extended, spherical envelope composed of hydrogen, helium, and oxygen from the disrupted star. The steady-state radiative transfer equation is coupled to a solver for the atomic level populations and ionization states that does not assume local thermodynamic equilibrium. Our calculations show how the hydrogen optical emission lines can become more effectively optically thick than their helium counterparts, causing them to remain hidden even in the disruption of a hydrogen-rich star. More generally, variations in the structure of the reprocessing material can give rise to a variety of hydrogen-to-helium line ratios, as has been seen in recent observations. We also determine the amount of material necessary to transfer enough radiative energy from x-ray to optical wavelengths to match what is observed, and we demonstrate how the partial absorption of ionizing radiation can give rise to events simultaneously observed in x-rays and in the optical.

**Author(s):** Nathaniel Roth<sup>2</sup>, Daniel Kasen<sup>2</sup>, James Guillochon<sup>1</sup>, Enrico Ramirez-Ruiz<sup>3</sup>

**Institution(s):** 1. *Harvard-Smithsonian Center for Astrophysics*, 2. *UC Berkeley*, 3. *UC Santa Cruz*

### 203.05D – The Debris Streams from Tidal Disruption Events

When a star comes within a critical distance of a supermassive black hole, the tidal force exerted by the hole overcomes the stellar self-gravity. The star is subsequently torn apart, creating a stream of tidally-shredded debris that initially recedes from the hole, eventually returns to pericenter, forms an accretion disk and generates a highly luminous event that can sometimes be accompanied by the production of relativistic jets. This entire process is known as a tidal disruption event (TDE), and dozens of these events have already been observed. I will discuss my most recent work that has analyzed the tidal disruption process, and in particular I will focus on the results of numerical and analytical investigations that show that the streams of debris produced during TDEs can be gravitationally unstable. Specifically, I will describe how compressive

motions augment the importance of self-gravity not long after the star is disrupted, resulting in the fragmentation of the debris stream into small-scale clumps. These findings will be discussed in the context of the observational signatures of tidal disruption events, and I will also relate these results to my past investigations concerning accretion disk formation and jet launching during TDEs.

**Author(s):** Eric Coughlin<sup>1</sup>

**Institution(s):** 1. JILA, University of Colorado and National Institute of Standards and Technology

## 204 – AGN, QSO, Blazars: Searches and Surveys

### 204.01 – Searching for Low-Mass AGN to $z < 1$

The strong correlation between the mass of supermassive black holes (SMBH) and that of the galaxy bulges in which they reside suggests a causal connection between AGN and their host galaxies. Indeed, understanding the growth of SMBHs is crucial for building a complete picture of galaxy evolution. However, there is so far very little observational information on how the smallest black holes, predicted to reside in the smallest galaxies, grew to become the SMBHs we see today in the local Universe. Using Hubble and the NEWFIRM Medium Band Survey in the AEGIS field, we have selected  $\sim 600$  galaxies with  $M_{\text{star}} \leq 10^9 M_{\odot}$  and analyzed their X-ray properties using deep 200–800 keV Chandra data to robustly identify those galaxies which contain actively growing SMBHs. We have identified 12 seemingly low-mass AGN with  $M_{\text{BH}} < 10^5 M_{\odot}$  and use these data to place new constraints on the AGN fraction in dwarf galaxies. These new limits are well-matched to large-scale simulations of black hole evolution and with other theoretical predictions of AGN fractions in dwarf galaxies.

**Author(s):** Kristina Pardo<sup>1</sup>, Andy D. Goulding<sup>1</sup>, Jenny E. Greene<sup>1</sup>, Rachel S. Somerville<sup>2</sup>

**Institution(s):** 1. Princeton University, 2. Rutgers University

### 204.02 – Interim results from the ongoing hunt for supermassive black hole binaries

Supermassive black hole binaries seem to be an inevitable product of the prevailing galaxy evolution scenarios in which most massive galaxies play host to a central black hole and undergo a history of mergers and accretion over the course of cosmic time. The early stages of this process have been observed in the form of interacting galaxy pairs as well as dual active galactic nuclei with kilo-parsec separations, but detections of the close, bound binaries that are expected to follow have proven elusive. With this motivation, we have been conducting a systematic observational search for sub-parsec separation supermassive black hole binaries. Specifically, we test the hypothesis that the secondary black hole in the system is active and the resulting broad emission lines are doppler shifted due to orbital motion in the binary (analogous to a single-line spectroscopic binary star). Our sample includes 88 binary candidates selected from  $z < 0.7$  Sloan Digital Sky Survey quasars based on substantial offsets ( $> 1000$  km/s) of their broad H $\beta$  emission lines relative to their systemic redshifts. I will present the latest results from the spectroscopic monitoring campaign that we are conducting to constrain the nature of the binary candidates. These include the radial velocity curves, which now use observations made through 2015, and the constraints that can be placed on the physical properties of the binary based on the radial velocity curves and observed flux variability of the binaries.

**Author(s):** Jessie C. Runnoe<sup>5</sup>, Gavin Mathes<sup>4</sup>, Alison Pennell<sup>5</sup>, Stephanie Meghan Brown<sup>5</sup>, Michael Eracleous<sup>5</sup>, Todd A. Boroson<sup>3</sup>, Tamara Bogdanovic<sup>2</sup>, Steinn Sigurdsson<sup>5</sup>, Jules P. Halpern<sup>1</sup>, Jia Liu<sup>1</sup>

**Institution(s):** 1. Columbia University, 2. Georgia Tech University, 3. LGOCT, 4. New Mexico State University, 5. The Pennsylvania State University

### 204.03 – The Chandra COSMOS Legacy Survey

In this talk, I will present the 4016 sources sample of the Chandra

COSMOS Legacy survey, a 4.6 Ms Chandra survey on the COSMOS field. We have multiwavelength information for 97% of the sources, including photometric and spectroscopic redshifts, and we can therefore study, in a statistical and complete way, the physical properties for all the sample including host galaxies properties. I will focus on the  $z > 3$  sample, the largest X-ray selected sample in this range of redshift on a contiguous field, presenting the space density and the clustering analysis using this sample, with a particular focus on how our results can put constraints on the predictions of both phenomenological and physical models of black hole and galaxy growth.

**Author(s):** Francesca M. Civano<sup>5</sup>, Stefano Marchesi<sup>1</sup>, Martin Elvis<sup>4</sup>, C. Megan Urry<sup>5</sup>, Andrea Comastri<sup>3</sup>, Hyewon Suh<sup>2</sup>

**Institution(s):** 1. Bologna University, 2. IfA, 3. INAF, 4. SAO, 5. Yale University

### 204.04 – Photometric redshifts of 5000 X-ray selected Stripe 82 sources

We present preliminary spectroscopic and photometric redshifts of 5000 X-ray-selected AGN sources from our Stripe 82X survey, which is designed to study rare high-redshift and/or high-luminosity AGN like the luminous quasars identified in the Sloan Digital Sky Survey but also including heavily reddened AGN not identified as such in SDSS.

The sample covers a total of 31.3 deg<sup>2</sup> in Stripe 82, a combination of 15.6 deg<sup>2</sup> XMM AO13 data, 10.6 deg<sup>2</sup> XMM AO10 and archival data, and 7.4 deg<sup>2</sup> archival Chandra data. About 80% of the newly discovered X-ray sources have an optical counterpart in the co-added SDSS data; of these, roughly half have spectroscopic redshifts. We derived estimates of the photometric redshifts for the rest, using multiwavelength photometry from GALEX, SDSS, UKIDSS, VISTA, 2MASS, Spitzer, and WISE.

The photometric redshifts will be used to determine the fraction of obscured black hole growth at high redshift and/or high luminosity, as well as to derive the evolving X-ray luminosity function and to measure AGN clustering in several redshift slices — information vital to understanding the co-evolution of galaxies and their central black holes.

**Author(s):** Tonima Tasnim Ananna<sup>3</sup>, Mara Salvato<sup>1</sup>, C. Megan Urry<sup>3</sup>, Stephanie M. LaMassa<sup>2</sup>

**Institution(s):** 1. Max Planck Institute for Extraterrestrial Physics, 2. Space Telescope Science Institute, 3. Yale University  
**Contributing team(s):** Stripe 82X Collaboration

### 204.05D – Exploring the Quasar Luminosity Function with Quasars Selected by both Color and Variability

Using a Bayesian selection algorithm, we determine the optimal combination of color and variability information to identify quasars in current and future multi-epoch optical surveys. The color analysis is based on SDSS photometry, and the variability parameters are calculated from power-law fits to the structure functions. Simultaneous color and variability classification improves classification over either color or variability selection alone, with particular improvement in the selection of quasars with colors similar to stars. This method identifies 22,867 new type 1 quasar candidates in SDSS Stripe 82, which can be combined with the WISE and SDSS photometric quasar candidate catalogs. The redshifts of the candidate quasars were estimated using all available bands, weighting each band by smoothing the PDF. We show how to correct the candidate quasar luminosity function (QLF) for the completeness fraction and systematic errors in redshifts. The corrected QLF is comparable to those determined by spectroscopic investigations, suggesting that LSST and other next-generation surveys will be able to accurately determine the QLF in the absence of spectra. Finally, the quasars are divided into high and low Eddington fractions, using  $\delta(g-i)$  and CIV blueshift as proxies. The candidate QLFs for the two populations are compared to look for changes as a function of redshift. This work was supported in part by NSF grant 1411773.

**Author(s):** Christina M. Peters<sup>1</sup>, Gordon T. Richards<sup>1</sup>

**Institution(s):** 1. Drexel University

### 204.06 – Star Formation of Type 2 AGN host galaxies

at 0

**We investigate the host galaxy properties of a large sample of ~2800 X-ray selected Type 2 AGN in the Chandra-COSMOS (C-COSMOS) Legacy Survey in order to understand the connection between the nuclear activity and the star formation in galaxies. Making use of the existing multi-wavelength photometric data, C-COSMOS Legacy survey provides a uniquely large sample to derive host galaxy properties over a wide range of redshift. We perform a multi-component SED fitting with nuclear hot dust torus, galaxy, and starburst components. Through detailed analysis of SEDs, we derive the stellar masses and the star formation rates of Type 2 AGN host galaxy as well as the nuclear and galaxy contribution at each frequency. We find that AGN, on average, have similar star formation rates to normal star-forming main sequence galaxies at low redshift. However, a large fraction of relatively low-mass galaxies hosting Type 2 AGNs lie above the main sequence at high redshift ( $z > 1.5$ ), indicating higher star formation rates compared to non-AGN star-forming galaxies.**

**Author(s):** Hyewon Suh<sup>2</sup>, Francesca M. Civano<sup>3</sup>, Martin Elvis<sup>1</sup>, Guenther Hasinger<sup>2</sup>, Stefano Marchesi<sup>3</sup>  
**Institution(s):** 1. *Harvard-Smithsonian Center for Astrophysics*, 2. *Institute for Astronomy, University of Hawaii*, 3. *Yale Center for Astronomy and Astrophysics*

#### 204.07 – Mapping the WISE sky in 3D

I present the clustering-based redshift estimation of obscured and unobscured AGN detected by the Wide-field Infrared Survey Explorer (WISE). The clustering redshift technique is a data-driven method proposed to estimate the redshift distributions from measurements of spatial correlations without any assumption on spectral energy distributions. Applying this technique to the obscured and unobscured AGN population estimates the growth and environment of these objects with unprecedented accuracy and better understand different AGN phases.

**Author(s):** Alexander Mendez<sup>1</sup>, Brice Ménard<sup>1</sup>, Mubdi Rahman<sup>1</sup>  
**Institution(s):** 1. *Johns Hopkins University*

#### 204.08 – Using $R-W1$ to Find Obscured Black Hole Growth

Obscured AGN constitute a significant fraction of cosmic black hole growth. X-ray surveys provide an efficient way to directly detect emission associated with black hole fueling, but obscured AGN can be harder to identify than their unobscured counterparts. We therefore explore the efficacy of  $m_T$  (optical) -  $m_{3.4\mu m}$  (mid-infrared) (i.e.,  $R-W1$ , where  $W1$  is the shortest wavelength WISE band) as a color diagnostic of to identify candidate obscured black holes missed in optical surveys, taking advantage of the all-sky coverage of WISE. We have used the 16.5 deg<sup>2</sup> release of the Stripe 82 X-ray survey to test this color, finding that obscured AGN beyond  $z=0.5$ , including those lacking any optical signatures of AGN accretion, have red colors ( $R-W1 > 4$ ). We expect our results to be helpful in informing best-effort practices for following-up obscured AGN candidates detected in current, and future, wide area X-ray surveys, providing a more comprehensive view of supermassive black hole growth by recovering AGN missed in optical surveys.

**Author(s):** Stephanie M. LaMassa<sup>4</sup>, Francesca M. Civano<sup>6</sup>, Marcella Brusa<sup>1</sup>, Daniel Stern<sup>2</sup>, Eilat Glikman<sup>3</sup>, Sarah Gallagher<sup>5</sup>, C. Megan Urry<sup>6</sup>  
**Institution(s):** 1. *INAF - Bologna*, 2. *JPL*, 3. *Middlebury College*, 4. *NASA-GSFC*, 5. *University of Western Ontario*, 6. *Yale University*

### 205 – Young Stellar Objects, Very Young Stars

#### 205.01 – 30 Doradus - Relating Young Stars Imaged by Spitzer and Hubble to the CO Molecular Gas Observed with ALMA

The majority of stars have masses less than 8 solar mass and form in clumps that are less than 1 pc in size. The sub-parsec scales in which star formation takes place makes it difficult to resolve the effects star formation and the surrounding dense gas have on each other. The Magellanic Clouds are more active in forming high mass stars as compared to the Milky Way. The SAGE and Heritage surveys combined with the Hubble Tarantula Treasury Project provide us the opportunity to study high-mass ( $>15$  solar masses) and low-mass ( $<1$  solar mass) star formation. ALMA observations cover a 60 pc x 30 pc region of CO gas slightly north of the R136 cluster in 30 Doradus. We find 16 young stellar objects and about a 100 pre-main-sequence stars within the ALMA footprint. We define young stellar objects to be very early stage stars that are about 10,000 years old and whose SEDs peak in the infrared, and we use pre-main-sequence stars to refer to slightly older stars that can be seen in the optical. I will use dendrograms to analyze both the high- and low-mass star properties with respect to the CO gas structure observed with ALMA. Preliminary results show that not all massive young stellar objects are associated with CO gas, higher mass clumps tend to form higher mass stars and are more likely to have multiple young stars, and lower mass clumps tend to not be gravitationally bound however the larger clouds are bound. Looking at the interplay between dense molecular gas and the newly forming stars in a stellar nursery will shed light on how these stars formed: monolithic collapse or competitive accretion.

**Author(s):** Omnarayani Nayak<sup>2</sup>, Margaret Meixner<sup>3</sup>, Remy Indebetouw<sup>4</sup>, Elena Sabbi<sup>3</sup>, Guido De Marchi<sup>1</sup>, Nino Panagia<sup>3</sup>  
**Institution(s):** 1. *European Space Agency*, 2. *Johns Hopkins University*, 3. *Space Telescope Science Institute*, 4. *The University of Virginia*

#### 205.02D – A Wide Angle Survey of Young Stellar Associations for Hot Jupiters and Pre-Main Sequence Binaries

The past two decades have seen a significant advancement in the detection, classification and understanding of exoplanets and binary star systems. The vast majority of these systems consist of objects on the main sequence or the giant branch, leading to a dearth of knowledge of properties at early times ( $<50$  Myr). Only a dozen binaries and 1 possible transiting Hot Jupiter are known among pre-main sequence objects, yet these are the systems that can provide the best constraints on stellar formation and planetary migration models. The deficiency in the number of well characterized systems is driven by the inherent and aperiodic variability found in pre-main sequence objects which can mask and mimic eclipse signals. Nevertheless a dramatic increase in the total number of systems at early times is required to alleviate the conflict between theory and observation. I have recently completed a photometric survey of 3 nearby ( $<150$  pc) and young ( $<50$  Myr) moving groups with a small aperture telescope. I have discovered over 300 likely pre-main sequence binaries and have ruled out 7 possible transiting Hot Jupiters using techniques developed by reducing crowded, defocused images from an analogous system. I will present the photometric detection and follow-up for these systems, the spectroscopic measurements of pre-main sequence binary candidates and my lower bound on the Hot Jupiter migration timescale.

**Author(s):** Ryan J. Oelkers<sup>2</sup>, Lucas M. Macri<sup>2</sup>, Jennifer L. Marshall<sup>2</sup>, Darren L. Depoy<sup>2</sup>, Diego Garcia Lambas<sup>1</sup>  
**Institution(s):** 1. *Observatorio Astronomico*, 2. *Texas AandM University*

#### 205.03 – Protostellar Multiplicity in Perseus Characterized by the VLA Nascent Disk and Multiplicity (VANDAM) Survey

The formation of multiple star systems is thought to begin early in the star formation process. However, there have not been sufficient numbers of young protostars observed with high enough resolution to determine when and where most multiple systems form. To significantly improve our knowledge of protostellar multiplicity, we have carried out the VLA Nascent Disk and Multiplicity (VANDAM) survey, a 264 hour VLA program at wavelengths of 8 mm, 1 cm, 4 cm, and 6 cm toward all known Perseus protostars ( $N \sim 80$ )

down to 15 AU (0.065") resolution. The unbiased nature of the survey has enabled us to conduct the most complete characterization of protostellar multiplicity to date, finding evidence for a bi-modal distribution of multiple protostar system separations. The bi-modal distribution may be evidence for multiple processes contributing to the formation of multiple systems. The inner peak at  $\sim 75$  AU could be produced from disk fragmentation, while the outer peak at  $\sim 3000$  AU could be produced by turbulent and/or rotational fragmentation. Moreover, three systems are found to reside within larger, disk-like structures suggesting that they may be the product of disk fragmentation via gravitational instability. The results of this survey demonstrate the power and utility of unbiased surveys toward young stars.

**Author(s):** John J. Tobin<sup>2</sup>, Leslie Looney<sup>7</sup>, Zhi-Yun Li<sup>8</sup>, Claire J. Chandler<sup>4</sup>, Michael Dunham<sup>1</sup>, Dominique Segura-Cox<sup>7</sup>, Sarah Sadavoy<sup>3</sup>, Carl Melis<sup>5</sup>, Robert J. Harris<sup>7</sup>, Kaitlin M. Kratter<sup>6</sup>, Laura M. Perez<sup>4</sup>

**Institution(s):** 1. Harvard-CfA, 2. Leiden Observatory, 3. Max Planck Institute for Astronomy, 4. NRAO, 5. UC San Diego, 6. University of Arizona, 7. University of Illinois, 8. University of Virginia

### 205.04D – Dynamical Masses Demonstrate the Discordant Model Ages for Upper Scorpius

We present the results of a long term orbit monitoring program, using sparse aperture masking observations taken with NIRC2 on the Keck-II telescope, of seven G to M-type members of the Upper Scorpius subgroup of the Sco-Cen OB association. We present astrometry and derived orbital elements of the binary systems we have monitored, and also determine the age, component masses, distance and reddening for each system using the orbital solutions and multi-band photometry, including Hubble Space Telescope photometry, and a Bayesian fitting procedure. We find that the models can be forced into agreement with any individual system by assuming an age, but that age is not consistent across the mass range of our sample. The G-type binary systems in our sample have model ages of  $\sim 11.5$  Myr, which is consistent with the latest age estimates for Upper Scorpius, while the M-type binary systems have significantly younger model ages of  $\sim 7$  Myr. Based on our fits to the data, this age discrepancy in the models corresponds to a luminosity under-prediction of 0.8-0.15 dex, or equivalently an effective temperature over-prediction of 100-300 K for M-type stars at a given pre-main-sequence age.

**Author(s):** Aaron C Rizzuto<sup>2</sup>, Michael Ireland<sup>1</sup>, Adam L. Kraus<sup>2</sup>, Trent J. Dupuy<sup>2</sup>

**Institution(s):** 1. Australian National University, 2. University of Texas at Austin

### 205.05D – Older and colder: The impact of starspots on stellar masses, ages, and lithium during the pre-main sequence

Starspots are ubiquitously found on young, active stars on the pre-main sequence (pre-MS), and may cover up to  $\sim 50\%$  of their surfaces, but their effects on early stellar evolution have never been fully explored. I study the impact of such extreme spot coverage on pre-MS stellar evolution by modifying an existing stellar evolution code to account for spot effects on both the surface boundary conditions and the transport of energy in the interior. I show that heavy spot coverage systematically increases the radii of young stars, while reducing their luminosity and average surface temperature. Such increased radii may underlie the well-known radius inflation of some young, active stars, while the decreased luminosity and effective temperature displace stars on the HR diagram, leading to systematic under-estimation of stellar masses by up to 2x, and of stellar ages by up to 10x, if spotted stars are interpreted with un-spotted isochrones. The inhomogeneous surfaces of spotted stars also distort the emission spectrum, and can thus explain the anomalous colors of the rapidly rotating K dwarfs of the Pleiades, a young open cluster. I further find that spots reduce the central temperature of stars, leading to a suppression of lithium burning during the pre-MS. As a result, pre-MS stars of equal mass but differing spot properties reach the zero-age main sequence with different surface lithium abundances. I show that this effect can

account for the previously unexplained lithium abundance dispersions observed at fixed Teff in the Pleiades, and other young clusters.

Synthesizing these results, I argue that the inclusion of spots, a prominent phenomenon on the pre-MS, can explain several outstanding mysteries associated with young stars: inflated radii, age spreads in young clusters, the anomalous colors of rapid rotators, and the lithium abundance dispersions in young star clusters. I discuss implications of under-estimated masses and ages for measuring age spreads in young clusters, studying the initial mass function, measuring planet formation timescales, and inferring the lifetimes of circum-stellar disks.

**Author(s):** Garrett Somers<sup>1</sup>

**Institution(s):** 1. The Ohio State University

### 205.06 – Polarization Complicates Images of Protoplanetary Disks

A popular method for obtaining high-contrast images of gas-rich optically thick protoplanetary disks around young stars is polarimetric imaging. The rationale for this is that light scattered off the disk surface is preferentially polarized, while light emitted directly from the star is not. Polarimetric imaging has resulted in images of disk surfaces that show morphological complexity, such as gaps, spiral arms, and dark spots. However, these images need to be interpreted with care, because as the angle of scattering varies across the surface of an inclined disk, so does the polarization fraction vary. We present simulated images of disks in scattered polarized light, showing that a relatively simple structure, such as an axisymmetric gap, can give the appearance of more complex asymmetric structure when the disk is inclined. This demonstrates that polarimetric imaging must be interpreted with great caution.

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**Institution(s):** 1. University of Wyoming

## 206 – Extrasolar Planet Detection with Coronagraphy

### 206.01 – WFIRST-AFTA Coronagraphic Instrument Science Yield Modeling Updates

We present updated results for the distributions of potential science yields for the Wide-Field Infrared Survey Telescope Astrophysics Focused Telescope Assets (WFIRST-AFTA) coronagraph using the EXOSIMS mission simulation software package. We model the latest coronagraph, observatory and missions design updates. In particular we explore the effects of updated planet parameter distributions based on the latest observational and modeling results, refinements to the target list selection algorithm and varying observing strategies. We present the range of potential outcomes in terms of new planetary detections, characterizations of known exoplanets and the sampling effects of the instrument on various assumed input distributions of orbital and physical planet parameters.

**Author(s):** Dmitry Savransky<sup>1</sup>, Daniel Garrett<sup>1</sup>

**Institution(s):** 1. Cornell University

### 206.02D – SDC: a multistage coronagraphic platform at Palomar observatory

Direct imaging of planets is challenging for two main reasons: first, stars are brighter than their planets by many orders of magnitude (requiring high contrast), and second, planets and their host stars are close to each other (require a low inner working angle instrument). Many exciting new technologies are attempting to address these challenges to enable imaging and spectroscopy of exoplanets. To this end, we present a new instrument, the "Stellar Double Coronagraph" (SDC), a flexible coronagraphic platform. Situated at Palomar Observatory's 200" Hale telescope, it supports a number of interchangeable observing configurations. These include multiple vortex coronagraphs in series, hybrid pupil/phase masks, and novel focal-plane wavefront sensing and control schemes for improved contrast and inner working angles. We describe the motivation,

design, observing modes, wavefront control strategies, and data reduction pipeline. We also present early science results, demonstrating the capabilities and potential of these approaches.

**Author(s):** Michael Bottom<sup>1</sup>, Eugene Serabyn<sup>3</sup>, Chris Shelton<sup>3</sup>, J. Kent Wallace<sup>3</sup>, Randall D. Bartos<sup>3</sup>, Jonas Kuhn<sup>2</sup>, Dimitri Mawet<sup>1</sup>, Bertrand Mennesson<sup>3</sup>, Rick Burruss<sup>3</sup>  
**Institution(s):** 1. *California Institute of Technology*, 2. *ETH Zurich*, 3. *Jet Propulsion Lab*

### 206.03 – PIAACMC coronagraph on WFIRST-AFTA

The WFIRST-AFTA coronagraph technology development effort includes a PIAACMC design. This design offers a high-throughput, small inner-working-angle option that promises to produce a large number of observable planetary targets. PIAACMC performance is, in general, limited by tip-tilt sensitivity, and so depends on the combination of telescope stability and low-order wavefront sensing and control (LOWFS/C) residual performance. Modeled science yield will be presented, including performance through LOWFS/C, along with measured mask fabrication results and testbed updates.

**Author(s):** Brian D. Kern<sup>1</sup>, Olivier Guyon<sup>3</sup>, Ruslan Belikov<sup>2</sup>, Daniel Wilson<sup>1</sup>, Ilya Poberezhskiy<sup>1</sup>  
**Institution(s):** 1. *JPL*, 2. *NASA Ames Research Center*, 3. *University of Arizona*

### 206.04D – Recursive Focal Plane Wavefront and Bias Estimation for the Direct Imaging of Exoplanets

To image the reflected light from exoplanets and disks, an instrument must suppress diffracted starlight by about nine orders of magnitude. A coronagraph alters the stellar PSF to create regions of high contrast, but it is extremely sensitive to wavefront aberrations. Deformable mirrors (DMs) are necessary to mitigate these quasi-static aberrations and recover high-contrast. To avoid non-common path aberrations, the science camera must be used as the primary wavefront sensor. Focal plane wavefront correction is an iterative process, and obtaining sufficient signal in the dark holes requires long exposure times. The fastest coronagraphic wavefront correction techniques require estimates of the stellar electric field. The main challenge of coronagraphy is thus to perform complex wavefront estimation quickly and efficiently using intensity images from the camera. The most widely applicable and tested technique is DM Diversity, in which a DM modulates the focal plane intensity and several images are used to reconstruct the stellar electric field in a batch process. At the High Contrast Imaging Lab (HCIL) at Princeton, we have developed an iterative extended Kalman filter (IEKF) to improve upon this technique. The IEKF enables recursive starlight estimation and can utilize fewer images per iteration, thereby speeding up wavefront correction. This IEKF formulation also estimates the bias in the images recursively. Since exoplanets and disks are embedded in the incoherent bias signal, the IEKF enables detection of science targets during wavefront correction. Here we present simulated and experimental results from Princeton's HCIL demonstrating the effectiveness of the IEKF for recursive electric field estimation and exoplanet detection.

**Author(s):** A J Eldorado Riggs<sup>1</sup>, N. Jeremy Kasdin<sup>1</sup>, Tyler Dean Groff<sup>1</sup>  
**Institution(s):** 1. *Princeton University*

### 206.05 – High Contrast Imaging in Multi-Star Systems: Technology Development and First Lab Results

Several starlight suppression systems have been demonstrated in the lab that can remove the leakage of light from a star down to almost  $10^{-10}$  contrast, but only for single-star systems. Despite the ubiquity and importance of multi-star systems, they are typically excluded from mission target lists and multi-star imaging technology has not been strongly pursued.

We show preliminary laboratory results advancing the technology readiness of a method to directly image planets and disks in *multi-star* systems such as Alpha Centauri. This method works with almost any coronagraph (or external occulter with a DM) and

requires little or no change to existing and mature hardware. Because of the ubiquity of multi-star systems, this method potentially multiplies the science yield of many missions and concepts such as AFTA, Exo-C, Exo-S, EXCEDE, and potentially enables the detection of Earth-like planets (if they exist) around our nearest-neighbor star, Alpha Centauri, with a small and cheap space telescope such as ACESat or Centaur+.

We identified two main challenges associated with double-star (or multi-star) systems and methods to solve them. The first challenge is that multi-star separation is typically beyond the outer working angle (spatial Nyquist frequency) of the deformable mirror. To address this, we are developing “Super-Nyquist Wavefront Control” where a mild grating or the DM itself effectively diffracts low-spatial frequency modes of the DM into higher frequencies.

The second challenge is to separate and independently remove overlapping speckles from multiple stars. We solve this challenge by a new method we call “Multi-Star Wavefront Control”, which involves partitioning the correction zone and DM modes in a way that completely decouples the wavefront control of the two stars and enables simultaneously solving for both.

We present our first lab results and model validation of Super-Nyquist Wavefront Control, where we demonstrate a dark zone beyond the spatial Nyquist limit of a  $32 \times 32$  DM (i.e. beyond  $16 \lambda/D$ ). The demonstration is carried out at the Ames Corroanograph Experiment (ACE) testbed at NASA ARC in monochromatic as well as broadband light.

**Author(s):** Ruslan Belikov<sup>2</sup>, Eduardo Bendek<sup>2</sup>, Eugene Pluzhnik<sup>2</sup>, Sandrine Thomas<sup>1</sup>  
**Institution(s):** 1. *LSST*, 2. *NASA Ames Research Center*

### 206.07 – Technology Needs for the Direct Imaging of Exoplanets

This talk will describe the technology needs for space telescopes to directly image Earth-size planets in the Habitable Zone of Sun-like stars. Direct imaging of faint, potentially terrestrial exoplanets begins with starlight suppression - the ability to block out the light from the target star and capture the reflected light from its nearby, faint exoplanet. I will provide an update for the technology needs in the fields of space coronagraphy (internal occulters) and starshades (external occulters) along with other key needs such as segmented primary mirrors, deformable mirrors, ultra-low-noise detectors, and large structure deployments.

**Author(s):** Nicholas Siegler<sup>1</sup>  
**Institution(s):** 1. *Jet Propulsion Laboratory*

## 208 – Supernova Explosions: Models and Constraints

### 208.01 – Shock Breakout and Early Light Curves of Type II-P Supernovae Observed with Kepler

We discovered two transient events in the Kepler field with light curves that strongly suggest they are type II-P supernovae. Using the fast cadence of the Kepler observations we precisely estimate the rise time to maximum for KSN2011a and KSN2011d as  $10.5 \pm 0.4$  and  $13.3 \pm 0.4$  rest-frame days respectively. We find the progenitor radius of KSN2011a ( $280 \pm 20 R_{\odot}$ ) to be significantly smaller than that for KSN2011d ( $490 \pm 20 R_{\odot}$ ) but both have similar explosion energies of  $2.0 \pm 0.3 \times 10^{51}$  erg.

The rising light curve of KSN2011d is an excellent match to that predicted by simple models of exploding red supergiants (RSG). However, the early rise of KSN2011a is faster than the models predict possibly due to the supernova shockwave moving into pre-existing wind or mass-loss from the RSG. A mass loss rate of  $10^{-4} M_{\odot} \text{ yr}^{-1}$  from the RSG can explain the fast rise without impacting the optical flux at maximum light or the shape of the post-maximum light curve.

No shock breakout emission is seen in KSN2011a, but this is likely

due to the circumstellar interaction suspected in the fast rising light curve. The early light curve of KSN2011d does show excess emission consistent with model predictions of a shock breakout. This is the first optical detection of a shock breakout from a type II-P supernova.

**Author(s):** Peter M. Garnavich<sup>4</sup>, Bradley E. Tucker<sup>1</sup>, Armin Rest<sup>3</sup>, Edward J. Shaya<sup>6</sup>, Robert Olling<sup>6</sup>, Daniel Kasen<sup>5</sup>, Victoria Villar<sup>2</sup>

**Institution(s):** 1. Australian National University, 2. CfA, 3. STScI, 4. Univ. of Notre Dame, 5. University of California, Berkeley, 6. University of Maryland

**Contributing team(s):** KEGS

### 208.02 – Rapidly Rising Transients in the Supernova - Superluminous Supernova Gap

We recently discovered four rapidly (~10-day) rising transients with peak luminosities between those of supernovae (SNe) and superluminous SNe in the PTF and SNLS archives. The light curves resemble those of SN 2011kl, recently shown to be associated with an ultra-long-duration gamma ray burst (GRB). The rapid rise to a luminous peak places these events in a unique part of SN phase space, challenging standard SN emission mechanisms. Spectra of the PTF event formally classify it as a Type II SN due to broad H-alpha emission, but an unusual absorption feature (which can be interpreted as either substantial high velocity hydrogen or Si II) is also observed. Existing models of white dwarf detonations, CSM interaction, shock breakout in a wind (or steeper CSM) and magnetar spindown can not readily explain the observations. Theoretical models (including those of "Type 1.5 SNe") may need to be expanded to account for this new class of transients.

**Author(s):** Iair Arcavi<sup>1</sup>, William M Wolf<sup>2</sup>, Dale Andrew Howell<sup>1</sup>, Lars Bildsten<sup>2</sup>

**Institution(s):** 1. Las Cumbres Observatory Global Telescope, 2. UCSB

**Contributing team(s):** PTF, SNLS

### 208.03D – Investigating SNe Ia progenitor diversity through late-time IR spectroscopy

Late-time spectra of SNe Ia show numerous strong emission features of iron and cobalt throughout the NIR. As the spectrum ages, the cobalt features fade as is expected from the decay of <sup>56</sup>Co to <sup>56</sup>Fe. The strong 1.64  $\mu$ m [Fe II] feature is sensitive to the central density of the white dwarf just prior to the thermonuclear runaway of C in the core because of electron capture in the early stages of burning, which increases as a function of density. The line profile is dependent on the extent of mixing during any deflagration burning in addition to asymmetries in the distribution of burning products or an off-center ignition. Normalization of a time-series of spectra to the 1.64  $\mu$ m line allows separation of features produced by stable versus unstable isotopes of iron group elements. Evolution of the width of this feature probes the strength and morphology of magnetic fields in the expanding ejecta. Results of this technique are shown for SN 2005df, with observations spanning 200-400 days past the explosion. A sample of these late-time spectroscopic observations in the NIR of SNe Ia will provide insight into the natural variety of these objects, improving our understanding of the underlying physical processes and their usability in cosmology.

**Author(s):** Tiara Diamond<sup>1</sup>

**Institution(s):** 1. NPP, Goddard Space Flight Center

### 208.05 – Effects of Turbulence on the Critical Conditions of Explosion

Turbulence is an important factor to consider in the supernova problem; computer simulations show that turbulence reduces the critical conditions necessary for a successful explosion. We propose a global turbulence model that captures the effects of previous simulations, and we use this turbulence model to derive the reduced critical conditions. Enthalpy flux, turbulent dissipation, and Reynolds stress are all potentially impactful components in reducing the threshold for explosion. To examine the weight of these effects, we isolate each element's contribution and compare their respective

magnitudes to the neutrino heating. By exploring these reduced critical curves, we hope to further understand how turbulence aids explosion.

**Author(s):** Quintin Mabanta<sup>1</sup>, Jeremiah Wayne Murphy<sup>1</sup>

**Institution(s):** 1. Florida State University

### 208.06D – The effects of resolution, dimensionality, and nuclear network size on detonations in low-density Type Ia supernovae environments

Type Ia supernovae are most likely thermonuclear explosions of carbon/oxygen white dwarves in binary stellar systems, but the explosion scenario(s) that give rise to these events have still not been conclusively determined. However, nearly all of the currently favored explosion scenarios involve detonations, so we focus on this supersonic mode of burning. Using the FLASH code, we investigate the effects of resolution, dimensionality, and nuclear network size on detonations in low-density Type Ia supernova environments. We perform our simulations at small, resolved scales and then apply our findings to a large-scale application.

**Author(s):** Thomas Papatheodore<sup>1</sup>, O. E. Bronson Messer<sup>1</sup>, William R. Hix<sup>2</sup>

**Institution(s):** 1. Oak Ridge National Laboratory, 2. University of Tennessee

### 208.07 – Do Single-Degenerate Type Ia Supernovae Generally Lead to Normal Type Ia Supernovae?

Recent observational and theoretical progress has favored merging and helium-accreting sub-Chandrasekhar mass white dwarfs (WDs) in the double-degenerate and the double-detonation channels, respectively, as the dominant progenitors of normal Type Ia supernovae (SNe Ia). Thus the fate of rapidly-accreting Chandrasekhar mass WDs in the single-degenerate channel remains more mysterious than ever. In this talk, I will clarify the nature of ignition in Chandrasekhar-mass single-degenerate SNe Ia and demonstrate that the overwhelming majority of ignition events within Chandrasekhar-mass WDs in the single-degenerate channel are generally expected to be buoyancy-driven, and consequently lack a vigorous deflagration phase. I will show, using both analytic criteria and multidimensional numerical simulations, that the single-degenerate channel is inherently stochastic and leads to a variety of outcomes from failed SN 2002cx-like events through overluminous SN 1991T-like events. I will also demonstrate how the rates predicted from both the population of supersoft X-ray sources (SSSs) and binary population synthesis models of the single-degenerate channel can be brought into agreement with single-degenerate SNe Ia. I will further demonstrate that the single-degenerate channel contribution to the normal and failed 2002cx-like rates is not likely to exceed 1% of the total SNe Ia rate. I will conclude with a range of observational tests which will either support or strongly constrain the single-degenerate scenario.

**Author(s):** Robert Fisher<sup>1</sup>

**Institution(s):** 1. University of Massachusetts Dartmouth

## 209 – Elliptical and Spiral Galaxies II

### 209.01 – Characterizing "Radio Mode" AGN Outbursts: the Recent 12 Myr History of the Supermassive Black Hole in M87

M87, the bright active galaxy dominating the core of the Virgo cluster, is ideal for studying the interaction of a supermassive black hole with a gas rich environment. We combine results from a deep Chandra observation with a simple shock model to derive the properties of the outburst that created the 13 kpc shock previously reported around M87. The principal constraints for the model are 1) the observed temperature and density profiles, 2) the measured Mach number (about 1.2) and radius of the 13 kpc shock, 3) the observed size of the inner cavity (~3 kpc) that serves as the piston to drive the shock, and 4) the absence of a hot, low density plasma surrounding the central cavity. Qualitatively, the absence of a hot,

low density (shocked) region surrounding the inner radio lobes (the piston), requires a "slowly" expanding piston and "long" duration outburst rather than a Sedov-like outburst. Quantitatively, a roughly  $5 \times 10^{57}$  ergs outburst that began about 12 Myr ago and lasted about 2 Myr matches all the constraints. In the context of the model, ~20% of the energy is carried by the shock as it expands to large radii while ~80% of the outburst energy is available to heat the core gas. For an outburst repetition rate of about 12 Myrs (the outburst age), 80% of the outburst energy is sufficient to balance radiative cooling. We discuss the outburst history of M87 as chronicled in its radio and X-ray images and the implications of these outbursts for heating gas rich environments.

**Author(s):** William R. Forman<sup>3</sup>, Eugene Churazov<sup>2</sup>, Christine Jones<sup>3</sup>, Sebastian Heinz<sup>4</sup>, Ralph P. Kraft<sup>1</sup>, Alexey Vikhlinin<sup>1</sup>  
**Institution(s):** 1. *Harvard Smithsonian Center for Astrophysics*, 2. *MPA*, 3. *SAO*, 4. *University of Wisconsin*

### 209.02 – Circumnuclear molecular gas in M87 detected with ALMA

We present the detection of circumnuclear molecular gas residing within 100 pc of the supermassive black hole (SMBH) in the galaxy M87 (3C 274), using the Atacama Large Millimeter/submillimeter Array (ALMA) to image the gas on spatial scales from 100 to 10 pc. The proximity of M87, the archetypical giant elliptical radio galaxy at the centre of the Virgo galaxy cluster, presents a unique opportunity to investigate in detail the circumnuclear molecular gas revealed first by single-dish observations and recently imaged for the first time with ALMA (Vlahakis et al., in prep). ALMA's unique long baseline capability now allows us to make the first detailed investigation of the properties of the interstellar medium around the galaxy's SMBH on scales down to 10 pc (0.1 arcsec). Here, we present results of ALMA Band 3 CO J=1-0 observations obtained at different angular resolutions. With this data we are able to trace the bulk of the molecular gas as well as the continuum emission, providing the deepest and highest spatial resolution images yet of the molecular gas content of this giant elliptical galaxy. The highest resolution data allow us to unambiguously resolve the molecular gas structures for the first time and investigate, in unprecedented detail, the nature and origin of molecular gas that resides within the sphere of influence of the SMBH.

**Author(s):** Catherine E Vlahakis<sup>1</sup>  
**Institution(s):** 1. *Joint ALMA Observatory*

### 209.03 – Evidence for Expulsion of the Star Formation Gas Reservoir by the AGN in Local Blue Ellipticals

The formation and assembly of the local galaxy population remains a major open question. Recent works show that elliptical galaxies can rapidly transition from blue star forming to red quiescent systems. Such rapid reddening of stellar populations implies that gas reservoirs are being depleted on timescales which are much shorter than mere exhaustion thanks to ongoing star formation. Feedback, either from star formation itself or from nuclear activity associated with black hole growth is typically invoked. Yet observational confirmation has remained elusive.

Using the 10.4-m CSO, we recently obtained 12CO(2-1) observations for a sample of blue star forming local elliptical galaxies to probe the state of the gas and look at the changes in excitation temperature across the star forming sequence. Previous IRAM 12CO(1-0) measurements indicate this population is undergoing a sudden decline in molecular gas fraction. This drop occurs ~200 Myr after a recent peak in star formation- a timescale suggesting AGN triggered feedback switches on rapidly and is immediately effective. The jets or outflows from the central supermassive black hole likely either heat or expel residual gas cutting off star formation, but the 12CO(1-0) measurements alone were insufficient to distinguish between these two scenarios. The 12CO(2-1) to 12CO(1-0) ratio has previously proved diagnostic of the conditions which exist in star forming galaxies. Combining the new 12CO(2-1) measurements with the previous 12CO(1-0) data, we find evidence for active quenching of star formation due to the expulsion of the gas reservoir by the central massive black holes residing in these galaxies. We will discuss our

observations and analysis and compare our results to those from other early type populations.

**Author(s):** Megan E. Schwamb<sup>1</sup>, Chris Lintott<sup>2</sup>, Rebecca Smethurst<sup>2</sup>, Sandor Kruk<sup>2</sup>, Satoki Matsushita<sup>1</sup>, Ivy Wong<sup>3</sup>, Shiang-Yu Wang<sup>1</sup>  
**Institution(s):** 1. *Institute of Astronomy & Astrophysics, Academia Sinica (ASIAA)*, 2. *University of Oxford*, 3. *UWA/ICRAR*

### 209.04 – Early-type Host Galaxies of Type Ia Supernovae: Origin of the Correlation between Hubble Residual and Host Mass

Recent studies show that the Hubble residual from type Ia supernova (SN Ia) is correlated with the morphology and mass of host galaxy, implying the possible dependence of SN Ia luminosity on host galaxy properties. In order to investigate this more directly, we have initiated spectroscopic survey for the early-type host galaxies, for which population age and metallicity can be more reliably determined from the Lick absorption-line indices. In this talk, we present the results from high signal-to-noise ratio (> 100) spectra for 27 nearby host galaxies observed in Las Campanas Observatory. For the first time, we find a significant correlation between host galaxy mass (velocity dispersion) and population age, which is consistent with the "downsizing" trend among non-host early-type galaxies. Since we find no correlation with metallicity, our result suggests that stellar population age is mainly responsible for the relation between host mass and Hubble residual. If confirmed, this would imply that the luminosity evolution plays a major role in the systematic uncertainties of SN Ia cosmology.

**Author(s):** Yijung Kang<sup>1</sup>, Young-Lo Kim<sup>1</sup>, Dongwook Lim<sup>1</sup>, Chul Chung<sup>1</sup>, Young-Wook Lee<sup>1</sup>  
**Institution(s):** 1. *Yonsei University*

### 209.05 – IMF or Abundance Variations? Steep Gradients at the Centers of Elliptical Galaxies

We present high signal-to-noise spectra for six early-type galaxies with Keck/LRIS, covering 350-1050 nm and probing spatial scales from 100 pc to several kpc. Some of our objects exhibit steep absorption-line gradients within the central ~300 pc, indicating a rapid increase in [Na/Fe] and [N/Fe] toward the galaxy center. While stellar population synthesis (SPS) modeling may address whether the stellar initial mass function (IMF) varies as a function of radius, we caution that the competing effects of chemical abundance variations and IMF variations demands extreme care in interpreting SPS models of integrated-light spectra. The steep abundance variations themselves may offer insight to star formation and gas retention in progenitors of today's early-type galaxies, including the possible overabundance of stars above ~3 Msun.

**Author(s):** Nicholas J. McConnell<sup>1</sup>, Jessica R. Lu<sup>2</sup>, Andrew Mann<sup>3</sup>  
**Institution(s):** 1. *NRC Herzberg*, 2. *University of Hawaii*, 3. *University of Texas*

### 209.06 – The Dark Matter Conspiracy in Early-type Galaxies

The extended mass profiles of early-type galaxies, including their dark matter distributions, have remained uncertain many decades after dark matter was established in late-type galaxies, owing to the lack of cold gas disks as dynamical tracers. We have combined kinematics data from the ATLAS<sup>3</sup>D and SLUGGS surveys over wide fields in 14 early-type galaxies, providing strong and unique constraints on their mass distributions out to 4 effective radii. We find ubiquitous near-isothermal total mass profiles in these galaxies, from their central to outer regions. This result is remarkably similar to the constant rotation curves found for late-type galaxies, and implies a "conspiracy" between stellar and dark matter distributions in both galaxy types. Further examination of the implications for dark matter distributions will be presented.

**Author(s):** Aaron J. Romanowsky<sup>2</sup>, Michele Cappellari<sup>1</sup>, Jean P. Brodie<sup>3</sup>

**Institution(s):** 1. Oxford University, 2. San Jose State University, 3. University of California Observatories

**Contributing team(s):** SLUGGS team

### 209.07 – Testing the Universality of the Stellar IMF with Chandra

The stellar initial mass function (IMF), which is often assumed to be universal, has recently been suggested to vary with elliptical galaxy mass. The observed optical/near-IR spectra of massive ellipticals show evidence for an excess of low-mass stars (based on gravity sensitive absorption lines like Na and FeH) over that expected from a standard Milky Way-like IMF, which is observed in low-mass ellipticals. This suggests that massive ellipticals have a “bottom heavy” IMF with substantially steeper slopes than standard IMFs. An extrapolation of such a steep-slope IMF to high stellar masses would lead to a deficit of black hole and neutron star formation compared to a standard IMF; correspondingly, fewer low-mass X-ray binaries (LMXBs) per unit stellar mass would be expected for the steep-slope IMF. Using new Chandra observations of six low-mass ellipticals plus seven previously observed high-mass ellipticals, we test whether the number of LMXBs per unit K-band luminosity (N/LK) is consistent with a changing IMF with galaxy mass. We find nearly constant values of N/LK over the full mass range, implying there is very little change in the high stellar-mass (>8 M<sub>sol</sub>) end of the IMF for these galaxies despite the optical/near-IR evidence for changes in the low stellar-mass end of the IMF. We will discuss implications for how the overall IMF shape of elliptical galaxies changes as a function of galaxy mass.

**Author(s):** David Coulter<sup>4</sup>, Bret Lehmer<sup>6</sup>, Rafael T. Eufrazio<sup>2</sup>, Arunav Kundu<sup>1</sup>, Mark Peacock<sup>3</sup>, Ann E. Hornschemeier<sup>2</sup>, Antara Basu-Zych<sup>2</sup>, Anthony H. Gonzalez<sup>7</sup>, Tom Maccarone<sup>5</sup>, Claudia Maraston<sup>8</sup>, Steve E. Zepf<sup>3</sup>

**Institution(s):** 1. Eureka Scientific, 2. Goddard Space Flight Center, 3. Michigan State University, 4. Portland State University, 5. Texas Tech University, 6. University of Arkansas, 7. University of Florida, 8. University of Portsmouth

### 209.08D – A sub-kiloparsec scale view of star formation in M31

Tracking star formation rates within galaxies is essential to understanding not only how efficiently gas transforms into stars, but also how entire galaxies evolve. In the nearby Universe, observations of resolved stellar populations enable the measurement of star formation rates as a function of position and time — spatially-resolved star formation histories (SFHs) — within a single galaxy. Combined with multi-wavelength observations of dust and gas, these resolved SFHs represent the most direct way to holistically probe galaxy evolution. Leveraging observations from the Panchromatic Hubble Andromeda Treasury program, I have measured the spatially-resolved SFH of M31's disk at a resolution of 0.1 kpc over the past 500 Myr. This resolved SFH has provided new insights into a broad range of astrophysical processes from the dynamical longevity of M31's star-forming rings to the connection between star formation and M31's gas and dust contents. In addition to analyzing the star formation efficiency in M31, I have examined spatial and temporal correlations between star formation and the interstellar medium to investigate the star formation cycle on physical scales of order the size of star-forming regions. I have used the resolved SFHs derived with optical data to predict the spatially-resolved ultraviolet flux of M31 to an accuracy of >95%. The small differences may indicate the UV contribution of ancient stellar populations. Data products from my work are being used to empirically constrain stellar feedback, which will inform future treatment of such feedback in galaxy simulations. These studies together reveal the most finely spatially-resolved view of star formation in an L<sub>star</sub> galaxy to date.

**Author(s):** Alexia Lewis<sup>1</sup>, Julianne Dalcanton<sup>1</sup>

**Institution(s):** 1. University of Washington

### 210.01D – Fundamental Parameters of Low-Mass Stars, Brown Dwarfs, and Planets

Despite advances in evolutionary models of low-mass stars and brown dwarfs, these models remain poorly constrained by observations. In order to test these predictions directly, masses of individual stars must be measured and combined with broadband photometry and medium-resolution spectroscopy to probe stellar atmospheres. I will present results from an astrometric and spectroscopic survey of low-mass pre-main sequence binary stars to measure individual dynamical masses and compare to model predictions. This is the first systematic test of a large number of stellar systems of intermediate age between young star-forming regions and old field stars. Stars in our sample are members of the Tuc-Hor, AB Doradus, and beta Pictoris moving groups, the last of which includes GJ 3305 AB, the wide binary companion to the imaged exoplanet host 51 Eri. I will also present results of Spitzer observations of secondary eclipses of LHS 6343 C, a T dwarf transiting one member of an M+M binary in the Kepler field. By combining these data with Kepler photometry and radial velocity observations, we can measure the luminosity, mass, and radius of the brown dwarf. This is the first non-inflated brown dwarf for which all three of these parameters have been measured, providing the first benchmark to test model predictions of the masses and radii of field T dwarfs. I will discuss these results in the context of K2 and TESS, which will find additional benchmark transiting brown dwarfs over the course of their missions, including a description of the first planet catalog developed from K2 data and a program to search for transiting planets around mid-M dwarfs.

**Author(s):** Benjamin Montet<sup>2</sup>, John A. Johnson<sup>3</sup>, Brendan Bowler<sup>2</sup>, Evgenya Shkolnik<sup>1</sup>

**Institution(s):** 1. Arizona State University, 2. California Institute of Technology, 3. Harvard University

### 210.02D – Fundamental Parameters and Spectral Energy Distributions of Young and Field Age Objects with Masses Spanning the Stellar to Planetary Regime

The physical and atmospheric properties of ultracool dwarfs are deeply entangled due to the degenerate effects of mass, age, metallicity, clouds and dust, activity, rotation, and possibly even formation mechanism on observed spectra. Accurate determination of fundamental parameters for a wide diversity of objects at the low end of the IMF is thus crucial to testing stellar and planetary formation theories. To determine these quantities, we constructed and flux calibrated nearly-complete spectral energy distributions (SEDs) for 221 M, L, T, and Y dwarfs using published parallaxes and 0.3-40  $\mu$ m spectra and photometry. From these homogeneous SEDs, we calculated bolometric luminosity (L<sub>bol</sub>), effective temperature (T<sub>eff</sub>), mass, surface gravity, radius, spectral indexes, synthetic photometry, and bolometric corrections (BCs) for each object. We used these results to derive L<sub>bol</sub>, T<sub>eff</sub>, and BC polynomial relations across the entire very-low-mass star/brown dwarf/planetary mass regime. We use a subsample of objects with age constraints based on nearby young moving group membership, companionship with a young star, or spectral signatures of low surface gravity to define new age-sensitive diagnostics and characterize the reddening of young substellar atmospheres as a redistribution of flux from the near-infrared into the mid-infrared. Consequently we find the SED flux pivots at Ks band, making BC<sub>Ks</sub> as a function of spectral type a tight and age independent relationship. We find that young L dwarfs are systematically 300 K cooler than field age objects of the same spectral type and up to 600 K cooler than field age objects of the same absolute H magnitude. Finally, we present preliminary comparisons of these empirical results to best fit parameters from four different model atmosphere grids via Markov-Chain Monte Carlo analysis in order to create prescriptions for the reliable and efficient characterization of new ultracool dwarfs.

**Author(s):** Joe Filippazzo<sup>2</sup>, Emily L. Rice<sup>2</sup>, Jacqueline K. Faherty<sup>1</sup>, Kelle L. Cruz<sup>3</sup>, Paige A. Godfrey<sup>2</sup>

**Institution(s):** 1. Carnegie Institution of Washington, 2. College of Staten Island, 3. Hunter College

**Contributing team(s):** BDNYC

## 210 – Stars III: Brown Dwarfs and Exoplanets

### 210.03D – The BASS survey for brown dwarfs in young moving groups

I will present in this dissertation talk the construction and follow-up of the BANYAN All-Sky Survey (BASS) that we led to identify dozens of new isolated young brown dwarfs in the Solar neighborhood, several of which have physical properties such as mass, age and temperature that make them similar to exoplanets that were recently discovered using the method of direct imaging.

Such isolated analogs of the giant, gaseous exoplanets are precious benchmarks that will allow a deep characterization of their atmospheres using high-resolution and high signal-to-noise spectroscopy, which is made possible due to the absence of a nearby and bright host star.

I will end by describing BASS-Ultracool, an extension of BASS that focuses on the identification of extremely cool isolated exoplanet analogs that display methane in their atmospheres. This survey has already uncovered the first bonafide T dwarf member of a moving group, the  $\sim 150$  Myr AB Doradus T5, SDSS1110+0116.

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### 210.04D – Auroral Phenomena in Brown Dwarf Atmospheres

Since the unexpected discovery of radio emission from brown dwarfs some 15 years ago, investigations into the nature of this emission have revealed that, despite their cool and neutral atmospheres, brown dwarfs harbor strong kG magnetic fields, but unlike the warmer stellar objects, they generate highly circularly polarized auroral radio emission, like the giant planets of the Solar System. Our recent results from Keck LRIS monitoring of the brown dwarf LSR1835+32 definitively confirm this picture by connecting the auroral radio emission to spectroscopic variability at optical wavelengths as coherent manifestations of strong large-scale magnetospheric auroral current systems. I present some of the results of my dissertation work to understand the nature brown dwarf auroral phenomena. My efforts include a survey of Late L dwarfs and T dwarfs, looking for auroral H $\alpha$  emission and a concurrent survey looking for the auroral emission of H $_3^+$  from brown dwarfs with radio pulse detections. I discuss the potential connection of this auroral activity to brown dwarf weather phenomena and how brown dwarf aurorae may differ from the analogous emission of the magnetized giant planets in the Solar System.

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### 210.05 – A Statistical Study of Brown Dwarf Companions from the SDSS-III MARVELS Survey

We present 23 new Brown Dwarf (BD) candidates from the Multi-object APO Radial-Velocity Exoplanet Large-Area Survey (MARVELS) of the Sloan Digital Sky Survey III (SDSS-III). The BD candidates were selected from the processed MARVELS data using the latest University of Florida 2D pipeline, which shows significant improvement and reduction of systematic errors over the 1D pipeline results included in the SDSS Data Release 12. This sample is the largest BD yield from a single radial velocity survey. Of the 23 candidates, 18 are around main sequence stars and 5 are around giant stars. Given a giant contamination rate of  $\sim 24\%$  for the MARVELS survey, we find a BD occurrence rate around main sequence stars of  $\sim 0.7\%$ , which agrees with previous studies and

confirms the BD desert, while the BD occurrence rate around the MARVELS giant stars is  $\sim 0.6\%$ . Preliminary results show that our new candidates around solar type stars support a two population hypothesis, where BDs are divided at a mass of  $\sim 42.5 M_{\text{Jup}}$ . BDs less massive than  $42.5 M_{\text{Jup}}$  have eccentricity distributions consistent with planet-planet scattering models, where BDs more massive than  $42.5 M_{\text{Jup}}$  have both period and eccentricity distributions similar to that of stellar binaries. Special Brown Dwarf systems such as multiple BD systems and highly eccentric BDs will also be presented.

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**Contributing team(s):** The MARVELS Team

## 211 – Astrobiology/Laboratory Astrophysics - Atoms and Plasmas

### 211.01 – Planetary Habitability over Cosmic-Time Based on Cosmic-Ray Levels

Extreme cosmic-ray (CR) fluxes have a negative effect on life when flux densities are high enough to cause excessive biological, especially DNA, damage. The CR history of a planet plays an important role in its potential surface habitation. Both global and local CR conditions determine the ability of life to survive for astrobiologically relevant time periods. We highlight two CR life-limiting factors: 1) General galactic activity, starburst and AGN, was up by about a factor of 30 at redshift 1 - 2, per comoving frame, averaged over all galaxies. And 2) AGN activity is highly intermittent, so extreme brief but powerful bursts (Her A for example) can be detrimental at great distances. This means that during such brief bursts of AGN activity the extragalactic CRs might even overpower the local galactic CRs. But as shown by the starburst galaxy M82, the local CRs in a starburst can also be quite high. Moreover, in our cosmic neighborhood we have several super-massive black holes. These are in M31, M32, M81, NGC5128 (Cen A), and in our own Galaxy, all within about 4 Mpc today. Within about 20 Mpc today there are many more super-massive black holes. Cen A is of course the most famous one now, since it may be a major source of the ultra-high-energy CRs (UHECRs). Folding in what redshift means in terms of cosmic time, this implies that there may have been little chance for life to survive much earlier than Earth's starting epoch. We speculate, on whether the very slow start of life on Earth is connected to the decay of disturbing CR activity.

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### 211.02 – The Fragility of the Terrestrial Planets During a Giant Planet Instability

Many features of the outer solar system are replicated in numerical simulations if the giant planets undergo an orbital instability that ejects one or more ice giants. During this instability, the orbits of Jupiter and Saturn are believed to diverge, crossing their 2:1 mean motion resonance (MMR), and this resonance-crossing can excite the orbits of the terrestrial planets. Using a large ensemble of numerical simulations of this giant planet instability, we directly model the evolution of the terrestrial planet orbits during this process, paying special attention to those systems that reproduce the basic features of the outer planets. In systems that retain four giant planets and finish with Jupiter and Saturn beyond their 2:1 MMR, we find at least an 85% probability that at least one terrestrial planet is lost. Moreover, systems that manage to retain all four terrestrial planets often finish with terrestrial planet eccentricities and inclinations larger than the observed ones. There is less than a 5% chance that the terrestrial planet orbits will have a level of excitation comparable to the observed orbits. If we factor in the probability that the outer planetary orbits are well-replicated, we find a probability of 1% or less that the orbital architectures of the inner and outer planets are

simultaneously reproduced in the same system. These small probabilities raise the prospect that the giant planet instability may have occurred before the terrestrial planets had formed. Such a scenario implies that the giant planet instability is not the source of the Late Heavy Bombardment and that terrestrial planet formation finished with the giant planets in their post-instability configuration.

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### 211.03 – Solar Irradiance Changes And Photobiological Effects At Earth's Surface Following Astrophysical Ionizing Radiation Events

Astrophysical ionizing radiation events have been recognized as a potential threat to life on Earth for decades. Although there is some direct biological damage on the surface from redistributed radiation several studies have indicated that the greatest long term threat is from ozone depletion and subsequent heightened solar ultraviolet (UV) radiation. It is known that organisms exposed to this irradiation experience harmful effects such as sunburn and even direct damage to DNA, proteins, or other cellular structures. Simulations of the atmospheric effects of a variety of events (such as supernovae, gamma-ray bursts, and solar proton events) have been previously published, along with estimates of biological damage at Earth's surface. In the present work, we employed a radiative transfer model to expand and improve calculations of surface-level irradiance and biological impacts following an ionizing radiation event. We considered changes in surface-level UVB, UVA, and photosynthetically active radiation (visible light). Using biological weighting functions we have considered a wide range of effects, including: erythema and skin cancer in humans; inhibition of photosynthesis in the diatom *Phaeodactylum* sp. and dinoflagellate *Prorocentrum micans*; inhibition of carbon fixation in Antarctic phytoplankton; inhibition of growth of oat (*Avena sativa* L. cv. Otana) seedlings; and cataracts. We found that past work overestimated UVB irradiance, but that relative estimates for increase in exposure to DNA damaging radiation are still similar to our improved calculations. We also found that the intensity of biologically damaging radiation varies widely with organism and specific impact considered; these results have implications for biosphere-level damage following astrophysical ionizing radiation events. When considering changes in surface-level visible light irradiance, we found that, contrary to previous assumptions, a decrease in irradiance is only present for a short time in very limited geographical areas; instead we found a net increase for most of the modeled time-space region. This result has implications for proposed climate changes associated with ionizing radiation events.

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### 211.04 – Spectral identification of abiotic O<sub>2</sub> buildup from early runaways and rarefied atmospheres

The spectral detection of oxygen (O<sub>2</sub>) in a planetary atmosphere has been considered a robust signature of life because O<sub>2</sub> is highly reactive on planets with Earth-like redox buffers and because significant continuous abiotic sources were thought to be implausible. However, recent work has revealed the possibility that significant O<sub>2</sub> may build-up in terrestrial atmospheres through (1) photochemical channels or (2) through the escape of hydrogen. We focus on the latter category here. Significant amounts of abiotic O<sub>2</sub> could remain in the atmospheres of planets in the habitable zones of late type stars, where an early runaway greenhouse and massive hydrogen escape during the pre-main-sequence phase could have irreversibly oxidized the crust and mantle (Luger & Barnes 2015). Additionally, it has been hypothesized that O<sub>2</sub> could accumulate in the atmospheres of planets with sufficiently low abundances of non-condensable gases such as N<sub>2</sub> where water would not be cold trapped in the troposphere, leading to H-escape from UV photolysis in a wet stratosphere (Wordsworth & Pierrehumbert 2014). We self-consistently model the climate, photochemistry, and spectra of both rarefied and post-runaway, high-O<sub>2</sub> atmospheres. Because an early runaway might not have lasted long enough for the entire water

inventory to escape, we explore both completely desiccated scenarios and cases where a surface ocean remains. We find “habitable” surface conditions for a wide variety of oxygen abundances, atmospheric masses, and CO<sub>2</sub> mixing ratios. If O<sub>2</sub> builds up from massive or sustained H escape, the O<sub>2</sub> abundance should be very high, and could be spectrally indicated by the presence of O<sub>2</sub>-O<sub>2</sub> (O<sub>4</sub>) collisionally-induced absorption (CIA) features. We generate synthetic direct-imaging and transit transmission spectra of these atmospheres and calculate the strength of the UV/Visible and NIR O<sub>4</sub> features. We find that while both the UV/Visible and NIR O<sub>4</sub> features are strong in the radiance spectra of very high-O<sub>2</sub> atmospheres, only the NIR O<sub>4</sub> features are strong in transmission spectra. We also conclude that detection of N<sub>2</sub>-N<sub>2</sub> CIA near 4.2 μm in transmission or direct-imaging spectra could rule out O<sub>2</sub> origination from H-escape from thin atmospheres.

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### 211.05 – Non-equilibrium modelling of Fe XVII emission in an intense X-ray free electron laser and the implications for the 3C/3D oscillator strength ratio

Recent measurements using an X-ray Free Electron Laser and an Electron Beam Ion Trap at the Linac Coherent Light Source facility highlighted large discrepancies between the observed and theoretical values for the Fe XVII 3C/3D line intensity ratio, calling into question the oscillator strengths currently in the literature. We show that non-equilibrium effects can dramatically reduce the 3C/3D line intensity ratio. Once these time-dependent effects are accounted for, the measured line intensity ratio can be used to determine a revised value for the 3C/3D oscillator strength ratio, giving a range from 3.0 to 3.5. A discussion is given on the implications of these results on use of this Fe XVII line ratio in spectral diagnostics.

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### 211.06 – The velocity dependence of X-ray emission due to Charge Exchange in the Cygnus Loop

The fundamental collisional process of charge exchange (CX) has been established as a primary source of X-ray emission from the heliosphere [1], planetary exospheres [2], and supernova remnants [3,4]. In this process, X-ray emission results from the capture of an electron by a highly charged ion from a neutral atom or molecule, to form a highly-excited, high charge state ion. As the captured electron cascades down to the lowest energy level, photons are emitted, including X-rays.

To provide reliable CX-induced X-ray spectral models to realistically simulate these environments, line ratios and spectra are computed using theoretical CX cross-sections obtained with the multi-channel Landau-Zener, atomic-orbital close-coupling, and classical-trajectory Monte Carlo methods for various collisional velocities relevant to astrophysics for collisions of bare and H-like C to Al ions with H, He, and H<sub>2</sub>. Using these line ratios, XSPEC models of CX emission in the northeast rim of the Cygnus Loop supernova remnant will be shown as an example with ion velocity dependence.

- [1] Henley, D. B. & Shelton, R. L. 2010, ApJSS, 187, 388
- [2] Dennerl, K. et al. 2002, A&A 386, 319
- [3] Katsuda, S. et al. 2011, ApJ 730 24
- [4] Cumbee, R. S. et al. 2014, ApJ 787 L31

This work was partially supported by NASA grant NNX09AC46G.

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## 211.07 – Improved and Expanded Near-IR Oscillator Strengths for Ti I

We report on recent work to produce an improved and expanded set of near-IR oscillator strengths for Ti I. Emission branching fractions are measured from several spectra recorded with the NIST 2-m FTS covering the region from 4000 Å to 5.5 μm. Traditionally, branching fractions are combined with level lifetimes measured using laser-induced fluorescence; however, this technique becomes problematic for near-IR oscillator strength studies. Instead, we employ thorough and robust reverse stellar analyses of the Sun and Arcturus to obtain lifetimes for new levels of interest. This work makes use of an extensive set of previously reported laboratory Ti I oscillator strengths in the visible to better understand uncertainties and check for systematic effects in the reverse stellar analyses. This method will soon be applied to other species to help address the scarcity of near-IR Fe-group atomic data and support the growing interests of the near-IR astronomical community.

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## 211.08 – AtomDB and PyAtomDB: Atomic Data and Modelling Tools for High Energy and Non-Maxwellian Plasmas

The release of AtomDB 3 included a large wealth of inner shell ionization and excitation data allowing accurate modeling of non-equilibrium plasmas. We describe the newly calculated data and compare it to published literature data. We apply the new models to existing supernova remnant data such as W49B and N132D. We further outline progress towards AtomDB 3.1, including a new energy-dependent charge exchange cross sections.

We present newly developed models for the spectra of electron-electron bremsstrahlung and those due to non-Maxwellian electron distributions.

Finally, we present our new atomic database access tools, released as PyAtomDB, allowing powerful use of the underlying fundamental atomic data as well as the spectral emissivities.

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## 212 – Extrasolar Planet Atmospheres: BART Atmospheric Modelling Code and Applications

### 212.01 – A Random Walk on WASP-12b with the Bayesian Atmospheric Radiative Transfer (BART) Code

We present the Bayesian Atmospheric Radiative Transfer (BART) code for atmospheric property retrievals from transit and eclipse spectra, and apply it to WASP-12b, a hot (~3000 K) exoplanet with a high eclipse signal-to-noise ratio. WASP-12b has been controversial. We (Madhusudhan et al. 2011, Nature) claimed it was the first planet with a high C/O abundance ratio. Line et al. (2014, ApJ) suggested a high CO<sub>2</sub> abundance to explain the data. Stevenson et al. (2014, ApJ, atmospheric model by Madhusudhan) add additional data and reaffirm the original result, stating that C<sub>2</sub>H<sub>2</sub> and HCN, not included in the Line et al. models, explain the data. We explore several modeling configurations and include Hubble, Spitzer, and ground-based eclipse data.

BART consists of a differential-evolution Markov-Chain Monte Carlo sampler that drives a line-by-line radiative transfer code through the phase space of thermal- and abundance-profile parameters. BART is written in Python and C. Python modules generate atmospheric profiles from sets of MCMC parameters and integrate the resulting spectra over observational bandpasses, allowing high flexibility in modeling the planet without interacting with the fast, C portions that

calculate the spectra. BART's shared memory and optimized opacity calculation allow it to run on a laptop, enabling classroom use. Runs can scale constant abundance profiles, profiles of thermochemical equilibrium abundances (TEA) calculated by the included TEA code, or arbitrary curves. Several thermal profile parameterizations are available. BART is an open-source, reproducible-research code. Users must release any code or data modifications if they publish results from it, and we encourage the community to use it and to participate in its development via <http://github.com/ExOSPORTS/BART>.

This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G. J. Blečić holds a NASA Earth and Space Science Fellowship.

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### 212.02 – Bayesian Atmospheric Radiative Transfer (BART) Code and Application to WASP-43b

We present a new open-source Bayesian radiative-transfer framework, Bayesian Atmospheric Radiative Transfer (BART, <https://github.com/exosports/BART>), and its application to WASP-43b. BART initializes a model for the atmospheric retrieval calculation, generates thousands of theoretical model spectra using parametrized pressure and temperature profiles and line-by-line radiative-transfer calculation, and employs a statistical package to compare the models with the observations. It consists of three self-sufficient modules available to the community under the reproducible-research license, the Thermochemical Equilibrium Abundances module (TEA, <https://github.com/dzesmin/TEA>, Blečić et al. 2015), the radiative-transfer module (Transit, <https://github.com/exosports/transit>), and the Multi-core Markov-chain Monte Carlo statistical module (MCCubed, <https://github.com/pcubillos/MCCubed>, Cubillos et al. 2015). We applied BART on all available WASP-43b secondary eclipse data from the space- and ground-based observations constraining the temperature-pressure profile and molecular abundances of the dayside atmosphere of WASP-43b. This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G. JB holds a NASA Earth and Space Science Fellowship.

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### 212.03 – Constraining the atmosphere of exoplanet WASP-34b

WASP-34b is a short-period exoplanet with a mass of 0.59 ± 0.01 Jupiter masses orbiting a G5 star with a period of 4.3177 days and an eccentricity of 0.038 ± 0.012 (Smalley, 2010). We observed WASP-34b using the 3.6 and 4.5 micron channels of the Infrared Array Camera aboard the Spitzer Space Telescope in 2010 (Program 60003). We applied our Photometry for Orbits, Eclipses, and Transits (POET) code to present eclipse-depth measurements, estimates of infrared brightness temperatures, and a refined orbit. With our Bayesian Atmospheric Radiative Transfer (BART) code, we characterized the atmosphere's temperature and pressure profile, and molecular abundances. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G. J. Blečić holds a NASA Earth and Space Science Fellowship.

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## 212.04 – Analysis of Secondary Eclipse Observations of Hot-Jupiters WASP-26b and CoRoT-1b

WASP-26b is a hot-Jupiter planet that orbits an early G star every 2.7566 days at a distance of 0.03985 AU. Using the Spitzer Space Telescope in 2010 as a part of the Spitzer Exoplanet Target of Opportunity program (program 60003) we observed two secondary eclipses of the planet, one in the 3.6  $\mu\text{m}$  channel on 7 September and one in the 4.5  $\mu\text{m}$  channel on 3 August. We also reanalyze archival Spitzer data of CoRoT-1b, which is another hot Jupiter orbiting a G star every 1.5089686 days at a distance of 0.0254 AU, in the 3.6 and 4.5  $\mu\text{m}$  channels. The eclipse depths for WASP-26b are  $0.00117 \pm 0.00012$  and  $0.001507 \pm 0.00016$ , for the 3.6 and 4.5  $\mu\text{m}$  channels respectively. The eclipse depths for CoRoT-1b are  $0.0047 \pm 0.0003$  and  $0.0046 \pm 0.0004$  respectively. We also refine their orbits using our own secondary eclipse measurements in combination with external radial-velocity and transit observations from both professional and amateur observers. Using our Bayesian Atmospheric Radiative Transfer code, we characterize the atmospheres of these planets. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G. Blečić holds a NASA Earth and Space Science Fellowship.

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## 212.05 – Atmospheric, Orbital and Secondary Eclipse Analysis of HAT-P-30-WASP-51b

HAT-P-30-WASP-51b is a hot-Jupiter planet that orbits an F star every 2.8106 days at a distance of 0.0419 AU. Using the Spitzer Space Telescope in 2012 (Spitzer Program Number 70084) we observed two secondary eclipses of the planet, one in the 3.6  $\mu\text{m}$  channel on 3 January and one in the 4.5  $\mu\text{m}$  channel on 17 January. We present eclipse-depth measurements of  $0.00163 \pm 0.0001$  and  $0.00146 \pm 0.00013$  and we estimate the infrared brightness temperatures to be  $1900 \pm 50$  and  $1600 \pm 60$  for these two channels, respectively, from an analysis using our Photometry for Orbits, Eclipses, and Transits (POET) pipeline. We also refine its orbit using our own secondary-eclipse measurements in combination with radial-velocity and transit observations from both professional and amateur observers. The most notable result from this orbital analysis is a detection of eccentricity in the planet's orbit. Using only the phase of our secondary eclipses, we can constrain  $e \cos \omega$  to a minimum of  $0.0084 \pm 0.0004$ , a 20 sigma detection of one component of the orbit's eccentricity that is independent of the effects that stellar tides have on radial velocity data. We then characterize its atmosphere's temperature-pressure profile and molecular abundances using our Bayesian Atmospheric Radiative Transfer code (BART). Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G. J. Blečić holds a NASA Earth and Space Sciences Fellowship.

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## 212.06 – Secondary Eclipse Observations and Orbital Analysis of WASP-32b

We report two Spitzer secondary eclipses of the exoplanet WASP-32b. Discovered by Maxted et al. (2010), this hot-Jupiter planet has a mass of  $3.6 \pm 0.07 \text{ M}_J$  a radius of  $1.18 \pm 0.07 \text{ R}_J$  and an orbital period of  $2.71865 \pm 0.00008$  days around a G-type star. We observed two secondary eclipses in the 3.6  $\mu\text{m}$  and 4.5  $\mu\text{m}$  channels using the Spitzer Space Telescope in 2010 as a part of the Spitzer Exoplanet Target of Opportunity program (program 60003). We present eclipse depth estimates of  $0.0013 \pm 0.00023$  in the 4.5  $\mu\text{m}$  band and inconclusive results in the 3.6  $\mu\text{m}$  band. We also report an infrared brightness temperature of  $1538 \pm 110$  in the 4.5  $\mu\text{m}$  channel and refinements of orbital parameters for WASP-32b from our eclipse measurement as well as amateur and professional data that closely match previous results. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G. JB holds a NASA Earth and Space Science Fellowship.

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## 214 – Astronomy Education Research

### 214.01 – First Light Observations from the International Study of Astronomy Reasoning (ISTAR) Database

During the period between Fall 2014 and Summer 2015, the International Astronomical Union reorganized its structure to include the IAU Working Group on Theory and Methods in Astronomy Education. The initial goals of that working group are 1) promoting Astronomy Education Research (AER) by adopting the international collaboration model used by astronomy researchers, 2) fostering international astronomy education and AER capacity through the development of networks, training and shared resources, and 3) improving astronomy education by describing research based approaches to the teaching and learning of astronomy. In support of those efforts, the working group began a collaboration with the Center for Astronomy & Physics Education Research to develop the International Study of Astronomy Reasoning (ISTAR) Database, an online, searchable research tool, intended to catalog, characterize, and provide access to all known astronomy education research production, world-wide. Beginning in the Summer of 2015, a test of ISTAR's functionality began with a survey of a previously uncatalogued set of test objects: U.S.-based doctoral dissertations and masters. This target population was selected for its familiarity to the ISTAR developers, and for its small expected sample size (50-75 objects). First light observations indicated that the sample exceeded 300 dissertation objects. These objects were characterized across multiple variables, including: year of production, document source, type of resource, empirical methodology, context, informal setting type, research construct, type of research subject, scientific content, language, and nation of production. These initial observations provide motivation to extend this project to observe masters levels thesis, which are anticipated to be ten times more numerous as doctoral dissertations, other peer-reviewed contributions, contributions from the larger international community.

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### 214.02 – Assessing NASE Professional Development in Astronomy Workshops

Since 2009, the Network for Astronomy School Education (NASE) has held 55+ workshops in countries in Asia, Africa, Europe and Latin America, training more than 1200 teachers and potentially

reaching one million or more students. Like most modern professional development programs, NASE's emphasis is on interactive, hands-on learning. However, our emphasis is on "low-tech" tools that are readily available, and, inexpensive. Teachers are led through a series of activities that cover a wide range of topics in astronomy, more or less equivalent to that covered in the typical 1st year astronomy course in US colleges.

In 2014 we adopted the Astronomy Diagnostic Test as pre- and post-workshop tests to gauge the change in teachers' knowledge as a result of participation in this intervention. We chose the ADT because it is a reliable and validated instrument and is available in Spanish. In this paper we discuss our results using the Astronomy Diagnostic Test 2.0 in several countries.

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### **214.03 – Examining the Role of Numeracy in College STEM Courses: Results from the Quantitative Reasoning for College Science (QuaRCS) Assessment Instrument**

Is quantitative literacy a prerequisite for science literacy? Can students become discerning voters, savvy consumers and educated citizens without it? Should college science courses for nonmajors be focused on "science appreciation", or should they engage students in the messy quantitative realities of modern science? We will present results from the recently developed and validated Quantitative Reasoning for College Science (QuaRCS) Assessment, which probes both quantitative reasoning skills and attitudes toward mathematics. Based on data from nearly two thousand students enrolled in nineteen general education science courses, we show that students in these courses did not demonstrate significant skill or attitude improvements over the course of a single semester, but find encouraging evidence for longer term trends.

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### **214.04 – A Research-Informed Approach to Teaching about Interferometry in STEM Classrooms**

In collaboration with Associated Universities Inc. (AUI), we have engaged in a research and curriculum development program to create a new suite of evidence-based educational materials that bring the science of radio interferometry into STEM classrooms. These materials, which include Think-Pair-Share questions, presentation slides, and a new *Lecture-Tutorial*, can be used together or separately to help students understand the advantages of radio interferometers over single telescopes. Appropriate for physical science classrooms from middle school to the introductory college level, the learner-centered active engagement activities we developed are going through an iterative research and assessment process to ensure that they enable students to achieve increased conceptual understandings and reasoning skills. In this talk, we present several of the conceptually challenging collaborative learning tasks that students encounter with this new suite of educational materials and some of the assessment questions we are using to assess the efficacy of their use in general education college-level astronomy courses.

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### **214.05 – Status and Evolution of the Journal of Astronomy & Earth Science Education's First Year**

The Journal of Astronomy & Earth Science Education (JAESE.org) is a recently created, peer-reviewed journal designed to serve the discipline-based astronomy, planetary, and geo-sciences education research community. JAESE's first issue was published on December 31, 2014 and has published two volumes and three issues since that

time, encompassing 15 peer-reviewed articles. By far, the median article topic has been focused on planetarium education research, while there has only been one article on solid Earth geosciences education research. Although there is not yet an even distribution of topics across the field, there is a relatively even distribution among author demographics. Authors include a range of both junior and senior members of the field. There have been slightly female authors than male authors. Submissions are distributed to two or three reviewers with authors' names redacted from the manuscript. The average time to complete the first round of peer-review reviewers is 6.2-weeks. There have been too few manuscripts to reliably publish a "percentage acceptance rate." Finally, the majority of recently completed astronomy education research doctoral dissertations have been published in JAESE. Taken together, JAESE's guiding Editorial Advisory Board judges this to be a successful first year. In a purposeful effort to make JAESE authors' scholarly works as widely accessible as possible, JAESE adopted an open-access business model. JAESE articles are available to read free-of-charge over the Internet, delivered as PDFs. To date, the most common way articles are downloaded by readers is through Google Scholar. Instead of charging readers and libraries recurring subscription fees, JAESE charges authors a nominal submission fee and a small open-access fee, averaging about \$500 USD. These charges are similar to the traditional page charges typically charged to authors or their institutions by scientific journals, making JAESE an attractive publishing venue for many scholars to make their work as widely read as possible.

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### **214.06 – Vision Forward for NASA's Astrophysics Education Program**

NASA has recently re-structured its Science Education program with the competitive selection of twenty-seven programs. Of these, ~60% are relevant to Astrophysics, and three have primarily Astrophysics content. A brief overview of the rationale for re-structuring will be presented. We have taken a strategic approach, building on our science-discipline based legacy and looking at new approaches given Stakeholder priorities. We plan to achieve our education goals with the selection of organizations that utilize NASA data, products, or processes to meet NASA's education objectives; and by enabling our scientists and engineers with education professionals, tools, and processes to better meet user needs. Highlights of the selected programs will be presented, and how they enable the vision going forward of achieving the goal of enabling NASA scientists and engineers to engage more effectively with learners of all ages.

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### **214.07 – The Legacy of NASA Astrophysics E/PO: Conducting Professional Development, Developing Key Themes & Resources, and Broadening E/PO Audiences**

For the past six years, NASA's Science Mission Directorate (SMD) has coordinated the work of its mission- and program-embedded education and public outreach (E/PO) efforts through four forums representing its four science divisions. The Astrophysics Forum, as the others, has built on SMD's long-standing principle of partnering scientists and educators and embedding E/PO in its missions to encourage and coordinate collaborative efforts to make the most efficient and effective use of NASA resources, personnel, data and discoveries in leveraged ways, in support of the nation's science education. Three priorities established early in the Forum's period of activity were to collaboratively enhance professional development for formal and informal educators, develop key themes & resources centered on astrophysics topics, and broaden the reach of astrophysics E/PO to traditionally underserved audiences in STEM subjects. This presentation will highlight some of the achievements of the Astrophysics E/PO community and Forum in these priority areas. This work constitutes an ongoing legacy--a firm foundation on which the new structure of NASA SMD education efforts will go forward.

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**Contributing team(s):** the NASA Astrophysics E/PO Community

## 214.08 – The Legacy of NASA Astrophysics E/PO: Scientist Engagement and Higher Education

For the past six years, NASA's Science Mission Directorate has coordinated the work of its mission- and program-embedded education and public outreach (E/PO) efforts through four forums representing its four science divisions. The Astrophysics forum, as the others, has built on the long-standing mission E/PO 1% allocation and embedded scientist/educator partnerships to encourage and coordinate collaborative efforts to make the most efficient and effective use of NASA resources, personnel, data and discoveries in leveraged ways, in support of the nation's science education. Two of the priorities established early in the forum's period of activity were to enhance scientist engagement in E/PO and to coordinate the community in providing useful higher education resources based on determined needs. This presentation will highlight some of the achievements for these two priorities over the past six years, how the products and efforts are being preserved, and how they can continue to be accessed as NASA SMD transitions to a new Education and Communication landscape. The work constitutes an ongoing legacy—a firm foundation on which the new structure of NASA SMD Education efforts will go forward.

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## 217 – Multi-faceted Studies of Galaxy Evolution

### 217.01 – The interplay between galaxy transition and molecular gas in the next generation of radio facilities

The well-known galaxy color bimodality suggests that the paths which galaxies transition from blue, gas-rich spirals to red, gas-poor early-type (elliptical and lenticular) galaxies must be traveled rapidly to explain the dearth of intermediate stage objects. Studying the relationship between the interstellar fuel out of which stars form, and the global changes that galaxies undergo provides a window not only into the paths of transitions that galaxies take, but also how the transition mechanisms can feed back upon the relationship between molecular gas and star formation. I will discuss our results from  $z=0$  transitioning galaxy surveys from CARMA and IRAM, and the ways in which next generation radio telescopes will not only provide detailed insights into the relationship between gas and transition at  $z=0$ , but also how this relationship evolves with redshift.

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**Contributing team(s):** The SPOGS Team

### 217.02D – Galactic Conformity Beyond the Virial Radius in Observations and Simulations

We report on the presence of galactic conformity at distances out to 10 Mpc in the Illustris suite of simulations, as well as on a search for conformity in the PRIMUS redshift survey. Galactic conformity, where red galaxies preferentially surround other red galaxies at fixed mass, is used as a probe of galaxy assembly bias — the picture in which environmental factors and assembly history, other than dark matter halo mass, are necessary to understand the halo occupation statistics of galaxies. Using the Illustris suite of simulations, we demonstrate how a galactic conformity signal at  $z=0$  can arise from a combination of the underlying dark matter clustering as a function of halo formation age and a galaxy color–halo age relation. With

observations from the PRIMUS redshift survey, we probe the deprojected 3D galactic conformity signal as a function of redshift over the range  $0.2 < z < 1$ . Together, these results motivate further observations to discern the effect size of to discern the effect size of the galactic conformity signal, its variation in redshift, and what baryonic processes, such as feedback or accretion, play a dominant role in its creation.

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**Contributing team(s):** Primus Team, Illustris Team

### 217.03D – Shining a light on star formation driven outflows: the physical conditions within galactic outflows

Stellar feedback drives energy and momentum into the surrounding gas, which drives gas and metals out of galaxies through a galactic outflow. Unfortunately, galactic outflows are difficult to observe and characterize because they are extremely diffuse, and contain gas at many different temperatures. Here we present results from a sample of 37 nearby ( $z < 0.27$ ) star forming galaxies observed in the ultraviolet with the Cosmic Origins Spectrograph on the Hubble Space Telescope. The sample covers over three decades in stellar mass and star formation rate, probing different morphologies such as dwarf irregulars and high-mass merging systems. Using four different UV absorption lines (O I, Si II, Si III and Si IV) that trace a wide range of temperatures (ionization potentials between 13.6 eV and 45 eV), we find shallow correlations between the outflow velocity or the equivalent width of absorption lines with stellar mass or star formation rate. Absorption lines probing different temperature phases have similar centroid velocities and line widths, indicating that they are comoving. Using the equivalent width ratios of the four different transitions, we find the ratios to be consistent with photo-ionized outflows, with moderately strong ionization parameters. By constraining the ionization mechanism we model the ionization fractions for each transition, but find the ionization fractions depend crucially on input model parameters. The shallow velocity scalings imply that low-mass galaxies launch outflows capable of escaping their galactic potential, while higher mass galaxies retain all of their gas, unless they undergo a merger.

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### 217.04 – The gaseous environments of quasars: outflows, feedback & cold mode accretion

We are interested in the early stages of massive galaxy formation at high redshifts, when cold mode accretion and outflows that drive galaxy-scale blowouts and feedback are expected to occur. It is quite possible that infall (e.g. cold mode accretion) and outflow (e.g. a blowout) occur together, leading to complex gas structures. We are conducting a study of rich complexes of narrow CIV absorption lines to find direct evidence for cold mode accretion and gaseous fragments shredded and dispersed by powerful outflows. Study of these rich complexes will provide us critical information of gas, such as velocity, ionization, metallicity, column density, kinetic energy, etc. The information could help us to understand the gas origins. We search SDSS, VLT and Keck archives for quasars with complex multi-component CIV systems or/and strong infalling systems. We obtain particular interesting results for the quasar Q0119-046. The spectra show rich infalling and partial covering complexes. The electron density of the gas is  $\sim 10^{3.4} \text{ cm}^{-3}$ , and the gas is at a distance  $\sim 3.6 \text{ kpc}$  from the central source. The gas is metal poor and seems to be infalling at the speed  $\sim 70 \text{ km/s}$  into the galaxy. And it appears to partially cover the continuum source, requiring absorber size scales less than  $0.01 \text{ pc}$ . This result for very small clouds on galactic ( $> 3.6 \text{ kpc}$ ) scales is unusual but not unprecedented. It may provide evidence that the clouds are fragments from a shredded cloud, dispersed by an unseen high-speed quasar-driven outflow.

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## 217.05D – The Bivariate Luminosity--HI Mass Distribution Function of Galaxies based on the NIBLES Survey

We use 21cm HI line observations for 2610 galaxies from the Nançay Interstellar Baryons Legacy Extragalactic Survey (NIBLES) to derive a bivariate luminosity--HI mass distribution function. Our HI survey was selected to randomly probe the local ( $900 < cz < 12,000$  km/s) galaxy population in each 0.5 mag wide bin for the absolute z-band magnitude range of  $-13.5 < M_z < -24$  without regard to morphology or color. This targeted survey allowed more on-source integration time for weak and non-detected sources, enabling us to probe lower HI mass fractions and apply lower upper limits for non-detections than would be possible with the larger blind HI surveys. Additionally, we obtained a factor of four higher sensitivity follow-up observations at Arecibo of 90 galaxies from our non-detected and marginally detected categories to quantify the underlying HI distribution of sources not detected at Nançay. Using the optical luminosity function and our higher sensitivity follow up observations as priors, we use a 2D stepwise maximum likelihood technique to derive the two dimensional volume density distribution of luminosity and HI mass in each SDSS band.

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## 217.06 – The Cosmic Infrared Background as a Test of Cold versus Warm Dark Matter

Redshifted UV emission from reionization era galaxies is expected to contribute to the cosmic infrared background (CIB). A warm dark matter universe should have a lower (CIB) than a cold dark matter universe due to the suppression of low mass halos. Future deep surveys will resolve fainter high redshift galaxies, eventually resolving the halo mass threshold of typical warm dark matter models. Any remaining unresolved component of the CIB attributable to redshift  $\sim 10$  sources will reflect the luminosity function of faint galaxies in low mass halos. If we live in a warm dark matter universe, then we should be able to "resolve away" the high redshift galactic stellar contribution to the diffuse CIB. However, if we live in a CDM universe, some diffuse background from stars in small high redshift halos should remain. Recent measurements of the CIB suggest a large component due to redshift  $\sim 10$  galactic UV emission (Mitchell-Wynne et al.). Although current uncertainties are large, such a high CIB signal from redshift  $\sim 10$  galaxies, if confirmed, would be difficult to reconcile not only in WDM, but also in CDM.

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## 218 – Black Holes II: Surveys and Individual Objects

### 218.01D – Are we baffled? Astrophysical implications of Parkes Pulsar Timing Array gravitational-wave constraints

Mergers of massive galaxies are thought to host binary supermassive black holes (SMBHs), which are driven to coalesce by their gravitational-wave (GW) emission. The ubiquity of galaxy mergers through cosmic time then implies the existence of a GW background (GWB) from binary SMBHs. For the last decade, collaborations worldwide have been searching for signatures of GWs in millisecond radio pulsar timing data. This dissertation work is focussed on predicting the nature of the GWB, and on constraining GWB models with pulsar timing data from the Parkes telescope. We find that current estimates of galaxy stellar mass functions, merger rates, and SMBH masses, coupled with the assumption of GW-driven binary SMBH coalescence in each galaxy merger, result in a power-law GWB strain spectrum with amplitude  $5.1 \times 10^{-16} < A_{\gamma} < 2.4 \times 10^{-15}$  at  $(1 \text{ year})^{-1}$  (95% confidence). This prediction is however in tension with recent 11-year Parkes data on four millisecond pulsars, which imply an upper limit on the GWB amplitude of  $A_{\gamma} < 1 \times 10^{-15}$  (95% confidence). Indeed, all current predictions for the GWB that include

the assumption of universal GW-driven binary SMBH coalescence are excluded with between 91% and 99.7% probability. This startling result challenges the assumptions underlying these predictions. Based on modeling of the growth and demographics of SMBHs, and for the evolution of binary SMBHs in galaxy merger remnants, we consider a series of possible implications of our result, and how they may be tested. It is possible that galaxy merger rates are overestimated, or that the formation of milliparsec-separation binary SMBHs is not ubiquitous in mergers. Alternatively, while emitting detectable GWs, binary SMBHs may also lose energy and angular momentum to their environments, hence attenuating the GWB. Other, intriguing, possibilities are a non-unity SMBH occupation fraction in massive galaxies beyond the local Universe due to rare seed formation, or that the GW "background" is dominated by emission from just a few nearby massive binary systems.

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**Contributing team(s):** Parkes Pulsar Timing Array

### 218.02 – The Best and the Brightest: Tidal Disruption Events Discovered by ASAS-SN

Even today only human eyes scan the entire optical sky for the violent, variable, and transient events that shape our universe. The All-Sky Automated Survey for SuperNovae (ASAS-SN or "Assassin") is changing this by monitoring the visible sky to 17th magnitude every 2-3 days using multiple telescopes in the northern and southern hemispheres. Having been in operation for two years, ASAS-SN is discovering new transient objects daily, and while the primary goal of ASAS-SN is a complete survey of bright, nearby supernovae, ASAS-SN also discovers many other interesting nearby transients. Notably, ASAS-SN has discovered three bright tidal disruption events (TDEs), the three closest such events ever discovered at optical wavelengths, providing the opportunity to obtain detailed follow-up data at many wavelengths. ASAS-SN is discovering roughly 1 TDE for every 60 Type Ia supernovae, a rate that is significantly higher than other surveys. By virtue of their brightness, TDEs discovered by ASAS-SN can also be studied in unprecedented detail for many months, allowing deeper insight into their physics.

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**Contributing team(s):** ASAS-SN

### 218.03 – Using Microlensing Maps to Determine Spin of Black Holes

Quasar accretion disks are expected to have central cavities corresponding to their Supermassive Black Hole's (SMBH) Innermost Stable Circular Orbit (ISCO). Cavity size depends on black hole mass, spin, and relative accretion direction, and so given a mass estimate, measurement of ISCO size constrains SMBH spin; such a measurement would be invaluable in determining the role of spin in AGN emission processes, and also in understanding SMBH growth by constraining the magnitude of accretion events. While not spatially resolvable, ISCO cavities are expected to leave a signature on the light curves of gravitationally lensed quasars when they undergo a strong microlensing event. Using simulations of these events for Q2237+030, the Einstein Cross, we have shown that ISCO width can be measured using current observatories if monitored through a cusp-crossing microlensing event.

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### 218.05 – Detection of Extended Radio Emission in the Center of NGC 404: Implications for the Accreting Intermediate-Mass Black Hole Scenario

We present the results of a 0.15"-resolution (2.25 pc), Ku-band (12–18 GHz) Karl G. Jansky Very Large Array (VLA) study of the

nucleus of NGC 404. Previous 5 GHz VLA observations at a spatial resolution of 0.4" revealed compact radio emission co-located with a hard X-ray nuclear point source and the optical center of the galaxy, within the known errors. This was interpreted as evidence that the candidate intermediate-mass black hole (IMBH) in the center of NGC 404 is actively accreting material at low levels. However, follow-up milliarcsecond-resolution, very long baseline interferometric (VLBI) observations did not detect any emission, challenging the accreting IMBH interpretation. Our Ku-band observations bridge the gap in spatial resolution between the previous VLA and VLBI observations, and successfully resolve the radio emission ( $d \sim 17$  pc) previously imaged at lower resolution. In combination with the existing VLA data, the new Ku-band data indicate a steep integrated radio spectral index from 1 to 18 GHz, suggesting the source is dominated by optically-thin synchrotron emission. We build upon the existing multiwavelength observations of this galaxy and provide a re-assessment of the physical origin of the extended radio emission near the center of NGC 404. While an accreting IMBH remains a strong possibility for the origin of the radio source, our new analysis strengthens the case for a supernova remnant origin. We discuss future observational tests needed to distinguish between these scenarios, as well as the importance of accurately determining the properties of the NGC 404 nuclear engine in the context of the fundamental plane of black hole activity.

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### 218.06 – A Super-Eddington, Compton-Thick Wind in GRO J1655-40?

During its 2005 outburst, GRO J1655-40 was observed at high spectral resolution with the *Chandra* HETGS, revealing a spectrum rich with blueshifted absorption lines of elements ranging from oxygen to nickel, including exotic metals like titanium and scandium. It has been argued that magnetic fields must be responsible for the dense accretion disk wind that produces these deep absorption lines. But questions about this outburst remain, because the presence of this exotic wind coincides with extremely soft and curved X-ray spectra, remarkable X-ray variability, and bright, unexpected optical/infrared emission that varies on the orbital period. I will argue that the unusual features of this "hypersoft state" are natural consequences of a super-Eddington Compton-thick wind from the disk.

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### 218.07 – How Massive are the Heaviest Black Holes in X-ray Binaries? Exploring IC 10 X-1 and its Kind.

Black hole X-ray binaries represent a unique probe of stellar evolution and the most extreme physical conditions found in nature. The X-ray binary IC 10 X-1 occupies an important niche as a link between BH-XRBs and Ultra Luminous X-ray Sources (ULX) due to its intermediate luminosity ( $10^{38}$  erg/s), and role as a central exemplar of the association of between low metallicity galaxies and maximum BH mass.

The most secure and direct dynamical evidence for any BH mass comes from the radial velocity (RV) curve coupled with eclipse timing measurements. We phase-connected X-ray timing data accumulated over a decade with *Chandra*/XMM, with the optical RV curve, revealing a surprising simultaneity of mid X-ray eclipse and the maximum blueshift velocity of He II emission lines. Our interpretation is that the optical emission lines originate in a shadowed sector of the WR star's stellar wind which escapes X-ray ionization by the compact object. The RV shifts are therefore a projection effect of the stellar wind, and unrelated to the system's mass function which becomes completely unknown. *Chandra*, XMM and NuStar datasets present a complex picture of radiative transfer through a photo-ionized wind. A search for the orbital period derivative (P-dot) by X-ray timing offers additional insights, and we present a simulation for the feasibility of constraining P-dot via optical means.

This is a substantial change to our understanding of IC 10 X-1, and

with similar results reported for its "near twin" NGC 300 X-1, adds new a dimension to the fascinating question of the maximum mass for stellar BHs.

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### 218.08 – Fast IR photometry of V404 Cyg in outburst with CIRCE/GTC

We used the fast photometry mode of the Canarias InfraRed Camera Experiment (CIRCE) on the 10.4-meter Gran Telescopio Canarias to observe V404 Cyg, a stellar mass black hole binary, on June 25th for about one and a half hour during its 2015 outburst. CIRCE provided 10Hz sampling in the Ks-band (2.2 microns) In addition, we obtained simultaneous multi wavelength data from our collaborators: three GHz radio bands from the AMI telescope and two optical bands (g'-r') from ULTRACAM on the William Herschel 4.2-meter telescope. We extract spectral indices from the three radio bands and an optical-to-infrared color index from infrared and optical lightcurves. With a positive and increasing radio spectral index, we have identified an infrared outburst about 30 minutes with a clear self absorbed synchrotron ejection event. We further investigate the correlation between spectral indexes and multi wavelength flux measurements to understand evolution of ejection event. We also report on very fast IR flares and their correlation with optical events.

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## 219 – AGN, QSO, Blazars: Host Galaxies and Individual Sources

### 219.01 – The dynamics and energetics of FR-II radio galaxies

Determining the shape of the energy spectrum for an electron population can often give key insights into the underlying physics of a radio source. In principle, a region emitting via synchrotron radiation will preferentially cool higher energy electrons leading to a steeper, more strongly curved spectrum in older regions of plasma. Models of this so-called spectral aging have become a commonly used tool when describing the processes involved in emission from the lobes of FR-II radio galaxies; however, the lack of high resolution, broad-bandwidth observations has historically meant the details of these spectra have remained largely unexplored on small spatial scales. The broad-bandwidth capabilities of telescopes such as the JVLA, LOFAR, e-MERLIN and ultimately the SKA, will mean that the spectrum of any given source can be determined within the bandwidth of any given observation, producing a detailed spectral shape. This type of detailed spectral analysis is therefore set to become standard practice when dealing with any new broadband radio observations.

In this talk, we provide details of the Broadband Radio Astronomy ToolS (BRATS) software package that uses innovative techniques to analyze this new generation of radio data. Through the application of BRATS to LOFAR and JVLA observations, we present results from our latest investigations into the dynamics and energetics of nearby FR-II radio galaxies and their spectral structure on small spatial scales. We go on to discuss how these new findings impact upon our current understanding of the underlying physics of FR-II radio galaxies and, ultimately, their impact of galaxy evolution as a whole.

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### 219.02 – Host galaxies of luminous type II AGN: Winds, shocks, and comparisons to The SAMI Galaxy Survey

We present IFS observations of luminous ( $\log(L[\text{O III}]/L_{\odot}) > 8.7$ ) local ( $z < 0.11$ ) type II AGN, and demonstrate that winds are ubiquitous within this sample and have a direct influence on the ISM of the host galaxies. We use both non-parametric (e.g. line width and asymmetry) and multi-Gaussian fitting to decompose the complex emission profiles close to the AGN. We find line widths containing 80% flux in the range 400 – 1600 km/s with a mean of  $790 \pm 90$  km/s, such high velocities are strongly suggestive that these AGN are driving ionized outflows. Additionally, multi-Gaussian fitting reveals that 14/17 of our targets require 3 separate kinematic components in the ionized gas in their central regions. The broadest components of these fits have FWHM = 530 – 2520 km/s, with a mean value of  $920 \pm 50$  km/s. By simultaneously fitting both the  $\text{H}\beta/[\text{O III}]$  and  $\text{H}\alpha/[\text{N II}]$  complexes we construct ionization diagnostic diagrams for each component. 13/17 of our galaxies show a significant ( $> 95\%$ ) correlation between the  $[\text{N II}]/\text{H}\alpha$  ratio and the velocity dispersion of the gas. Such a correlation is the natural consequence of a contribution to the ionization from shock excitation and we argue that this demonstrates that the outflows from these AGN are directly impacting the surrounding ISM within the galaxies. In addition, we use stellar absorption features to measure kinematics for these AGN host galaxies and those of a control sample selected from the SAMI Galaxy Survey to search for evidence of these luminous AGN being preferentially hosted by disturbed or merging systems.

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**Contributing team(s):** The SAMI Galaxy Survey Team

### 219.03 – Three LINERs Under the Hubble Spectral Microscope

The majority of low-ionization nuclear emission regions (LINERs) harbor supermassive black holes (SMBHs) with very low accretion rates. Since SMBHs spend most of their lifetimes in these low accretion-rate states, understanding LINERs is important for understanding active galactic nuclei (AGN) in the context of galaxy evolution. On scales of  $\sim 100$  pc, the energy budget of LINERs appears to be deficient when the only source of power considered is the AGN. Thus, other energy sources are likely to contribute to the excitation of the emission-line gas. To probe these sources, we observed three nearby, bright, and representative LINERs with the Space Telescope Imaging Spectrograph (STIS) on the Hubble Space Telescope (HST). We specifically looked at the 0.1-1 arcsecond scale (corresponding to  $\sim 5$ -50 pc) to find what these energy sources are and how far from the nucleus they take over the excitation of the gas. After subtracting both the unresolved nuclear light and the spatially-extended starlight, we measured a number of diagnostic emission line ratios. We find that within 10 pc, the observed line ratios of  $[\text{O III}]/[\text{O II}]$  vs  $[\text{O III}]/\text{H-beta}$  are consistent with AGN photoionization. The line ratios of  $[\text{N II}]/\text{H-alpha}$  vs  $[\text{O III}]/\text{H-beta}$  show that at larger distances, the excitation mechanism is most likely consistent with hot stars or shocks. Shocks are particularly appealing in the case of NGC 4278, which harbors a Gigahertz-Peaked radio source with small jets detected by the VLBA. If hot stars are the primary excitation mechanism, these are most likely post-AGB stars (from the old stellar population). We conclude from these representative cases that the characteristic LINER emission-line spectrum does not result from a single excitation mechanism, but rather from a combination of different mechanisms within the central 100 pc of each object that varies from object to object.

**Author(s):** Mallory Molina<sup>5</sup>, Michael Eracleous<sup>5</sup>, Aaron J. Barth<sup>6</sup>, Dan Maoz<sup>3</sup>, Jonelle Walsh<sup>4</sup>, Luis C. Ho<sup>1</sup>, Joseph C. Shields<sup>2</sup>

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### 219.04D – Multi-wavelength polarimetry and variability study of M87 jet during 2002-2008

In this dissertation, we present the multi-wavelength study of M87 jet. We compare the radio and optical polarimetry and variability. We attempt to study the spectrum of the jet in radio through X-rays wavelengths. By comparing the data with previously published VLA and HST observations, we show that the jet's morphology in total and polarized light is changing significantly on timescales of  $\sim 1$  decade. We are looking for the variability of different knots and changes in their spectra using our deep, high resolution observations of the jet between 2002 and 2008. The observations have 2-3 times better resolution than any similar previous study (Perlman et al. 1999) in addition allowing us to observe variability. During this time, the nucleus showed month-scale variability in optical and X-rays and also flared twice in all wave-lengths including radio. The knot HST-1, located closest to the nucleus, displayed a huge flare, increasing about 100 times in brightness. The knot A and B complex shows variations in polarization structures indicating the presence of a helical magnetic field which may be responsible for the in-situ particle accelerations in the jet. We compare the evolution of different knots and components of the jet, when our observations overlap with the multi-wavelength monitoring campaigns conducted with HST and Chandra and comment on particle acceleration and main emission processes. We further use the data to investigate the observed 3-dimensional structure of the jet and the magnetic field structure.

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### 219.05 – Morphological research on radio loud AGN 4C39.25 using KaVA observations

4C39.25 (0923+392) is a distant radio loud AGN placed at redshift 0.695. Its kilo-parsec scale jet observed by VLBA (Kollgaard et al. 1990) and parsec scale jet observed by VLBA (Kellermann et al. 1998) are misaligned. This might indicate episodic-jet activity which recently turned on.

This object currently shows two stationary compact parsec-scale components: a bright jet component on the east and less luminous core on the west. Also, it is known that there have been superluminal jet components which are flowing from the core toward east, and then merging with the bright jet component (Marscher et al. 1991, Alberdi et al. 2000, Lister et al. 2013). Including the detection of broad emission lines (SDSS), its viewing angle was concluded to be small. However, the jet component being more luminous than the core is abnormal for a source with a small viewing angle.

Furthermore, it has young radio galaxy-like properties such as non-variation in total flux (Alberdi et al. 1997, 2000, MOJAVE database) and a high frequency peak in the spectral energy distribution (Orienti et al 2007). In this case, it is more reliable to think that viewing angle of 4C39.25 is large.

Korean VLBI Network (KVN) and VLBI Exploration of Radio Astronomy (VERA) Array (KaVA) is a cooperated VLBI system of Korea and Japan which provides high-frequency (23GHz and 43GHz) and high spatial resolution (1.2mas and 0.6mas). Their advantages of multi-wavelength and relatively high S/N ratio relative to its number of baseline allow us to discover the central region and dim structures of 4C39.25. We present results of several epochs observed during 2013 to 2014, focusing on morphological changes of 4C39.25 using KaVA images. According to these results, we were able to find a recently emitted counter-jet component for images of first 6 epochs. Also the counter-jet component propagates along a curved trajectory, and it shows an extreme superluminal motion. This might indicate a necessity of relatively large viewing angle or a helical motion of jet flow.

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**Contributing team(s):** KaVA AGN WG members

### 219.06 – Discovery of a Fast, Broad, Transient outflow in NGC 985

We observed the Seyfert 1 galaxy NGC 985 on multiple occasions using XMM-Newton and the Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope (HST) to search for variability in its UV and X-ray absorption features. Our observations are simultaneous and span timescales of days to years. We find that soft X-ray obscuration that absorbed the low energy continuum of NGC 985 in August 2013 diminished greatly by January 2015. The total X-ray column density decreased from  $2.1 \times 10^{22} \text{ cm}^{-2}$  to  $6 \times 10^{21} \text{ cm}^{-2}$ . We also detect broad, fast UV absorption lines in COS spectra obtained during the 2013 obscuration event. Lines of C III\*, Ly alpha, S IV and C IV with outflow velocities of  $\sim 5970 \text{ km s}^{-1}$  and a full-width at half-maximum of  $1420 \text{ km s}^{-1}$  are prominent in the 2013 spectrum, but have disappeared in all but Ly alpha in the 2015 spectra. The ionization state and the column density of the UV absorbing gas is compatible with arising in the same gas as that causing the X-ray obscuration. The high velocity of the UV-absorbing gas suggests that the X-ray obscurer and the associated UV outflow are manifestations of an accretion disk wind.

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### 220 – Extrasolar Planet Detection with High-Precision Radial Velocity

#### 220.01 – $\nu$ Octantis: a conjectured S-type retrograde planet in a spectroscopic binary system

$\nu$  Octantis is a single-lined spectroscopic binary system consisting of a K-giant primary and a secondary orbiting near 1050 days. Radial velocity observations reveal an additional  $\sim 400$  day periodicity with a semi-amplitude of 40 m/s. If this signal is planetary in nature, the  $\nu$  Octantis system would be unique amongst all known exoplanet systems in that long-term stability can only be achieved if the orbit is retrograde with respect to the stellar companions (i.e. mutual inclination  $\sim 180^\circ$ ).

Spectral line analyses suggest this signal is unlikely to be due to surface activity or pulsations (Ramm 2015). We also rule out an exotic scenario where the secondary itself is a binary.

We report an analysis of 1437 radial velocity measurements taken with HERCULES at the Mt. John Observatory spanning nearly 13 years, 1180 being new iodine iodine-cell velocities (2009-2013). The sensitive orbital dynamics of the two-companion model allow us to constrain the three-dimensional orbital architecture directly from the observations. Posterior samples obtained from an n-body Markov chain Monte Carlo (Nelson et al. 2014) yields a mutual inclination of  $158.4 \pm 1.2^\circ$ . None of these are dynamically stable beyond 106 years. However, a grid search around the posterior sample suggests that they are in close proximity to a region of parameter space that is stable for at least 106 years.

If real, the tight orbital architecture here imposes a considerable challenge for formation of this dynamically extreme system.

**Author(s):** Benjamin E. Nelson<sup>1</sup>, David Ramm<sup>2</sup>, Michael Endl<sup>3</sup>  
**Institution(s):** 1. CIERA - Northwestern University, 2. University of Canterbury, 3. University of Texas, Austin

#### 220.02D – Giant Planets in Open Clusters and Binaries: Observational Constraints on Migration

Some giant planets migrate from their birthplace beyond the ice line to short-period orbits just a fraction of an AU from their host stars. Though many theories have been proposed, it is not yet clear which mechanism is most important for migration, and by extension, in

which types of planetary system we can expect a greater prevalence of disruptive gas giant migration. One way to constrain this process is to observe the orbital properties of migrating planets, which are expected to be shaped according to the mode of migration: in general, interaction with the gas disk should produce circular, coplanar orbits, while multi-body processes stir up eccentricities and inclinations. Unfortunately, tidal and magnetic interactions between hot Jupiters and their host stars can obscure these differences by damping eccentricities and inclinations over time, so the most direct constraints will come from difficult-to-observe young systems. Additional constraints on migration can be obtained by observing the architectures of systems containing short-period giant planets: if an outer companion is often responsible for driving migration, there should be a higher incidence of massive companions on wide orbits in hot Jupiter systems than in systems not hosting a short-period giant planet. Further, the properties of these outer companions can help differentiate between multi-body migration mechanisms. We describe two complementary surveys that we have carried out to address these problems. The first, a precise radial-velocity survey in nearby adolescent (100-600 Myr) open clusters, characterizes the orbits of giant planets soon after migration. The second, an adaptive optics imaging survey of hot Jupiter host stars, constrains the population of wide companions in hot Jupiter systems. We present the results from these two surveys and discuss the orbital properties and system architectures of our discoveries in the context of giant planet migration.

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#### 220.03D – Weighing Rocky Exoplanets with Improved Radial Velocimetry

The synergy between Kepler and the ground-based radial velocity (RV) surveys have made numerous discoveries of small and rocky exoplanets, opening the age of Earth analogs. However, most (29/33) of the RV-detected exoplanets that are smaller than 3 Earth radii do not have their masses constrained to better than 20% - limited by the current RV precision (1-2 m/s). Our work improves the RV precision of the Keck telescope, which is responsible for most of the mass measurements for small Kepler exoplanets. We have discovered and verified, for the first time, two of the dominant terms in Keck's RV systematic error budget: modeling errors (mostly in deconvolution) and telluric contamination. These two terms contribute 1 m/s and 0.6 m/s, respectively, to the RV error budget (RMS in quadrature), and they create spurious signals at periods of one sidereal year and its harmonics with amplitudes of 0.2-1 m/s. Left untreated, these errors can mimic the signals of Earth-like or Super-Earth planets in the Habitable Zone. Removing these errors will bring better precision to ten-year worth of Keck data and better constraints on the masses and compositions of small Kepler planets. As more precise RV instruments coming online, we need advanced data analysis tools to overcome issues like these in order to detect the Earth twin (RV amplitude 8 cm/s). We are developing a new, open-source RV data analysis tool in Python, which uses Bayesian MCMC and Gaussian processes, to fully exploit the hardware improvements brought by new instruments like MINERVA and NASA's WYIN/EPDS.

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**Contributing team(s):** the California Planet Survey Consortium

#### 220.04 – The Latest Results from Project NIRRVS: Precise Near Infrared Radial Velocity Surveys

We will present the latest results from a prototype PRV survey with CSHELL. With CSHELL at the NASA Infrared Telescope Facility atop Mauna Kea ( $R \sim 46,000$ ), we have completed a PRV 2.3 micron survey to detect exoplanets around  $\sim 30$  red, low mass, and young stars. We are able to reach long-term radial velocity dispersions of  $\sim 30$  m/s on our survey targets. We are following up candidate RV variables, and have confirmed other previously known RV variables. With a spectral grasp of only 5 nm at 2.3 microns, this performance with CSHELL is limited by detector artifacts, and fringing in the data

and flatfields. iSHELL will replace CSHELL at IRTF, with first light expected in April 2016. iSHELL is a 1.15-5.4 micron high spectral resolution ( $R \sim 70,000$ ) immersion grating, cross-dispersed, white pupil spectrograph. With iSHELL we should be able to obtain a precision of less than 5 m/s in the NIR with iSHELL from the improvements in spectral grasp alone.

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**Contributing team(s):** NIRRVS Collaboration

### 220.05D – The Automated Planet Finder's automation & first two years of science

The Automated Planet Finder (APF) is the newest facility at Lick Observatory, comprised of a 2.4m telescope coupled with the high-resolution Levy echelle spectrograph. Purpose built for exoplanet detection and characterization, 80% of the telescope's observing time is dedicated to these science goals. The APF has demonstrated 1 m/s radial velocity precision on bright, RV standard stars and performs with the same speed-on-sky as Keck/HIRES when observing M-dwarfs.

The telescope is fully automated for RV operations, using a dynamic scheduler that makes informed decisions on which targets to observe based on scientific interest, desired cadence, required precision levels and current observing conditions, all on a minute-to-minute basis. This ensures that time is not wasted chasing non-optimal targets on nights with poor conditions and enables rapid changes to the overall science observing strategy.

The APF has contributed to the detection of four planetary systems in its first two years of scientific operations. Our most recent detection is that of a 6-planet system around the bright ( $V=5.5$ ), nearby ( $d=6.5\text{pc}$ ), K3V star HD 219134. The planets in this system have masses ranging from 3.5 to  $108 M_{\text{Earth}}$ , with orbital periods from 3 to 2247 days. An independent detection of the inner 4 planets in this system by the HARPS-N team has shown that the 3d planet transits the star, making this system ideal for follow-up observations.

I will discuss the design and implementation of the APF's dynamic scheduler, the telescope's planet detections to date, overall performance results of the telescope and our future observing strategy.

**Author(s):** Jennifer Burt<sup>1</sup>, Greg Laughlin<sup>1</sup>, Steven S. Vogt<sup>1</sup>, Bradford Holden<sup>1</sup>

**Institution(s):** 1. University of California - Santa Cruz

### 220.06 – The Dharma Planet Survey (DPS), a Robotic, High Cadence and High Doppler Precision Survey of Habitable Rocky Planets around Nearby Stars

The Dharma Planet Survey (DPS) is to monitor  $\sim 100$  nearby very bright FGKM dwarfs (most of them brighter than  $V=8$ ) during 2014-2018 using the TOU optical very high resolution spectrograph ( $R \sim 100,000$ , 380-900nm) at the 2m Automatic Spectroscopy Telescope at Fairborn Observatory initially (2014-2015) and at the dedicated 50-inch Robotic Telescope (2016-2018) on Mt. Lemmon after the telescope is installed in the fall of 2015. Operated in high vacuum ( $< 0.01\text{mTorr}$ ) with precisely controlled temperature ( $\sim 1\text{-}2\text{ mK}$ ), TOU has delivered  $\sim 1\text{ m/s}$  (RMS) instrument stability after the hardware upgrade in September 2015. DPS aims at reaching better than 0.5 m/s Doppler measurement precision for bright survey targets after the instrument tiny drift is carefully calibrated with Thorium-Argon and Sine reference sources. With very high RV precision and high cadence ( $\sim 100$  observations per target randomly spread over 450 days), a large number of rocky planets, including possible habitable ones, are expected to be detected. The survey also provides the largest single homogenous high precision RV sample of nearby stars for studying low mass planet populations and constraining various planet formation models. Early scientific results from the DPS pilot survey of 25 FGKM dwarfs will be presented.

**Author(s):** Jian Ge<sup>2</sup>, Bo Ma<sup>2</sup>, Matthew W. Mutterspaugh<sup>1</sup>, Michael Singer<sup>2</sup>, Frank Varosi<sup>2</sup>, Scott Powell<sup>2</sup>, Michael W. Williamson<sup>1</sup>, Sirinrat Sithajan<sup>2</sup>, Nolan Grieves<sup>2</sup>, Bo Zhao<sup>2</sup>, Sidney Schofield<sup>2</sup>, Jian Liu<sup>2</sup>, Anthony Cassette<sup>2</sup>, Kevin Carlson<sup>2</sup>, Khaya Klanot<sup>2</sup>, Sarik Jeram<sup>2</sup>, Rory Barnes<sup>3</sup>

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## 223 – Cosmology, CMB, and Dark Matter I

### 223.01 – Testing Gravity using Cosmic Voids

Though general relativity is well-tested on small (Solar System) scales, the late-time acceleration of the Universe provides strong motivation to test GR on cosmological scales. The difference between the small and large scale behavior of gravity is determined by the screening mechanism in modified gravity theories. Dark matter halos are often screened in these models, especially in models with Vainshtein screening, motivating a search for signatures of modified gravity in cosmic voids. We explore density, force, and velocity profiles of voids found in  $N$ -body simulations, using both dark matter particles and dark matter halos to identify the voids. The prospect of testing gravity using cosmic voids may be limited by the sparsity of halos as tracers of the density field.

**Author(s):** Bridget Falck<sup>1</sup>

**Institution(s):** 1. University of Oslo

### 223.02D – Cosmological constraints from weak lensing non-Gaussian statistics

Weak gravitational lensing is one of the most promising techniques to probe dark energy. Our work to date suggests that the information in the nonlinear regime exceeds that in the two-point functions. Using the publicly available data from the  $154\text{ deg}^2$  CFHTLenS survey and a large suite of ray-tracing  $N$ -body simulations on a grid of 91 cosmological models, we find that constraints from peak counts are comparable to those from the power spectrum, and somewhat tighter when different smoothing scales are combined.

I will also introduce the utility of cross-correlating weak galaxy lensing maps with CMB lensing maps, a technique that will be useful to probe structures at an intermediate redshift of 0.9, as larger weak lensing surveys such as HSC, DES, KiDS, Euclid, and LSST come online. We cross-correlate the CFHTLenS galaxy lensing convergence maps with Planck CMB lensing maps. Our results show two sigma tension with the constraints obtained from the Planck temperature measurements. I will discuss possible sources of the tension, including intrinsic alignments, photo- $z$  uncertainties, masking of tSZ in the CMB maps, and the multiplicative bias.

**Author(s):** Jia Liu<sup>1</sup>, Zoltan Haiman<sup>1</sup>, Andrea Petri<sup>1</sup>, James Hill<sup>1</sup>, Lam Hui<sup>1</sup>, Jan Michael Kratochvil<sup>2</sup>, Morgan May<sup>1</sup>

**Institution(s):** 1. Columbia University, 2. UKZN

### 223.03 – 21 cm Power Spectrum Upper Limits from PAPER-64

We present power spectrum results from the 64 antenna deployment of the Donald C. Backer Precision Array for Probing the Epoch of Reionization (PAPER-64). We find an upper limit of  $\Delta^2 \leq (22.4\text{ mK})^2$  over the range  $0.15 < k < 0.5\text{ hMpc}^{-1}$  at  $z=8.4$ , resulting in the best published 21 cm power spectrum constraints to date. In addition, we use these results to place lower limits on the spin temperature at a redshift of 8.4. We find that the spin temperature is at least 10K for a neutral fraction between 15% and 80%. This further suggests that there was heating in the early universe through various sources such as x-ray binaries.

**Author(s):** Zaki Shiraz Ali<sup>2</sup>, Aaron Parsons<sup>2</sup>, Jonathan Pober<sup>1</sup>

**Institution(s):** 1. Brown University, 2. University of California Berkeley

**Contributing team(s):** Team PAPER

### 223.04 – Commissioning and Science Forecasts for the Hydrogen Epoch of Reionization Array (HERA)

The HERA is a low-frequency radio interferometer aiming to make precise measurements of the power spectrum of fluctuations in 21cm emission from the Epoch of Reionization at  $z=13-6$ . This project was recently awarded development funding under the 2014 cycle of the National Science Foundation's Mid-Scale Innovations Program (MSIP). We present initial results from the commissioning and testing of the 19-element HERA prototype in South Africa, including measurements of the performance of HERA's 14-m dish and feed via reflectometry, beam mapping, and on-sky commissioning tests. We then forecast the science results that HERA will deliver once it reaches its full size of 352 elements. These forecasts include constraints on the 21cm power spectrum, the impact of these constraints on parametrized models of ionization, and their relevance to cosmological models. Construction of HERA-352 is pending the outcome of the 2016 NSF MSIP cycle.

**Author(s):** Aaron Parsons<sup>1</sup>

**Institution(s):** 1. University of California, Berkeley

**Contributing team(s):** HERA Collaboration

### 223.05D – Testing Gravity using Galaxy Redshift Surveys and CMB

The Redshift Space Distortions (RSD) in galaxy redshift surveys can probe the local dynamics at a given epoch of galaxy. I will discuss how redshift can help us learn the local dynamics and hence measure the nature of gravity at the epoch of the galaxy. I will show results from our recent analysis of SDSS-III high redshift sample (CMASS). I will then talk about combining similar RSD measurements from various other surveys to learn more about cosmology and modified gravity. I will show some of the current best constraints we have obtained for popular  $\Lambda$ CDM and its extensions. I will end with a discussion on combining these measurements with CMB lensing in order to probe gravity to better precision and earlier time. I will also show the very first measurement by combining Planck CMB lensing and SDSS CMASS redshift space clustering.

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### 223.06 – The rise and fall of a challenger: the Bullet Cluster in $\Lambda$ cold dark matter simulations

The Bullet Cluster has provided some of the best evidence for the  $\Lambda$  cold dark matter ( $\Lambda$ CDM) model via direct empirical proof of the existence of collisionless dark matter, while posing a serious challenge owing to the unusually high inferred pairwise velocities of its progenitor clusters. Here we investigate the probability of finding such a high-velocity pair in large-volume N-body simulations, particularly focusing on differences between halo finding algorithms. We find that algorithms that do not account for the kinematics of infalling groups yield vastly different statistics and probabilities. When employing the Rockstar (RS) halo finder that considers particle velocities, we find numerous Bullet-like pair candidates that closely match not only the high pairwise velocity, but also the mass, mass ratio, separation distance, and collision angle of the initial conditions that have been shown to produce the Bullet Cluster in non-cosmological hydrodynamic simulations. The probability of finding a high pairwise velocity pair among haloes with  $M_{\text{halo}} \geq 10^{14} M_{\odot}$  is  $4.6 \times 10^{-4}$  using RS, while it is  $\approx 34 \times$  lower using a friends-of-friends (FOF) based approach as in previous studies. This is because the typical spatial extent of Bullet progenitors is such that FOF tends to group them into a single halo despite clearly distinct kinematics. Further requiring an appropriately high average mass among the two progenitors, we find the comoving number density of potential Bullet-like candidates to be on the order of  $\approx 10^{-10} \text{ Mpc}^{-3}$ . Our findings suggest that  $\Lambda$ CDM straightforwardly produces massive, high relative velocity halo pairs analogous to Bullet Cluster progenitors, and hence the Bullet Cluster does not present a

challenge to the  $\Lambda$ CDM model.

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**Institution(s):** 1. National Center for Supercomputing Applications, 2. University of Osaka, 3. University of Western Cape

223.07 –

### Unlocking Dark Matter Physics out of Galactic Substructures

Despite being ubiquitous throughout the Universe, the fundamental properties of dark matter remain a mystery. While dark matter physics plays little role in the current evolution of large-scale cosmic structures, it does have a major impact on small causal length scales. Studying the astrophysical structures that resulted from the gravitational collapse of fluctuations on these small scales can thus yield important clues about the physics of dark matter. Today, most of these structures are locked in deep inside the potential wells of galaxies, making the study of their properties difficult. Fortunately, due to fortuitous alignments between high-redshift bright sources and us, some of these galaxies act as spectacular strong gravitational lenses, allowing us to probe their inner structure. In this talk, we present a unified framework to extract information about the power spectrum of mass substructures inside lens galaxies. We determine which properties of mass substructures are most readily constrained by lensing data and forecast the constraining power of current and future observations.

**Author(s):** Francis-Yan Cyr-Racine<sup>1</sup>, Leonidas A. Moustakas<sup>2</sup>, Charles R. Keeton<sup>3</sup>

**Institution(s):** 1. Harvard University, 2. Jet Propulsion Lab, 3. Rutgers University

## 225 – Globular and Open Clusters

### 225.01D – Low-resolution Spectroscopic study of Globular Clusters with Multiple Populations

Recent studies of stellar populations in globular clusters (GCs) are facing a new paradigm as more and more GCs are observed to have multiple populations. In order to investigate the origin of these multiple stellar populations, we have performed low-resolution spectroscopy for red giant branch stars in M22, NGC 288, NGC 362, NGC 1851, NGC 6266, NGC 6273, NGC 6626, NGC 6642, NGC 6723, and 47 Tuc. We find significant differences in CN band strength for every sample GCs. However, the differences in calcium abundance (HK' index) between CN-strong and CN-weak subpopulations are found only in M22, NGC 1851, and NGC 6273. This difference in heavy elements would imply that later generation stars were enriched by Type II supernovae. In addition, we find interesting differences in CN-CH relation among sample GCs. While CN and CH are anti-correlated in normal GCs, which show no difference in calcium abundance, they show positive correlations in M22 and NGC 6273. NGC 1851, however, shows no difference in CH between the two groups of stars with different CN strengths. We suggest that all of these systematic differences would be best explained by how strongly supernovae enrichment has contributed to the chemical evolution of these GCs.

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### 225.02D – Neutron-Capture Abundances in the Milky Way: New Insights from Open Clusters

Recent spectroscopic studies of open clusters (OCs) show large increases in a few slow neutron-capture (s-process) element abundances, primarily Ba, for the youngest clusters, contradicting previous models of AGB star nucleosynthesis. These observations have prompted theorists to add new factors to models of low-mass ( $M < 1.5 M_{\odot}$ ) AGB star interiors to inflate yields *ad hoc*. However, these supersolar abundances in young clusters are based primarily on Ba lines which are extremely strong in most OC stars and display hyperfine and isotopic structure. We have assembled a sample of 68

red giant stars from 23 OCs and have measured eleven neutron-capture elements; here we focus on Ba and five other s-process elements (La, Ce, Sr, Y, and Zr) to see if the trends with age match that observed for Ba. Our OC sample ranges in age from 0.2 - 10 Gyr and covers  $7.5 < \text{RG} < 16.5$  kpc.

We find that [Ba/Fe] with cluster age does have a large, statistically significant downward trend with age ( $\sim -0.04$  dex/Gyr), but all other s-process elements have more modest trends ( $\sim -0.02$  dex/Gyr) that are not as significant and are mostly driven by the oldest cluster in our sample, Be 17. We explore other correlations between families of s-process elements as well. The puzzle of the disagreement between Ba and other s-process abundances leads us to question the reliability of the commonly measured Ba lines.

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### 225.03 – GEMS Observations of Obscured Galactic Bulge Globular Clusters

We will present results for several heavily obscured Galactic globular clusters lying in the bulge, including Liller 1 and NGC 6624. The observations were obtained exploiting the exceptional high-resolution capabilities of the near-IR camera GSAOI combined with the Gemini Multi-Conjugate Adaptive Optics System at the GEMINI South Telescope. The images in the J and K bands are generally sub-0.1", only slightly larger than the diffraction limit of the telescope, yielding the deepest and most accurate color-magnitude diagrams obtained so far from the ground for these clusters. We derived the structural and physical properties of both clusters, supplementing the GEMS data with data from the Vista Variables in the Via Lactea project. We were also able to investigate the age of NGC 6624. We find that Liller 1 is significantly less concentrated and less extended than previously thought. We estimated the mass of Liller 1 to be 2.3 million solar masses, comparable to that of the most massive clusters in the Galaxy. Also, Liller 1 has the second-highest collision rate among all star clusters in the Galaxy, thus confirming that it is an ideal environment for the formation of collisional objects (such as millisecond pulsars). The NGC 6624 CMD reveals the second knee of the main sequence and allows us to determine a very accurate age of  $12.0 \pm 0.5$  Gyr.

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### 225.05 – Effects of Stellar-Mass Black Holes on Star Cluster Evolution and Survival

Recent observations have revealed the existence of stellar mass black holes in globular clusters. These discoveries likely indicate the existence of large populations of black holes that are still bound in these clusters. This is in direct contrast to the past understanding that at most a few black holes can remain bound to an old cluster due to rapid mass segregation and dynamical ejection. Modern realistic star-by-star numerical simulations suggest that the retention fraction of stellar mass black holes is typically much higher than what was previously thought. The retention fraction over time depends intricately on the details of initial cluster properties as well as black hole formation physics. The presence of a population of black holes dramatically alters the cluster's evolution and even survival. I will present results from our latest numerical simulations with a focus on the observable global properties of star clusters that might serve as indicators of the presence of a large population of retained black holes.

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## 227 – Cataclysmic Variables and Supernova Progenitors

### 227.01 – An HST Study of the Ultraviolet Variability of Quiescent Cataclysmic Variables

A large HST program in Cycle 20 (PI Gaensicke) was awarded 122 orbits to obtain ultraviolet spectra of 40 cataclysmic variables. While the primary aim of the COS spectra was to obtain the temperature of the white dwarfs in these systems, the time-tag data could also be used to study the variability of each system during the time coverage of the allocated 2-5 HST orbits. This variability could encompass periodic orbital modulations on timescales of hours due to eclipses or hot spots, periodic variability on minute timescales due to white dwarf pulsations or spins, as well as non-periodic variability due to flickering and short term accretion changes. The light curves were created by summing the continuum portions of the spectrum and subtracting the background. Discrete Fourier Transforms were computed to assess any periodic behavior. Our results show that about a third of the systems show periodic behavior, including several new candidate accreting pulsators, several with UV detection of spin periods and eclipses, while the rest show various levels of flickering and minor accretion changes.

Support for this work was provided by HST grant GO-12870.

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**Contributing team(s):** HST 12870 Team

### 227.02 – Analysis of Positive Superhump Shapes Near Superoutburst Maximum in CV SU UMa-like Systems

Positive superhumps are hump-shaped modulations in light curves of some Cataclysmic Variables (CVs) that have a period that is slightly longer than the orbital period. In CV SU UMa-like systems, the shape of the positive superhump is known to change throughout the superoutburst, which thus slightly changes the published, observed, positive superhump period. In this presentation, we analyze numerical simulations of prograde precession in accretion disks of CV SU UMa-like systems near superoutburst maximum. We compare the simulated positive superhump shapes with the shapes obtained from observations, using AW Sge as our model. Similarly, we compare associated Fourier Transforms with associated periodograms. We conclude with our analysis of the likely sources that generate the shape of the positive superhump in CV SU UMa-like systems near superoutburst maximum.

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**Institution(s):** 1. Sternberg Astronomical Institute, 2. UCF, 3. Valencia College

### 227.03 – Non-Detection of Nova Shells Around Asynchronous Polars

Asynchronous polars (APs) are accreting white dwarfs (WDs) that have different WD and orbital angular velocities, unlike the rest of the known polars, which rotate synchronously (i.e., their WD and orbital angular velocities are the same). Past nova eruptions are the predicted cause of the asynchronicity, in part due to the fact that one of the APs, V1500 Cyg, was observed to undergo a nova eruption in 1975. We used the SALT 10m-class telescope and the MDM 2.4m Hiltner telescope to search for nova shells around three of the remaining four APs (V1432 Aql, BY Cam, and CD Ind) as well as one Intermediate Polar with a high asynchronicity (EX Hya). We found no evidence of nova shells in any of our images. We therefore cannot say that any of the systems besides V1500 Cyg had nova eruptions, but because not all post-nova systems have detectable shells, we also cannot exclude the possibility of a nova eruption occurring in any of these systems and knocking the rotation out of sync.

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### 227.04 – Search for Gamma-Ray Emission from

## Galactic Novae using Fermi-LAT Pass 8

Recently Galactic novae have been identified as a new class of GeV gamma-ray emitters, with 6 detected so far with the Fermi Large Area Telescope (Fermi-LAT) data. Based on optical observations we have compiled a catalog of  $\sim 70$  Galactic novae, which peak (in optical) during the operations of the Fermi mission. Based on the properties of known gamma-ray novae we developed a search procedure that we apply to all novae in the catalog to detect these slow transient sources or set flux upper limits using the Fermi-LAT Pass 8 data set. This is the first time a large sample of Galactic novae has been uniformly studied.

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**Contributing team(s):** on behalf of the Fermi-LAT collaboration

## 227.05 – Clues to the evolution of helium WD-WD binaries from the Palomar Transient Factory

The study of AM CVn stars - semi-detached He WD-WD binaries - has exploded in recent years thanks to long term light curves obtained by the Palomar Transient Factory. Systems are seen with binary periods ranging from about 5 minutes to about an hour. AM CVn stars are similar to dwarf novae in that they can undergo accretion disk outbursts. Systems with high  $dM/dt$  have steady disks in permanent outburst, whereas for very low  $dM/dt$  systems the disks are too cool to have outbursts. Disk instability theory gives a specific prediction for the zone of instability, therefore by matching the observed zone with the theoretical one we constrain  $dM/dt(P_{orb})$ , the rate of mass transfer versus orbital period. The inferred relation is consistent with expectations from stellar evolution. One also has predictions for the recurrence time for outbursts and outburst duration versus  $P_{orb}$  which can be compared to observations.

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## 227.06D – Late-time Constraints on the Fates of Supernova Impostors

Transients showing circumstellar interactions, low luminosities and low expansion velocities are generally considered to be non-terminal outbursts. Two main classes of such transients are 'supernova impostors', whose progenitors are massive stars ( $>20$  solar masses) and may be extra-galactic analogs of Eta Car's eruptions, and SN 2008S-like transients, which have lower-mass ( $\sim 10$  solar masses), dust-obscured progenitors. We present late-time Hubble and Spitzer Space Telescope observations of the archetypal 'supernova impostor', SN 1997bs, as well as the prototypes of the SN 2008S class of transients, SN 2008S and NGC 300 2008-OT1. All of these objects have faded below their progenitor luminosities in all bands for which comparisons are possible. We show that it is difficult to reconcile the late-time observations with models where surviving stars are obscured by either ejected shells or thick, dusty winds. Although some supernova impostors, such as SN 1954J, are clearly non-fatal, our results suggest that many of these weak stellar transients with circumstellar interactions may actually be low energy supernovae.

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## 227.07 – Discovery of Five Candidates for Present Day $\eta$ Carinae Analogs in Nearby Galaxies

Late-stage evolution of the most massive stars such as  $\eta$  Carinae is controlled by the effects of mass loss, possibly dominated by poorly understood episodic mass ejections. Through a systematic search utilizing archival Spitzer and HST data, we have discovered five objects in the nearby ( $<10$  Mpc) massive star-forming galaxies M51, M83, M101 and NGC6946 that have optical through mid-infrared photometric properties consistent with their being analogs of the

hitherto unique  $\eta$  Car as it is presently observed. Prior to this discovery there were no known analogs of  $\eta$  Car either in our or other galaxies. These objects are very luminous, with  $L_{bol}=3-6 \times 10^6 L_{\odot}$ . Their Spitzer mid-infrared spectral energy distributions rise steeply in the 3.6-8  $\mu m$  bands, then turn over between 8 and 24  $\mu m$  indicating the presence of warm ( $\sim 400-600$  K) circumstellar dust. Their optical counterparts, identified in deep HST images, are 1.5-2 dex fainter relative to mid-IR peaks and require the presence of  $\sim 5-10 M_{\odot}$  obscuring material. We present the properties of these five sources and discuss the implications of our discovery for understanding massive star evolution.

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## 227.08 – Constraining the Progenitor Masses of Core Collapse Supernova Remnants

Understanding the progenitor mass distribution of supernova explosions is an important observational constraint of stellar evolution theory. Recently, a novel approach was proposed to significantly increase the number of progenitor masses: characterize the progenitor mass of supernova remnants (SNRs) by age-dating the local stellar population. Preliminary statistical analyses suggested that there is a lack of SNRs around the most massive of massive stars. This suggested that there is a maximum mass for core collapse supernova explosions, or there is a bias against finding SNRs associated with the most massive stars. We test for a bias by considering the distribution of SNRs sizes using a Monte Carlo simulation. We find that the distribution of remnants sizes is the same for low mass progenitors and high mass progenitors. This implies that there is no bias against finding SNRs around the most massive progenitors. Our next step is to apply Bayesian statistical inference and obtain the joint probability for all the parameters involved in the statistical distribution model: the minimum mass, maximum mass, and slope of the mass distribution.

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## 228 – Circumstellar Disks and Dust

### 228.01 – Destruction of Refractory Carbon in Protoplanetary Disks

Rocky bodies in the inner solar system contain significantly less carbon than the dust of interstellar origin that seeded their formation. Even primitive meteorites exhibit carbon deficiencies, suggesting at least one process active prior to the formation of planetesimals. Selective erosion of carbonaceous materials by free oxygen atoms present in the photoactive surface layers of the protoplanetary disk provides one such mechanism for destroying refractory carbon while leaving silicate materials intact. We model this process with a large chemical network in a disk surrounding a T-Tauri star. We find that given sufficient turbulence to loft small grains into the oxidative surface regions of the disk, carbon grains are rapidly converted into CO. These oxidative regions can deplete carbon present in polycyclic aromatic hydrocarbons and small grains ( $\sim 0.02-20 \mu m$ ) by at least two orders of magnitude, enough to explain the deficiencies in meteorites compared to interstellar dust, and extend out to  $\sim 15-20$  AU from the central star at the disk surface in our static model. When turbulence is considered, the effects may reach the midplane causing depletion out to  $\sim 1$  AU. However, the amount of the total carbon reservoir at these radii that is affected by this mechanism depends on several unconstrained parameters concerning the nature of the disk and refractory carbon sources.

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### 228.02 – The Epsilon Eridani Debris Disk Resolved by

## Millimeter Interferometry

At a distance of only 3.22 pc, epsilon Eridani hosts the closest debris disk to the Sun. We present the first millimeter interferometric observations of this system, using the Submillimeter Array (SMA) at 1.3 mm and the Australia Telescope Compact Array (ATCA) at 7 mm, reaching 4 arcsec (13 AU) resolution. These observations reveal two distinct emission components: (1) the well-known outer dust belt, which is resolved in the radial direction, and (2) a compact source coincident with the position of the star. Model-fitting the visibilities constrains the basic properties of these components. The outer belt is located at  $64 \pm 3$  AU with fractional width 0.3, wider than the classical Kuiper Belt. This belt shows no significant azimuthal structure, or stellocentric offset, that might result from the presence of unseen giant planets on wide orbits in the system. The flux density of the unresolved central component exceeds predictions for the stellar photosphere; this excess may arise from a stellar chromosphere.

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## 228.03D – The Dust Properties of the Beta Pictoris Debris Disk from an Analysis of its Thermal Emission and Scattered Light

Although hundreds of debris disks have been characterized from their infrared spectral energy distributions, the composition of the dust comprising these disks has, in general, not been determined because it is degenerate with the size of the dust grains and their orbital location. Spatially resolved images at multiple wavelengths—including both scattered light and thermal emission—are required to break this degeneracy. The relatively nearby A6 star Beta Pictoris hosts a large, bright, edge-on debris disk that is amenable to a detailed characterization of its composition. We constrain the optical properties (and thus composition) of the dust in this system by simultaneously modelling images in the visible (HST/STIS), near-infrared (HST/WFC3), mid-infrared (Spitzer/MIPS), far-infrared (Herschel/PACS), and sub-mm (ALMA). The HST/WFC3 and Spitzer/MIPS data that we present have not been previously published. We find that a mixture of silicates and organic refractory material can fit this suite of data well. High amounts of water ice and highly porous grains are not favored, which is in agreement with a recent study of the debris disk around HR4796A that also combined thermal and scattered light constraints, but is in contrast with studies of other debris disks that did not include scattered light data. We also find that a model disk composed entirely of silicates will over-predict the scattered light brightness when fit to the thermal data—a discrepancy seen in the modelling attempts of other debris disks that assumed a purely silicate composition.

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## 228.04 – Revealing the structure and dust content of debris disks on solar systems scales with GPI

High contrast scattered light images offer the best prospect to assess the detailed geometry and structure of dusty debris disks. In turn, such images can yield profound insight on the architecture of the underlying planetary system as dust grains respond to the gravitational pull of planetary bodies. A new generation of extreme adaptive optics systems now enables an unprecedented exploration of circumstellar disks on solar system scales. Here we review the new science derived from over a dozen debris disks imaged with the Gemini Planet Imager (GPI) as part of the GPI Exoplanet Survey (GPIS). In addition to its exquisite imaging capability, GPI's polarimetric mode provides invaluable insight on the dust content of each disk, in most cases for the very first time. These early results typically reveal narrow belts of material with evacuated regions roughly 50-100 AU in radius, subtle asymmetries in structure and high degree of linear polarization. We will provide an overview of the disk observations made during the GPIS campaign to date and will

discuss in more detail some of the most remarkable systems.

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**Contributing team(s):** GPIES team

## 228.05 – Anomalous Microwave Emission in HII regions: is it really anomalous ? The case of RCW 49

The detection of an excess of emission at microwave frequencies with respect to the predicted free-free emission has been reported for several Galactic HII regions. Here, we investigate the case of RCW 49, for which the Cosmic Background Imager tentatively ( $\sim 3$  sigma) detected Anomalous Microwave Emission at 31 GHz on angular scales of  $7'$ . Using the Australia Telescope Compact Array, we carried out a multi-frequency (5 GHz, 19 GHz and 34 GHz) continuum study of the region, complemented by observations of the H109 alpha radio recombination line. The analysis shows that: 1) the spatial correlation between the microwave and IR emission persists on angular scales from  $3.4'$  to  $0.4''$ , although the degree of the correlation slightly decreases at higher frequencies and on smaller angular scales; 2) the spectral indices between 1.4 and 5 GHz are globally in agreement with optically thin free-free emission, however,  $\sim 30\%$  of these are positive and much greater than  $-0.1$ , consistently with a stellar wind scenario; 3) no major evidence for inverted free-free radiation is found, indicating that this is likely not the cause of the Anomalous Emission in RCW 49. Although our results cannot rule out the spinning dust hypothesis to explain the tentative detection of Anomalous Microwave emission in RCW 49, they emphasize the complexity of astronomical sources very well known and studied such as HII regions, and suggest that, at least in these objects, the reported excess of emission might be ascribed to alternative mechanisms such as stellar winds and shocks.

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## 228.06 – Mass Loss from Dusty AGB and Red Supergiant Stars in the Magellanic Clouds and in the Galaxy

Asymptotic giant branch (AGB) and red supergiant (RSG) stars are evolved stars that eject large parts of their mass in outflows of dust and gas. As part of an ongoing effort to measure mass loss from evolved stars in our Galaxy and in the Magellanic Clouds, we are modeling mass loss from AGB and RSG stars in these galaxies. Our approach is twofold. We pursue radiative transfer modeling of the spectral energy distributions (SEDs) of AGB and RSG stars in the Large Magellanic Cloud (LMC), in the Small Magellanic Cloud (SMC), and in the Galactic bulge and in globular clusters of the Milky Way. We are also constructing detailed dust opacity models of AGB and RSG stars in these galaxies for which we have infrared spectra; e.g., from the *Spitzer Space Telescope* Infrared Spectrograph (IRS). Our sample of infrared spectra largely comes from *Spitzer*-IRS observations. The detailed dust modeling of spectra informs our choice of dust properties to use in radiative transfer modeling of SEDs. We seek to determine how mass loss from these evolved stars

depends upon the metallicity of their host environments. BAS acknowledges funding from NASA ADAP grant NNX15AF15G.

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## **228.07D – Hot Exozodiacal Dust Disks, their Detection and Variability, as Measured with Long-Baseline Optical Interferometry.**

Near-infrared long-baseline optical interferometry has provided the first unambiguous resolved detections of hot dust around main sequence stars (Absil et al. 2006). This showed that an unexpectedly dense population of (sub)micrometer dust grains close exists to their sublimation temperature of approximately 1400K. A later survey (Absil et al. 2013) revealed that these "hot exozodiacal disks" are relatively common around spectral type A-K stars. Current models of circumstellar debris disks suggest that in the inner region, within 1 AU, of the disk the timescale for complete removal of submicron dust is on the order of a few years (Wyatt 2008). The presence of dust close to the star is surprising because most cold debris belts detected are collisionally dominated. Mutual collisions grind the dust down to the size where radiation pressure pushes the dust out before Poynting-Robertson drag has a chance to pull the dust inward. Competing models exist to explain the persistence of this dust; some of which suggest that dust production is a punctuated and chaotic process fueled by asteroid collisions and comet infall that would show variability on timescales of a few years. High precision long-baseline interferometry observations in the K-band with the FLUOR (Fiber Linked Unit for Optical Recombination) beam combiner at the CHARA (Center for High Angular Resolution Astronomy) Array provided the data for these exozodiacal dust detections. This original instrument has undergone upgrades as part of JouFLU (Jouissance of FLUOR) project. The new instrument has been used to expand the original survey and to re-observe stars from the previous exozodiacal disk survey to search for predicted variations in the detected disks. We have found evidence that for some systems the amount of circumstellar flux from these previously detected exozodiacal disks, or exozodis, has varied greatly. The flux from some exozodis has increased, others decreased, and for a few the amount has remained constant. These results are intriguing and will undoubtedly be useful for future modeling of this phenomenon. Furthermore, long-term monitoring is suggested for some of these objects to confirm detections and determine the rate of variation.

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## **229 – K-12 Education and Public Outreach**

### **229.01 – ThinkSpace: Spatial Thinking in Middle School Astronomy Labs**

Critical breakthroughs in science (e.g., Einstein's Theory of General Relativity, and Watson & Crick's discovery of the structure of DNA), originated with those scientists' ability to think spatially, and research has shown that spatial ability correlates strongly with likelihood of entering a career in STEM. Mounting evidence also shows that spatial skills are malleable, i.e., they can be improved through training. We report early work from a new project that will build on this research to create a series of middle schools science labs called "Thinking Spatially about the Universe" (ThinkSpace), in which students will use a blend of physical and virtual models (in WorldWide Telescope) to explore complex 3-dimensional phenomena in space science. In the three-year ThinkSpace labs project, astronomers, technologists, and education researchers are collaborating to create and test a suite of three labs designed to improve learners' spatial abilities through studies of: 1) Moon phases and eclipses; 2) planetary systems around stars other than the Sun; and 3.) celestial motions within the broader universe. The research program will determine which elements in the labs will best promote improvement of spatial skills within activities that emphasize

disciplinary core ideas; and how best to optimize interactive dynamic visualizations to maximize student understanding.

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## **229.02 – Astronomy in Chile Education Ambassadors Program' Gives On-site Experience to Build Knowledge and Enhance Impact: Success of Inaugural Class and Plans for the Future**

A collation of leading U.S. astronomy organizations and observatories selected its first class of educators who traveled to Chile in June/July 2015 as part of the Astronomy in Chile Educator Ambassadors Program (ACEAP). Chosen from a pool of more than 50 applicants, this inaugural group of nine amateur astronomers, planetarium personnel, and astronomy educators toured the major U.S.-funded astronomy facilities in Chile. While there, each ACEAP Ambassador received an in-depth, behind-the-scenes learning experience on the instruments, science, and research coming out of some of the world's most productive and advanced astronomy observatories. In addition, participants learned essential communication skills to help share these exciting experiences with others. Participants also experienced Chilean culture and society, as well as the astrotourism industry that has emerged in Chile.

The ultimate goal of this program is to have each ambassador share their experiences as broadly as possible with students and the public across the United States.

A first report of the program's inaugural year will be presented as well as the long-term impacts that have already emerged and are in development.

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**Contributing team(s):** ACEAP 2015 team

## **229.03 – Public Outreach Guerilla Style: Just Add Science to Existing Events**

We report on a campaign to use the visual appeal of astronomy as a gateway drug to inject public outreach into settings where people aren't expecting an encounter with science. Our inspiration came from the team at guerillascience.org, who have earned a reputation for creating, at sites around the world, "experiences and events that are unexpected, thought-provoking, but, above all, that delight and entertain." Our goal is to insert astronomy into existing festivals of music, culture, and art; county and state fairs; sporting events; and local farmer's markets. With volunteers and near-zero budgets, we have been able to meaningfully engage with audience members who would never willingly attend an event advertised as science related. By purposefully relating astronomy to the non-science aspects of the event that caused the audience members to attend, new learning experiences are created that alter the often negative pre-conceived notions about science that many of them held before our encounter.

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## **229.04 – Preparing the Public for JWST**

The James Webb Space Telescope is the successor to the Hubble Space Telescope. STScI and the Office of Public Outreach are committed to bringing awareness of the technology, the excitement, and the future science potential of this great observatory to the public, to educators and students, and to the scientific community, prior to its 2018 launch. The challenges in ensuring the high profile of JWST (understanding the infrared, the vast distance to the telescope's final position, and the unfamiliar science territory) requires us to lay the proper background. We currently engage the full range of the public and scientific communities using a variety of high impact, memorable initiatives, in combination with modern technologies to extend reach, linking the science goals of Webb to the

ongoing discoveries being made by Hubble. We have injected Webb-specific content into ongoing E/PO programs: for example, simulated scientifically inspired but aesthetic JWST scenes, illustrating the differences between JWST and previous missions; partnering with high impact science communicators such as MinutePhysics to produce timely and concise content; educational materials in vast networks of schools through products like the Star Witness News.

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**Institution(s):** 1. *Space Telescope Science Institute*

### **229.05 – Skynet Junior Scholars: Bringing Astronomy to Deaf and Hard of Hearing Youth**

Skynet Junior Scholars (SJS), funded by the National Science Foundation, aims to engage middle school youth from diverse audiences in investigating the universe with research quality robotic telescopes. SJS project development goals include: 1) Online access to optical and radio telescopes, data analysis tools, and professional astronomers, 2) An age-appropriate web-based interface for controlling remote telescopes, 3) Inquiry-based standards-aligned instructional modules. From an accessibility perspective, the goal of the Skynet Junior Scholars project is to facilitate independent access to the project by all youth including those with blindness or low vision and those who are Deaf or Hard of Hearing.

Deaf and Hard of Hearing (DHH) students have long been an underserved population within STEM fields, including astronomy. Two main barriers include: (1) insufficient corpus of American Sign Language (ASL) for astronomy terminology, and (2) DHH education professionals who lack astronomy background. A suite of vocabulary, accessible hands-on activities, and interaction with trained professionals, are critical for enhancing the background experiences of DHH youth, as they may come to an astronomy lesson lacking the basic “incidental learning” that is often taken for granted with hearing peers (for example, from astronomy in the media).

A collaboration between the Skynet Junior Scholars (SJS) project and the Wisconsin School for the Deaf is bringing astronomy to the DHH community in an accessible way for the first time. We follow a group of seven DHH youth over one semester as they interact with the SJS tools and curriculum to understand how they assimilate astronomy experiences and benefit from access to telescopes both directly (on school campus and at Yerkes Observatory) and through Skynet’s robotic telescope network (optical and radio telescopes, inquiry-based modules, data analysis tools, and professional astronomers). We report on our first findings of resources and best practices for engaging DHH youth in astronomy in the future.

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## **234 – Starburst Galaxies Poster Session**

### **234.01 – Sources of High-Energy Emission in the Green Pea Galaxies: New Constraints from Magellan Spectra**

The recently discovered Green Pea galaxies display extreme starburst activity and may be some of the only possible Lyman continuum emitting galaxies at low redshift. Green Peas are characterized by their unusually high [O III]/[O II] ratios, similar to the ratios observed in high-redshift galaxies. In addition, the presence of the high-energy He II 4686 line shows that the Green Peas are highly ionized. However, the origin of the He II emission in the Green Peas, and many other starburst galaxies, is still an open question. We analyze IMACS and MagE spectra from the Magellan telescopes in order to evaluate the most probable cause of this He II emission. We also analyze other properties like dust content, temperature and density, and kinematic components. Our IMACS spectra show no

Wolf-Rayet (WR) features. We set upper limits on the WR populations in our sample and conclude that Wolf-Rayet stars are not a likely candidate for the He II emission. With deeper MagE spectra we investigate energetic shocks as a possible source of the He II, and move one step closer to uncovering the origin of high-energy photons in these unique starbursts.

**Author(s):** Derek Alexander Carroll<sup>1</sup>  
**Institution(s):** 1. *University of Massachusetts Amherst*

### **234.02 – Peas in a Pod: Environment and Ionization in Green Pea Galaxies**

The Green Peas are extreme, highly ionized, starburst galaxies with strong [OIII] 5007 emission. Using the Sloan Digital Sky Survey, we present statistics on the environment of Green Peas and investigate its effects on their ionized gas properties. Although most dwarf starburst galaxies are in low-density environments, we identify a sample of Green Peas in dense environments. Emission line observations with the WIYN 0.9-meter telescope at Kitt Peak reveal that one cluster Green Pea is more highly ionized in the direction of the cluster center. Ram pressure stripping likely generates this ionization gradient. We explore the role of the environment in enhancing star formation rates and ionization, and we compare the nebular properties of Green Peas in high-density environments to those in low-density environments.

**Author(s):** Heather Kurtz<sup>1</sup>, Anne Jaskot<sup>1</sup>, Patrick Drew<sup>2</sup>, Dylan Pare<sup>2</sup>, Jon Griffin<sup>2</sup>, Michael Petersen<sup>2</sup>  
**Institution(s):** 1. *Smith College*, 2. *University of Massachusetts*

### **234.03 – The Conditions Underpinning Extreme Star Formation in ULIRGs and LIRGs as Revealed by Herschel Far-Infrared Spectroscopy**

We present a systematic survey of molecular and atomic line fluxes in all star-forming galaxies observed by the Herschel PACs instrument with detectable OH lines that also contain Herschel SPIRE FTS spectra, to determine how physical conditions vary as a function of star formation rate. Specifically, we measured selected CO, H<sub>2</sub>O, [CI], and [NII] integrated line fluxes in a sample of 145 star-forming galaxies covering a range of far-infrared luminosities ranging from 10<sup>9</sup> to above 10<sup>12</sup> L<sub>Sun</sub>. Thus, our sample includes typical, quiescent galaxies as well as Luminous Infrared Galaxies (LIRGs) and Ultra Luminous Infrared Galaxies (ULIRGs), known to be creating stars extremely rapidly. We find evidence suggesting that ULIRGs with far-infrared luminosities of L<sub>FIR</sub> > 10<sup>12</sup> L<sub>Sun</sub> require an additional heating mechanism other than UV heating from star formation, while LIRGs and less luminous star-forming galaxies may be heated primarily by their star formation. We also find that the [NII] 3P<sub>1</sub> - 3P<sub>0</sub> fine structure line flux and those of the CO J=5-4, CO J=7-6, and CO J=8-7 transitions are generally weaker for ULIRGs compared to LIRGs and less luminous star-forming galaxies, while we find the CO J=11-10, CO J=12-11, and CO J=13-12 transitions are generally stronger. In all these respects, ULIRGs are shown to differ significantly from other galaxies undergoing less extreme star formation. This work was supported in part by the NSF REU and DoD ASSURE programs under NSF grant no. 1262851 and by the Smithsonian Institution.

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**Institution(s):** 1. *Florida State University*, 2. *Harvard Smithsonian Center for Astrophysics*, 3. *University of Maryland*

### **234.04 – Stellar Masses and Star Formation Rates of Lensed Dusty Star-Forming Galaxies from the SPT Survey**

To understand cosmic mass assembly in the Universe at early epochs, we primarily rely on measurements of stellar mass and star formation rate of distant galaxies. In this paper, we present stellar masses and star formation rates of six high-redshift (2.8 ≤ z ≤ 5.7) dusty, star-forming galaxies (DSFGs) that are strongly gravitationally lensed by foreground galaxies. These sources were first discovered by the South Pole Telescope (SPT) at millimeter wavelengths and all have spectroscopic redshifts and robust lens models derived from

ALMA observations. We have conducted follow-up observations, obtaining multi-wavelength imaging data, using HST, Spitzer, Herschel and the Atacama Pathfinder EXperiment (APEX). We use the high-resolution HST/WFC3 images to disentangle the background source from the foreground lens in Spitzer/IRAC data. The detections and upper limits provide important constraints on the spectral energy distributions (SEDs) for these DSFGs, yielding stellar masses, IR luminosities, and star formation rates (SFRs). The SED fits of six SPT sources show that the intrinsic stellar masses span a range more than one order of magnitude with a median value  $\sim 5 \times 10^{10} M_{\odot}$ . The intrinsic IR luminosities range from  $4 \times 10^{12} L_{\odot}$  to  $4 \times 10^{13} L_{\odot}$ . They all have prodigious intrinsic star formation rates of 510 to  $4800 M_{\odot} \text{yr}^{-1}$ . Compared to the star-forming main sequence (MS), these six DSFGs have specific SFRs that all lie above the MS, including two galaxies that are a factor of 10 higher than the MS. Our results suggest that we are witnessing the ongoing strong starburst events which may be driven by major mergers.

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**Institution(s):** 1. University of Florida  
**Contributing team(s):** SPT SMG Collaboration

### 234.05 – Exploring Extragalactic Emission: The H $\alpha$ Dot Survey

The H $\alpha$  Dot Survey was established as a result of finding point sources of strong line emission in the data obtained for the ALFALFA H $\alpha$  Survey (Van Sistine et al. 2015). In the latter survey, broad-band R and narrow-band H $\alpha$  filters were used to examine target galaxies from the ALFALFA blind HI survey (Giovanelli et al. 2005, Haynes et al. 2011). In the process of reducing the ALFALFA H $\alpha$  Survey data the “H $\alpha$  Dots” were discovered (Kellar et al. 2008, 2012). Using specialized image analysis tools, a large population of dots has already been detected in the more than 1500 ALFALFA H $\alpha$  narrow-band images taken with the 0.9m WIYN and 2.1m KPNO telescopes. Follow-up spectra of over 200 H $\alpha$  Dots discovered from the 0.9m images reveal that these objects are a mix of nearby low-luminosity star-forming galaxies, compact starbursts and Seyfert 2 galaxies at intermediate redshifts, and high-redshift QSOs. Here we present the first list of H $\alpha$  Dots detected using 2.1m telescope data. The 2.1m images yield a sample of Dots that average almost two magnitudes fainter than those detected with the 0.9m. The current REU project is designed to characterize the set of H $\alpha$  Dots detected in the deeper 2.1m telescope images, while the broad goals of the H $\alpha$  Dot Survey include the desire to understand better the chemical evolution of galaxies over cosmic time. This project was supported in part by the NSF REU grant 1358980, by the Maria Mitchell Association (Nantucket, MA), and by the Massachusetts Space Grant Consortium.

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### 234.06 – Spatially Resolved Stellar Populations Of Nearby Post-Starburst Galaxies In SDSS-IV MaNGA

We have selected five galaxies in the Mapping Nearby Galaxies at APO (MaNGA) project of the latest generation of the Sloan Digital Sky Survey (SDSS-IV) identified as post-starburst (E+A) systems, in the transition between “blue cloud” and “red sequence” galaxies. We measure the equivalent widths of the Balmer series, D4000 break, and metal lines across each galaxy, and produce maps of the stellar age, stellar mass, and metallicities of each galaxy using FIREFLY, a full spectral analysis code. We have found that the measured properties of the galaxies overall generally matches well with single-aperture SDSS spectra from which the original post-starburst identifications were made. The variation in the spatial distributions of the stellar populations, in particular the A-stars, give us insight into the details of the transitional E+A quenching phase. This work was supported by the Alfred P. Sloan Foundation via the SDSS-IV Faculty and Student Team (FAST) initiative, ARC Agreement No. SSP483 to the CUNY College of Staten Island.

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**Institution(s):** 1. CUNY College of Staten Island, 2. Northeastern University, 3. University of Portsmouth  
**Contributing team(s):** SDSS-IV MaNGA Team

### 234.07 – The Nearby Analogues of Pure Starburst Galaxies

The relationship between active galactic nuclei (AGN) and starburst galaxies is poorly understood, partially due to galaxies exhibiting both AGN and starburst activity. We have a sample of “pure” starburst galaxies at  $z \sim 0.1$  as selected by mean field independent component analysis (MFICA). In order to better understand these starburst galaxies, we attempt to identify nearby analogues. First, we degrade a random sample of nearby galaxies to a redshift of  $z \sim 0.1$  by decreasing brightness and spatial resolution and increasing signal-to-noise. We then compare the magnitude, color, morphology, and concentration of each of these galaxies to our pure starburst galaxies. Finally, we determine if the nearby galaxies most similar to the starbursts when degraded are consistent with the local optimally emitting cloud model (LOC). The LOC model makes predictions for the distribution of HII regions within starburst galaxies which have been previously tested with the spectra of  $z \sim 0.1$  galaxies, and may be further validated by examination of these nearby analogues.

**Author(s):** Benjamin C. Kaiser<sup>1</sup>, Anthony Crider<sup>1</sup>, Chris T. Richardson<sup>1</sup>  
**Institution(s):** 1. Elon University

### 234.08 – Spatially resolved star-formation in nearby analogues of Lyman break galaxies

At redshifts of  $z > 1.5$ , UV-selected galaxy populations (such as  $z \sim 3$  Lyman break galaxies = LBGs) have the largest number of spectroscopic redshifts. As a result, LBGs have an important role in our understanding of the history of galaxy formation. However, LBGs are rather poorly understood at longer wavelengths, and thus our understanding of the total star formation rates and (especially) gas masses in such galaxies is incomplete. A common strategy is to assume that the Kennicutt-Schmidt relation between star formation rate (SFR) surface density and gas mass surface density holds, even in these high redshift galaxies where testing the relation directly is not feasible. To help assess the validity of this assumption, we examine the Kennicutt-Schmidt relation in selected nearby ( $z \sim 0.2$ ) starburst galaxies in the hope of better understanding key questions regarding star formation processes in UV-selected galaxies. Several nearby galaxies with high UV luminosities and surface brightnesses, reminiscent of those found in LBGs, were identified and used for this project. We have obtained new, spatially resolved observations of these nearby analogues in Paschen alpha emission and carbon monoxide emission, from the ESO Very Large Telescope and the IRAM Plateau de Bure Interferometer, respectively. We examine whether the galaxies follow the expected Kennicutt-Schmidt relation, and investigate any implied variation in gas depletion times between and within galaxies. This research has been supported by National Science Foundation grant AST-0955810.

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**Institution(s):** 1. Johns Hopkins University, 2. Reed College, 3. Rutgers, the State University of New Jersey

### 234.09 – Green Pea Galaxies Reveal Secrets of Ly $\alpha$ Escape

In star-forming galaxies, a lot of Ly $\alpha$  photons were generated in HII regions surrounding massive stars. The escape of Ly $\alpha$  photons from galaxies is a key issue in studying high redshift galaxies and probing cosmic reionization with Ly $\alpha$ . To understand Ly $\alpha$  escape, it is valuable to study high quality Ly $\alpha$  profiles in Ly $\alpha$  emitters. However, such studies are rare due to the faintness of high- $z$  Ly $\alpha$  emitters and the lack of local analogs with high Ly $\alpha$  equivalent width. Here we show that “Green Pea” galaxies are the best local analogs of high- $z$  Ly $\alpha$  emitters and their high quality Ly $\alpha$  profiles demonstrate low HII column density is the key to Ly $\alpha$  escape. The Ly $\alpha$  escape fraction shows correlations with the ratio of Ly $\alpha$  blue peak velocity to H $\alpha$  line

width, the normalized flux density at valley of Ly $\alpha$  profile, and a few other features of Ly $\alpha$  profiles. We compared the Ly $\alpha$  profiles with outflowing HI shell radiative transfer model and found that the best-fit HI column density is anti-correlated with the Ly $\alpha$  escape fraction. We also found an anti-correlation between Ly $\alpha$  escape fraction and galactic metallicity. Our results support that LAEs with high Ly $\alpha$  escape fraction have low metallicity, low HI column density, and mild HI gas outflow.

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## 235 – Galaxy Clusters Poster Session

### 235.01 – SED Fitting of Virgo Cluster Galaxies and Evidence for Enhanced Star Formation due to Accretion

Using UV through FIR data in matched apertures, we modeled the spectral energy distributions (SED) of 49 Virgo cluster spiral galaxies with the modeling program Magphys (daCunha+ 2008). We used the results from these models to explore the relationships between the stellar masses ( $M^*$ ), specific star formation rates (sSFR), and HI properties in our sample. The poster highlights one initial result from these comparisons: supportive evidence for gas accretion in the outskirts of the Virgo cluster. The galaxies with the highest sSFRs in the mass range  $10^9$ – $10^{10} M_{\odot}$  are all HI-rich, have extended irregular HI envelopes, and lie in the outskirts of the cluster. We propose that these galaxies are accreting gas onto their disks, a process which enhances their SFRs.

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**Institution(s):** 1. University of Wisconsin - Madison, 2. Yale University

### 235.02 – Gas Sloshing in the Rich Cluster A2204: Putting Constraints on the Properties of the Magnetized Hot Plasma

We present results from our detailed analysis of the gas sloshing structures in the rich galaxy cluster Abell 2204, based on deep Chandra observations. We investigate the spiral structure in the X-ray surface brightness, which is a common signature of gas sloshing caused by an interaction with another nearby cluster. We identify discontinuities (edges) in the cluster surface brightness profiles in different directions from the cluster center. We measure the gas temperature, pressure and entropy across these surface brightness edges and find that the prominent surface brightness edges in the east and west are both typical “cold fronts”, likely produced by gas sloshing. We use the results of our analysis to constrain the strength of the magnetic field in the cluster. We also use our measurements to provide an upper limit on the velocity of the cold gas beneath the front surface of the cold front. Finally we identify two subcluster candidates in the cluster outskirts, which may have been responsible for the gas sloshing.

This research was supported by the Smithsonian Institution, Chandra Prime Contract NAS8-03060, Nanjing University, and the Massachusetts Institute of Technology.

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**Institution(s):** 1. Harvard-Smithsonian, CfA, 2. MIT, 3. Nanjing University

### 235.03 – A Cosmic Train Wreck: JVLA Radio Observations of the HST Frontier Fields Cluster Abell 2744

The galaxy cluster mergers observed in the HST Frontier Fields represent some of the most energetic events in the Universe. Major

cluster mergers leave distinct signatures in the ICM in the form of shocks, turbulence, and diffuse cluster radio sources. These diffuse radio sources, so-called radio relics and halos, provide evidence for the acceleration of relativistic particles and the presence of large scale magnetic fields in the ICM. Observations of these halos and relics allow us to (i) study the physics of particle acceleration and its relation with shocks and turbulence in the ICM and (ii) constrain the dynamical evolution of the merger events

We present Jansky Very Large Array 1-4 GHz observations of the Frontier cluster Abell 2744. We confirm the presence of the known giant radio halo and radio relic via our deep radio images. Owing to the much greater sensitivity of the JVLA compared to previous observations, we are able to detect a previously unobserved long Mpc-size filament of synchrotron emission to the south west of the cluster core. We also present a radio spectral index image of the diffuse cluster emission to test the origin of the radio relic and halo, related to the underlying particle acceleration mechanism. Finally, we carry out a search for radio emission from the ‘jellyfish’ galaxies in A2744 to estimate their star formation rate. These highly disturbed galaxies are likely influenced by the cluster merger event, although the precise origin of these galaxies is still being debated.

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### 235.04 – A Census of Star Formation and Active Galactic Nuclei Populations in Abell 1689

A recent survey of low- $z$  galaxy clusters observed a disjunction between X-ray and mid-infrared selected populations of active galactic nuclei (X-ray and IR AGNs) (Atlee+ 2011, ApJ 729, 22.). Here we present an analysis of near-infrared spectroscopic data of star-forming galaxies in cluster Abell 1689 in order to confirm the identity of some of their IR AGN and to provide a check on their reported star formation rates. Our sample consists of 24 objects in Abell 1689.  $H$  and  $K$  band spectroscopic observations of target objects and standard stars were obtained by David Atlee between 2010 May 17 and 2011 June 6 using the Large Binocular Telescope’s LUCI instrument.

After undergoing initial reductions, standard stars were corrected for telluric absorption using TelFit (Gullikson+ 2014, AJ, 158, 53). Raw detector counts were converted to physical units using the wavelength-dependent response of the grating and the star’s reported  $H$  and  $K$  band magnitudes to produce conversion factors that fully correct for instrumental effects. Target spectra were flux-calibrated using the airmass-corrected transmission profiles produced by TelFit and the associated  $H$  band conversion factor (or the average of the two factors, for nights with two standard stars). Star formation rates were calculated using the SFR- $L(\text{H}\alpha)$  relation reported in Kennicutt (1998), with the measured luminosity of the Pa- $\alpha$  emission line at the luminosity distance of the cluster used as a proxy for  $L(\text{H}\alpha)$  (Kennicutt 1998, ARA&A 36, 189; Hummer & Stoney 1987, MNRAS 346, 1055). The line ratios  $\text{H}_2$  2.121  $\mu\text{m}/\text{Br}\gamma$  and  $[\text{FeII}]/\text{Pab}$  were used to classify targets as starburst galaxies, AGNs, or LINERs (Rodriguez-Ardila+ 2005, MNRAS, 364, 1041).

Jones was supported by the NOAO/KPNO Research Experience for Undergraduates (REU) Program, which is funded by the National Science Foundation Research Experiences for Undergraduates Program (AST-1262829).

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**Institution(s):** 1. City University of New York, 2. University of Arkansas

### 235.06 – A Mid-IR Investigation of the GMBGC Catalogue using WISE

We present the preliminary results of a mid-infrared study of the

Brightest Cluster Galaxies (BCGs) of 55424 galaxy clusters. The clusters are taken from the Gaussian Mixture Brightest Cluster Galaxy (GMBCG) catalog based upon SDSS Data Release 7, covering the redshift range of  $0.1 < z < 0.55$ . Of particular interest, we investigate 458 BCGs that have significant detection at 22um according to the Wide-Field Infrared Survey (WISE) passband 4 (W4). We find that the mid-IR emissions of most of them are predominantly from star formation, which is quite contrary to the usual notion that low redshift BCGs are old, passively evolving galaxies (i.e. "red and dead"). We discuss the implications of our results.

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**Institution(s):** 1. University of Missouri - Columbia

### 235.07 – H-alpha Imaging Survey of Low-Redshift Cluster Dwarf Galaxies

We describe our on-going H-alpha imaging survey to measure the star formation activity of dwarf galaxies selected from a sample of low-redshift ( $0.02 < z < 0.15$ ) galaxy clusters using the KPNO 4-meter telescope+Mosaic camera. H-alpha observations are obtained using the narrow-band BATC filters centered on the redshifted H-alpha emission line. The continuum-subtracted H-alpha images allow us to constrain star formation rates via the correlation between star formation and H-alpha luminosity and equivalent width. The impact of the cluster environment can be quantified using radial-dependent measures of the star formation rate within individual clusters, and by comparing clusters within our sample on a cluster-to-cluster basis. Comparison of our H-alpha measurements to CFHT u-band imaging data of our cluster sample, permits us to explore the correlation between the UV continuum and H-alpha emission of the dwarf galaxy population. The goal of our survey is to further understand the mechanism that is responsible for the enhancement/quenching of star formation as dwarf galaxies fall into the galaxy cluster environment.

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### 235.08 – Using Herschel Far-Infrared Photometry to Constrain Star Formation Rates in CLASH Cluster Galaxies

The Cluster Lensing And Supernova survey with Hubble (CLASH) program obtained broadband images of 25 massive galaxy clusters in 16 passbands from the UV to the near-IR. The data was taken with the Wide-field Camera 3 (WFC3), and the Advanced Camera for Surveys (ACS) on the Hubble Space Telescope (HST). These 25 clusters have also been observed in the mid-IR by Spitzer IRAC, the far-IR by the Herschel Space Observatory PACS and SPIRE, and in the x-ray by the Chandra and XMM observatories. We focused on the two brightest cluster galaxies (BCGs) in the survey (MACS1931.8-2653 and RXJ1532.9+3021) that have reddening-corrected UV-derived star formation rates (SFRs)  $> 100 M_{\odot} \text{ yr}^{-1}$  as measured by Fogarty et al (2015). The inclusion of Herschel data provides unique constraints on dust content and independent estimates of the star formation rates in these interesting galaxies. We performed photometry on the five Herschel bands (100-500 $\mu\text{m}$ ), and removed any contamination from other cluster members. We fit a UV-FIR SED to each galaxy to measure the bolometric dust luminosity ( $L_{\text{bol}}$ ), which we use to derive the FIR obscured SFR. We calculate the sum of the measured UV unobscured SFR from the HST photometry and the FIR obscured SFR from the Herschel photometry to get a total SFR for these two BCGs. We compared this to the reddening-corrected SFRs and found they were in agreement within error. This confirms that the Kennicutt and Calzetti methods for calculating star formation rates are both applicable for these highly star-forming massive cluster galaxies.

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**Institution(s):** 1. John's Hopkins University, 2. Space Telescope Science Institute, 3. University of Texas at Austin

### 235.09 – Intracuster Light in Galaxy Groups and

### Clusters

We present recent results from our study on the origin and assembly history of the intracluster starlight (ICL) for a sample of 29 galaxy groups and clusters with  $3 \times 10^{13} < M_{\odot} < 3 \times 10^{15}$  between  $0.3 \leq z \leq 0.9$ . Using this sample of massive halos we constrain the progenitor population and formation mechanism of the ICL by measuring the ICL surface brightness profile, the ICL color and color gradient, and the total ICL luminosity within  $10 < r [\text{kpc}] < 110 \text{ kpc}$ . We find that the vast majority of our groups and clusters show clear negative color gradients. Such negative colour (and equivalently, metallicity) gradients can arise from tidal stripping of  $L^*$  galaxies and/or the disruption of dwarf galaxies, but not major mergers with the brightest cluster galaxy (BCG). We also find ICL luminosities of  $3-9 L^*$  in the range  $10 < r < 110 \text{ kpc}$  for these clusters. Dwarf disruption alone cannot explain the total luminosity of the ICL and remain consistent with the observed evolution in the faint-end slope of the luminosity function. The results of our study are suggestive of a formation history in which the ICL is built-up by a combination of stripping of  $L^*$  galaxies and/or dwarf disruption and disfavor significant contribution by major mergers with the BCG.

This sample of groups and clusters is the largest with HST/WFC3 data for ICL analysis that spans two orders of magnitude in halo mass at redshifts  $> 0.3$ . Because of this we can investigate how the ICL color profile changes as a function of cluster mass for the first time, as well as expand previous studies of the changing fraction of cluster luminosity that is contained in the BCG+ICL as a function of halo mass. We present our preliminary results and describe our next steps using this sample to investigate the intracluster light in massive halos.

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### 235.10 – Systematic Uncertainties in Characterizing Cluster Outskirts: The Case of Abell 133

The outskirts of galaxy clusters have low surface brightness compared to the X-ray background, making accurate background subtraction particularly important for analyzing cluster spectra out to and beyond the virial radius. We analyze the thermodynamic properties of the intracluster medium (ICM) of Abell 133 and assess the extent to which uncertainties on background subtraction affect measured quantities. We implement two methods of analyzing the ICM spectra: one in which the blank-sky background is subtracted, and another in which the sky background is modeled. We find that the two methods are consistent within the 90% confidence ranges. We were able to measure the thermodynamic properties of the cluster up to  $R_{500}$ . Even at  $R_{500}$ , the systematic uncertainties associated with the sky background in the direction of A133 are small, despite the ICM signal constituting only  $\sim 25\%$  of the total signal. This work was supported in part by the NSF REU and DoD ASSURE programs under NSF grant no. 1262851 and by the Smithsonian Institution. GAO acknowledges support by NASA through a Hubble Fellowship grant HST-HF2-51345.001-A awarded by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Incorporated, under NASA contract NAS5-26555.

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### 235.11 – Quantifying peculiarity of cluster galaxies and their kinematic features

Galaxy morphology involves complex effects from both secular and non-secular evolution of galaxies. Although it is a final product of galaxy evolution, it gives a clue to the processes that the galaxy suffer. Galaxy clusters are the sites where the most massive galaxies are found, and so the most dramatic merger histories are embedded. Our extra-ordinary deep ( $\mu_r \sim 28 \text{ mag/''}^2$ ) imaging of Abell 119 at  $z = 0.044$  using a Blanco 4-m telescope at CTIO enable us to detect low

surface brightness features, and we found post-merger signatures for 25% of red-sequence galaxies in the clusters suggesting that so many galaxies even in clusters have gone through galaxy mergers at recent epochs. We quantified the degree of peculiarity of morphology utilizing residual lights from model subtracted images to pin down the merger frequency in cluster environments more objectively. With our technique we measured the degree of features which in turn allow us to extract the details of the merger properties, such as the galaxy mass ratios and the merger frequency. We went further to understand the impact of galaxy mergers in cluster environment using the SAMI Integral Field Unit on the galaxies of Abell 119 and found that half of galaxies related to mergers show misalignment in the angle between the photometric major and the rotation axes, and most of them show complex kinematic features. Our research on quantification of merger features through deep imaging help us to understand the merger history of cluster galaxies, and we present our understanding of galaxy mergers in cluster environment from the perspective of kinematics.

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### 235.12 – Searching for Galaxy Overdensities in the Fields of 10 $z>6$ Quasars

The highest-redshift quasars ( $z>6$ ) host supermassive black holes ( $M_{\text{BH}} > 10^9 M_{\odot}$ ) and presumably reside in massive host galaxies located in some of the largest galaxy overdensities at early cosmic epochs. However, optical searches for such overdensities have so far been inconclusive. One caveat is that the sources could be too faint in optical wavelengths, so while overdensities may be present, they must be detected at a longer wavelength regime. The Atacama Large Millimeter Array (ALMA) now provides the sensitivity and resolution required to detect and resolve faint sources at very high redshift ( $z>5-6$ ). Instead of blind surveys, the data we present are observations of known bright quasars from the ALMA archive. Examining the sidelines of these quasars and comparing them with the number count of sources in blind surveys enables us to learn whether quasars are present in galaxy overdensities or if their environments are indistinguishable from a blank field. We use ALMA cycle 0, 1 and 2 data to map the vicinity of ten quasars at  $z>6$  in the continuum at  $\sim 1.2\text{mm}$ , tracing the far infrared dust emission, to perform an independent search for companions around the quasars. We also examine the presence of the [CII] line in these fields. We compare the number density of such sources to 'blank field' studies to see if there is evidence for an overdensity of sources in the immediate vicinity of the quasars. Either outcome ('overdensity' or 'no overdensity') would have important implications for early structure formation. Preliminary results show there is an excess of positive flux in these fields, and there is a total of a few ( $<10$ )  $+5\sigma$  detections in the ten fields, but further work to estimate the number of spurious detections is necessary.

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### 235.13 – The Importance of Compact Group Environments Over Cosmic Time

Galaxy interactions are critical to the evolution of the universe, influencing everything from star formation to the structure of the known universe. By studying galaxy interactions through computer simulations, we are able to observe what would normally take billions of years to progress. Compact groups are extremely dense clusters of at least three and typically no more than 10 galaxies interacting gravitationally that will often merge. These groups yield considerable information about galaxy interactions and mergers in dense environments but are difficult to observe at high redshifts. The Millennium Simulation is a massive  $n$ -body simulation of cold dark matter particles on a time scale equivalent to the known universe. It solves this problem as it allows us to study high redshift objects and timescales of billions of years. Using the simulation and what we know about compact groups from the Hickson surveys, we were able to examine the evolution of these groups through cosmic time. We built an algorithm that analyzed galaxies in the Millennium

Simulation and tuned it to various selection parameters. We found that roughly 7% of galaxies in the present day were once compact groups, as most groups merged into a single elliptical galaxy. There is also an epoch of group existence at  $z \sim 1.5$ , slightly after the well-known epoch of star formation at  $z \sim 2$ . This offset provides meaningful insight into the evolution of compact groups and the influence they have had on the universe we see today.

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### 235.14 – The Galaxy Cluster Environments of Wide Angle Tail Radio Sources

Generally found in the centers of galaxy clusters, Wide Angle Tail radio sources (WATs) are defined by their characteristic jet-hotspot-lobe transition and intermediate radio power. They are typically associated with the luminous central galaxy within the cluster and often appear bent due to interaction with the hot, X-ray bright intracluster medium (ICM). Their linear extent ( $r > 100\text{ kpc}$ ) and radio luminosity make them good tracers of high redshift systems where X-ray and optical observations are more difficult. In an effort to characterize the global X-ray properties of WAT clusters, we have assembled a sample of WAT systems from the Chandra archive. We have examined the distribution of substructure, temperature, abundance, density and pressure within the ICM. We find the majority of WAT clusters display some merger signatures and many show evidence of cool/high metallicity gas within 100 kpc of the WAT host galaxy. Most notably, we observe that clusters with the highest central densities and pressures host WATs with the shortest flare radii.

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### 235.15 – Using Strong Gravitational Lensing to Identify Fossil Group Progenitors

Fossil galaxy systems are thought to be the end result of group evolution, as galaxies experiencing dynamical friction sink to the center of the group potential and merge into a single elliptical that dominates the rest of the members in both mass and luminosity. However, two alternate formation mechanisms are possible: a group merger scenario where two smaller group BGG's merge into one large elliptical which then promotes the final group to fossil status or the group being initially "born that way." The group merger mechanism could explain why some fossils exhibit cool cores while others do not, as gas cooling timescales are significantly longer than galaxy merging timescales. Most fossil systems discovered lie within  $z<0.2$ , which begs the question: what did these systems look like in the past, and which formation process did they undergo? Such progenitors are expected to be systems with imminent or ongoing major mergers that will transition into fossil status before  $z=0$ . The group merger scenario (particularly along the line-of-sight), or even simply the dominance of the fossil BGG, suggests a highly concentrated system ideal for strong gravitational lensing. Strong lensing events also preferentially pick out merging systems which makes this an ideal selection criteria for our study. We use the CASSOWARY survey of strong lensing events as our sample with the goal of determining if lensing systems have a predisposition of being fossil systems or progenitors. We present a catalog of fossil progenitor candidates from the CASSOWARY survey with redshifts ranging from  $0.1<z<0.7$ . We find that 50% of these lensing groups are either fossils or fossil progenitors, suggesting that searching for strong lensing events may be a more efficient way of finding fossil and pre-fossil systems.

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### 235.16 – Cluster Dynamical Mass from Magellan

## Multi-Object Spectroscopy for SGAS Clusters

Galaxy clusters are giant structures in space consisting of hundreds or thousands of galaxies, interstellar matter, and dark matter, all bound together by gravity. We analyze the spectra of the cluster members of several strong lensing clusters from a large program, the Sloan Giant Arcs Survey, to determine the total mass of the lensing clusters. From spectra obtained with the LDSS3 and IMACS cameras on the Magellan 6.5m telescopes, we measure the spectroscopic redshifts of about 50 galaxies in each cluster, and calculate the velocity distributions within the galaxy clusters, as well as their projected cluster-centric radii. From these two pieces of information, we measure the size and total dynamical mass of each cluster. We can combine this calculation with other measurements of mass of the same galaxy clusters (like measurements from strong lensing or X-ray) to determine the spatial distribution of luminous and dark matter out to the virial radius of the cluster.

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## 235.17 – Sunyaev-Zel'dovich pressure profiles and masses of infrared-selected galaxy clusters

Using Atacama Cosmology Telescope (ACT) data, we analyze the stacked Sunyaev-Zel'dovich (SZ) temperature decrement for an infrared-selected sample of galaxy cluster candidates. The candidates come from the Spitzer/Hetdex Exploratory Large-Area (SHELA) survey with the Spitzer Space Telescope, and allow us to probe clusters at higher redshift than typical with optically-selected samples, with objects less massive than those typical with SZ surveys. Our sample contains 45 cluster candidates---overdensities identified using photometric redshifts of the member galaxies. The cluster candidates have 24-35 visible members, and were not individually detected in SZ by ACT. In the stacking analysis, ACT measurements show a temperature decrement at 148 GHz, but an excess at the 220 GHz SZ null, which we attribute to dust emission from the cluster galaxies. To correct the decrement for dust contamination we use two methods to determine the dust spectral energy distribution (SED). First we use the correlation in the CIB power spectra observed by Planck at 143 and 217 GHz. Second, we use catalog sources from the Herschel Stripe 82 (HerS) survey, combining the emission from all sources proximate to our sample at 600, 860, and 1200 GHz, and fitting a graybody spectrum. Both methods yield a similar dust SED from 220 GHz to 148 GHz, and we use this to extrapolate the 220 GHz increment and estimate the 148 GHz contamination. After the dust correction, we use the universal pressure profile to fit for an average SZ signal and cluster mass.

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**Contributing team(s):** ACT collaboration, SHELA collaboration

## 235.18 – Cluster Position Angle Alignments in the CLASH Survey

There exists strong evidence for nearby brightest cluster galaxies (BCGs) to exhibit preferential orientation with respect to their surroundings. Primarily, we see these bright member galaxies aligning themselves with the cluster's principal axis. We have examined the orientations of the 25 CLASH Survey galaxy clusters to see whether this tendency for BCGs to share the same major axis orientation as their host cluster extends to galaxy clusters at redshifts up to 0.9. We find evidence of preferential orientations existing in clusters at these redshifts. The significance of this finding for theories of the formation of clusters are discussed. Supported by NSF Grant #1358980 and the MA Space Grant Consortium.

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## 236 – Young Stellar Objects, Very Young Stars, T-Tauri Stars, H-H Objects Poster Session

### 236.01 – X-Ray Grating Spectroscopy of the T Tauri Star RY Tau

We present new results of X-ray observations of RY Tau, an accreting T Tauri star that drives a striking optically-revealed bipolar jet. We obtained sensitive X-ray grating observations with the Chandra High Energy Transmission Grating spectrometer (HETG) and the XMM-Newton Reflection Grating Spectrometer (RGS) in 2013-2014. These observations provide information on the temperature and emission measure distribution of the X-ray emitting plasma, a prerequisite for distinguishing between very hot plasma arising in magnetically-confined regions (e.g. the corona) and much cooler plasma that could originate in accretion shocks or the shocked jet. The emission measure distribution is dominated by hot plasma with a characteristic temperature  $T \sim 50$  MK ( $kT \sim 4 - 5$  keV), but higher temperatures were recorded during flares. Emission from the Fe K complex (Fe XXV; 6.7 keV) arising in very hot plasma was detected, as well as fluorescent Fe emission at 6.4 keV from cold surrounding material irradiated by the hard X-ray source. Spectral lines tracing cool plasma at temperatures of a few MK such as O VIII (0.654 keV) are also present in the RGS spectrum. We will summarize the X-ray spectral and variability properties of RY Tau and discuss possible origins of the cool plasma.

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### 236.02 – Ultraviolet Extinction Curves For Nearby T Tauri Stars

We present empirically-derived fits to the ultraviolet (UV) extinction curves along the line of sight towards young stars with circumstellar disks. Stellar UV radiation plays a strong role in heating the disk gas and driving chemical reactions. Thus, it is important to measure the UV extinction curve in order to reconstruct the intrinsic UV flux irradiating the disk, thereby enabling accurate photochemical modeling of the planet-forming environment. To measure the extinction, we first compare modeled H<sub>2</sub> fluorescence spectra to observed H<sub>2</sub> lines. Lyman-alpha radiation from the stars pumps electronic transitions of H<sub>2</sub> in the disk, and we model the flux that is re-emitted through the subsequent fluorescent cascade. We then extract an initial extinction curve over the 1100-1700 Angstrom wavelength region from the difference between the modeled H<sub>2</sub> fluorescence and the HST data. To account for self-absorption in the disk by the optically thick H<sub>2</sub>, we divide this initial extinction curve by the transmission in each fluorescence line. We then fit the resulting interstellar extinction curve with an interstellar reddening model characterized by an  $A_V$  and  $R_V$  value. The shape of the extinction curve allows us to characterize the dust grain distribution in the intervening material as well as to recover the intrinsic spectral energy distribution of the stars over a wide wavelength range.

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### 236.03 – Component Properties of T Tauri Star Binaries

This poster describes our study of the properties of individual components of young T Tauri binary stars. We observed about 100 multi-star systems in the near-infrared, within the relatively close star forming regions Taurus and Ophiuchus. Here we specifically focus on four systems in the Taurus sample, IS Tau, UZ Tau B, IW Tau, and Haro 6- 37 A. Their spectra were taken with the Keck 2 telescope's NIRSPEC spectrograph and the imaging data with the Keck 2 NIRC2 camera, both with adaptive optics. Properties that we determined include spectral type, radial velocity,  $v_{\sin i}$ , veiling, and near-infrared colors. On the basis of these data, we estimate stellar and circumstellar disk properties for the subset of binaries presented here.

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**Contributing team(s):** L. Prato, T. Allen, N. Wright-Garba, L. Biddle, J. McLane (Lowell Observatory), G. Schaefer (GSU & CHARA)

### **236.04 – An Update on the V582 Mon (KH 15D) Binary T Tauri System**

V582 Mon (KH 15D) is a binary T Tauri star, composed of a K1 and K7 star embedded in a circumbinary ring that is inclined to the binary orbit. The age of the stars is 1-3 Myr and their total mass is about 1.3 solar masses. Physics of the precession indicates that the center of the ring is at about 3.8 AU from the center of mass of the binary and the half-width of the ring is of order 2 AU. We are just entering the important phase of evolution of this system in which star B is completely unobscured during at least part of each orbital cycle. A wealth of photometric and spectroscopic data on the system is reviewed and analyzed, primarily addressing two questions: 1) What is the size and composition of the grains composing the ring? and 2) Is there evidence for a self-luminous planet having already formed in the disk beyond the ring?

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**Contributing team(s):** The KH 15D Team

### **236.05 – The DF Tau T Tauri Binary**

Most stars form in multiple systems. Despite this, there are observed differences in properties of stars formed within close proximity of each other. This makes obtaining images and spectra of resolved components in systems for individual analysis desirable. DF Tau is a young, low-mass, visual binary in the Taurus star-forming region with a semi-major axis of ~13 AU. With Adaptive Optics, we are able to acquire high-resolution spectroscopic and imaging data of the primary and secondary stars. We find the primary and secondary differ in a number of characteristics, including vsini and disk presence. This is in spite of the stars having identical spectral types. We are in the process of mapping the ~44-year orbit, and here we present our latest imaging and spectroscopic data.

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### **236.06 – Accretion and Magnetic Reconnection in the Pre-Main Sequence Binary DQ Tau as Revealed through High-Cadence Optical Photometry**

Protostellar disks are integral to the formation and evolution of low-mass stars and planets. A paradigm for the star-disk interaction has been extensively developed through theory and observation in the case of single stars. Most stars, however, form in binaries or higher order systems where the distribution of disk material and mass flows are more complex. Pre-main sequence (PMS) binary stars can have up to three accretion disks: two circumstellar disks and a circumbinary disk separated by a dynamically cleared gap. Theory suggests that mass may periodically flow in an accretion stream from a circumbinary disk across the gap onto circumstellar disks or stellar surfaces.

The archetype for this theory is the eccentric, PMS binary DQ Tau. Moderate-cadence broadband photometry (~10 observations per orbital period) has shown pulsed brightening events near most periastron passages, just as numerical simulations would predict for a binary of similar orbital parameters. While this observed behavior supports the accretion stream theory, it is not exclusive to variable accretion rates. Magnetic reconnection events (flares) during the collision of stellar magnetospheres at periastron (when separated by 8 stellar radii) could produce the same periodic, broadband behavior when observed at a one-day cadence. Further evidence for magnetic activity comes from gyrosynchrotron, radio flares (typical of stellar flares) observed near multiple periastron passages. To reveal the physical mechanism seen in DQ Tau's moderate-cadence observations, we have obtained continuous, moderate-cadence,

multi-band photometry over 10 orbital periods (LCOGT 1m network), supplemented with 32 nights of minute-cadence photometry centered on 4 separate periastron passages (WIYN 0.9m; APO ARCSAT). With detailed lightcurve morphologies we distinguish between the gradual rise and fall on multi-day time-scales predicted by the accretion stream theory and the hour time-scale, rapid-rise and exponential-decay typical of flares. While both are present, accretion dominates the observed variability providing evidence for the accretion stream theory and detailed mass accretion rates for comparison with numerical simulations.

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### **236.07 – 3-D MHD disk wind simulations of protostellar jets**

We present the results of large scale, three-dimensional magnetohydrodynamics simulations of disk winds for different initial magnetic field configurations. The jets are followed from the source to distances, which are resolvable by HST and ALMA observations. Our simulations show that jets are heated along their length by many shocks. The mass of the protostar is a free parameter that can be inserted in the post processing of the data, and we apply the simulations to both low mass and high mass protostars. For the latter we also compute the expected diagnostics when the outflow is photoionized by the protostar. We compute the emission lines that are produced, and find excellent agreement with observations. For a one solar mass protostar, we find the jet width to be between 20 and 30 au while the maximum velocities perpendicular to the jet are found to be 100 km s<sup>-1</sup>. The initially less open magnetic field configuration simulations result in a wider, two-component jet; a cylindrically shaped outer jet surrounding a narrow and much faster, inner jet. For the initially most open magnetic field configuration the kink mode creates a narrow corkscrew-like jet without a clear Keplerian rotation profile and even regions where we observe rotation opposite to the disk (counter-rotating). This is not seen in the less open field configurations.

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### **236.08 – The Inferred Magnetic Field on 50 AU Scales Around IRAS 4A**

Magnetic fields play a key role on all size scales of star formation. On the small scale, they can regulate disk formation, accretion and jet launching. Until recently, it has been difficult to obtain high resolution observations of the magnetic fields of the youngest protostars (Class 0 objects) in this critical region close to the protostar. The VLA Nascent Disk and Multiplicity (VANDAM) survey is a high resolution (~0.2") survey of continuum emission at 8.1 mm, 10.3 mm, 4.1 cm and 6.4 cm from all known protostars in the Perseus Molecular Cloud. Here we present the polarization results from 8.1 mm and 10.3 mm of one of our sources, NGC 1333 IRAS 4A. We then use CARMA polarization data of L1527 (another Class 0 object), and compare the two results. The CARMA data was taken at 1.3 mm and had a resolution of ~0.35". By characterizing the magnetic fields of these young protostars, we are able to better understand the conditions in which young stars form.

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### **236.09 – The VLA Nascent Disk and Multiplicity Survey (VANDAM): Resolved Candidate Disks around Class o and I Protostars**

The properties of young protostellar disks, particularly Class o disks, are not well studied observationally, and their expected properties are controversial. In particular, there is debate about whether or not the earliest disks are large and massive and about when and how disks form. To characterize the properties of the youngest disks and binaries we are conducting the VLA Nascent Disk and Multiplicity survey (VANDAM) toward all known protostars in the Perseus molecular cloud ( $d \sim 230$  pc). The survey is the largest and most complete high-resolution millimeter/centimeter wavelength survey of protostellar disks and binaries. We present the dust emission results toward a sample of  $\sim 15$  protostellar disk candidates around Class o and I sources in the Perseus molecular cloud from the VANDAM survey with  $\sim 0.05''$  or 12 AU resolution. We have begun to confirm the disk candidacy of these sources by fitting the Ka-band 8 mm dust-continuum data in the uv-plane to a simple, parametrized model based on the Shakura-Sunyaev disk model. The seven candidate disks this analysis has been performed on are well-fit by the disk shaped model, and have estimated masses from the measured flux in agreement with masses of previously known disks. The inner-disk surface densities of the VANDAM candidate disks have shallower density profiles compared to disks around more evolved Class II systems. The best-fit model radii of the seven early-result candidate disks are  $R > 10$  AU; at 8 mm, the radii reflect lower limits on the disk size since dust continuum emission is tied to grain size and large grains radially drift inwards. These disks, if confirmed kinematically, are inconsistent with theoretical models where the disk size is limited by strong magnetic braking to  $< 10$  AU at early times.

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### **236.10 – Finding Young Stars in IC417**

IC 417 is a young cluster in the constellation Auriga, towards the Galactic anti-center in the Perseus arm, at a distance of  $\sim 2.3$  kpc. Previous studies suggested that there are young stars in this region; Camargo et al. (2012) identified several few-Myr-old clusters in this region from 2MASS clustering, and Jose et al. (2008) identified H-alpha excess sources. Since stars form from clouds of interstellar dust and gas, a signature of star formation is excess infrared (IR) emission, which is interpreted as evidence for circumstellar dust around young stars. We identified new candidate young stellar objects (YSOs) in IC 417 by incorporating near- and mid-infrared observations from the Wide-field Infrared Survey Explorer (WISE) and the Two Micron All-Sky Survey (2MASS). Infrared excess sources were identified by using a series of color cuts in various 2MASS/WISE color-magnitude and color-color diagrams following Koenig & Leisawitz (2014). We also assembled a list of OB and H-alpha stars from the literature, including those from Jose et al. (2008), and H-alpha bright stars from the IPHAS survey (Witham et al. 2008). Starting with this compiled list of approximately 200 interesting objects in the region, we then set about checking their reliability in three ways. We inspected the POSS, 2MASS, and WISE images of the sources. We assembled and inspected spectral energy distributions (SEDs) from archival data ranging from wavelengths of 0.7 to 22  $\mu$ m. Finally, we created and inspected color-color and color-magnitude diagrams. We find enough new YSO candidates to more than double the number yet identified in the IC 417 region. This research was made possible through the NASA/IPAC Teacher Archive Research Program (NITARP) and was funded by NASA Astrophysics Data Program.

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### **236.11 – Properties of Young Stars in Nearby SFRs: Cepheus, Ophiuchus and Taurus**

We study the properties of young stars in several nearby star formation regions. Our approach examines both the aggregate properties of large samples of young stars and the detailed properties of a smaller sample of individual stars. The large aggregate sample helps our statistical understanding of how while studying individual young stars in detail informs our interpretation of the larger data set. The specific star formation regions we have been studying include Cep OB3b, a large cluster of thousands of young stars as well as Taurus and Ophiuchus, both smaller star formation regions that are close enough to examine individual stars in detail. We use a number of instruments that span much of the electromagnetic spectrum including the Discovery Channel Telescope in the ultraviolet and visible and Keck in the infrared. For the young stars in the Cep OB3b region we examine the X-ray and accretion properties. For the young stars in Taurus and Ophiuchus, we estimate properties, such as vsini, magnetic field strength, effective temperature and presence (or lack) of a disk.

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### **236.12 – The Mass-Radius Relation of Young Stars from K2**

Evolutionary models of pre-main sequence stars remain largely uncalibrated, especially for masses below that of the Sun, and dynamical masses and radii pose valuable tests of these theoretical models. Stellar mass dependent features of star formation (such as disk evolution, planet formation, and even the IMF) are fundamentally tied to these models, which implies a systematic uncertainty that can only be improved with precise measurements of calibrator stars. We will describe the discovery and characterization of ten eclipsing binary systems in the Upper Scorpius star-forming region from K2 Campaign 2 data, spanning from B stars to the substellar boundary. We have obtained complementary RV curves, spectral classifications, and high-resolution imaging for these targets; the combination of these data yield high-precision masses and radii for the binary components, and hence a dense sampling of the (nominally coeval) mass-radius relation of 10 Myr old stars. We already reported initial results from this program for the young M4.5 eclipsing binary UScoCTIO 5 (Kraus et al. 2015), demonstrating that theoretically predicted masses are discrepant by  $\sim 50\%$  for low-mass stars. K2's unique radius measurements allow us to isolate the source of the discrepancy: models of young stars do not predict luminosities that are too low, as is commonly thought, but rather temperatures that are too warm.

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### **236.13 – Probabilistic HR Diagrams: A New Infrared and X-ray Chronometer for Very Young, Massive Stellar Clusters and Associations**

We present a novel method for constraining the duration of star formation in very young, massive star-forming regions. Constraints

on stellar population ages are derived from probabilistic HR diagrams (pHRDs) generated by fitting stellar model spectra to the infrared (IR) spectral energy distributions (SEDs) of Herbig Ae/Be stars and their less-evolved, pre-main sequence progenitors. Stellar samples for the pHRDs are selected based on the detection of X-ray emission associated with the IR source, and the *lack* of detectable IR excess emission at wavelengths  $\leq 4.5 \mu\text{m}$ . The SED model fits were used to create two-dimensional probability distributions of the stellar parameters, specifically bolometric luminosity versus temperature and mass versus evolutionary age. We present first results from the pHRD analysis of the relatively evolved Carina Nebula and the unevolved M17 SWex infrared dark cloud, which reveal the expected, strikingly different star formation durations between these two regions. In the future, we will apply this method to analyze available X-ray and IR data from the MYStIX project on other Galactic massive star forming regions within 3 kpc of the Sun.

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## 237 – Supernovae Poster Session

### 237.01 – See Change: First Results from the Supernova Cosmology Project High Redshift Cluster Supernova Survey

Using the Hubble Space Telescope, the Supernova Cosmology Project is performing a type Ia supernova search in the highest-redshift, most massive clusters known to date. This large HST program spans Cycles 22-23. It will improve the constraint by a factor of 3 on the Dark Energy equation of state above  $z \sim 1$ , allowing an unprecedented probe of Dark Energy time variation. When combined with the improved cluster mass calibration from gravitational lensing provided by the deep WFC3-IR observations of the clusters, the SNe clusters observed also will triple the Dark Energy Task Force Figure of Merit. With Cycle 22 completed, we present preliminary supernova light curves above  $z=1.1$  and discuss the number of supernovae discovered compared to our expectations from different SN rates models. Our HST imaging and extensive ground-based campaign are already producing unique results; we have spectroscopically confirmed several of the highest redshift cluster members to-date, and confirmed one of the most massive clusters at  $z \sim 1.2$  expected over the entire sky.

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### 237.02 – Supernovae Detection in Dust Extinguished

## Galaxies - A Spitzer Survey

The rate at which supernovae (SNe) occur in ultraluminous infrared galaxies (ULIRGs) is explained by theory. However, past optical surveys of these galaxies have revealed a number 3 to 10 times lower than the number predicted. These surveys used ground-based radio and near-IR observations, but had a number of shortcomings including poor resolution and inability to detect high extinction events. The Spitzer Space Telescope (SST) offers several advantages over these ground-based surveys. First, the SST is able to maintain stable seeing in space. Furthermore, another advantage is at the longer wavelengths provided by Spitzer, the SNe in the nuclear regions of galaxies are less susceptible to extinction effects from dust. In order to detect the SNe through the heavy dust fields in ULIRGs, observations were taken at  $3.6 \mu\text{m}$  with the warm IRAC camera on the SST. Here we present preliminary results from our SST survey of 40 ULIRGs. We describe the sensitivity of the survey given our current detection algorithm, which is limited in large part by an asymmetric Point Spread Function. Ultimately, we explore whether the 'missing' SNe can be accounted for by an extinction from the nucleus.

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### 237.03 – Automated Artifact Rejection for Transient Identification in WFC3 IR Image Subtractions

We describe a set of features for identifying  $z > 1$  supernovae in reference-subtracted HST WFC3 IR images produced by the Supernova Cosmology Project's pipeline for the "See Change" project. These features, in combination with a random forest classifier, yield an effective system for automatically discriminating between supernovae and image artifacts produced by the instrumentation and the image processing procedure. When k-fold cross-validation is performed using a set of 30,000 artifacts and 10,000 synthetic supernovae, the classifier gives an efficiency comparable to that of a human scanner, correctly identifying 97 percent of the synthetic supernovae while rejecting 95 percent of the artifacts. This software will allow for less labor-intensive transient search procedures by automatically rejecting artifacts that would otherwise require human review.

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**Contributing team(s):** Supernova Cosmology Project

### 237.04 – The Host Galaxies of Superluminous Supernovae from the Palomar Transient Factory

Superluminous supernovae are a recently-discovered class of rare transient objects with luminosities tens to hundreds of times that of ordinary core-collapse supernovae. We present the sample of 31 SLSNe discovered by the Palomar Transient Factory between the years of 2009-2012, and provide a detailed observational characterization of their hosts including UV-to-NIR SEDs and Keck spectroscopy. With these data we determine star-formation rates, stellar masses, ages, and metallicities and compare the hosts of different classes of SLSNe to each other and to other transient objects (GRBs and cc-SNe). The hosts of hydrogen-poor Type I SLSNe show a pronounced (but not exclusive) preference for low-mass, low-metallicity galaxies; many occur in intense starbursts but a significant fraction occur in galaxies with extremely low present-day starformation rates. The hosts of hydrogen-rich Type II SLSNe are fairly representative of the star-forming galaxy population generally with only a mild preference for hosts with lower masses. While universally associated with massive stars, SLSNe of both types may have heterogeneous evolutionary pathways towards explosion.

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### 237.05 – Determination of $R_V$ and Distance for SN 2012cu, the Type Ia Supernova with Highest Extinction

Multi-epoch, flux-calibrated spectroscopic data of a highly reddened Type Ia supernova, SN2012cu, from 3300 – 9700 Å, were obtained using the SuperNova Integrated Field Spectrograph. We determine its best-fit color excess,  $E(B-V)$ , and total-to-selective extinction ratio,  $R_V$ . We detect in the near-maximum spectra two of the diffuse interstellar band features and we further find the dust extinction properties toward SN2012cu in its host to be like those of the Milky Way. We also compare the reddening laws of Cardelli et al. (1989), O'Donnell (1994), and Fitzpatrick (1999), and find the predictions of the latter fit the data the best. Finally, the distance to the host galaxy, NGC4772, is determined to within 6%. We compare our result with distance measurements based on the Tully-Fisher method in the literature.

**Author(s):** Xiaosheng Huang<sup>14</sup>, Zachary Raha<sup>14</sup>, Greg Scott Aldering<sup>7</sup>, Pierre Antilogus<sup>12</sup>, Cecilia Aragon<sup>7</sup>, Stephen J. Bailey<sup>7</sup>, Charles Baltay<sup>15</sup>, Kyle H. Barbary<sup>13</sup>, Derek Baugh<sup>9</sup>, Kyle Boone<sup>7</sup>, Sebastien Bongard<sup>12</sup>, Clement Buton<sup>10</sup>, Juncheng Chen<sup>9</sup>, Michael Childress<sup>2</sup>, Nicolas Chotard<sup>10</sup>, Yannick Copin<sup>10</sup>, Parker Fagrelis<sup>7</sup>, Hannah Fakhouri<sup>7</sup>, Ulrich Feindt<sup>5</sup>, Mathilde Fleury<sup>12</sup>, Dominique Fouchez<sup>1</sup>, Emmanuel Gangler<sup>3</sup>, Brian Hayden<sup>7</sup>, Alex G. Kim<sup>7</sup>, Marek Kowalski<sup>5</sup>, Pierre-Francois Leget<sup>3</sup>, Simona Lombardo<sup>5</sup>, Jakob Nordin<sup>5</sup>, Reynald Pain<sup>12</sup>, Emmanuel Pecontal<sup>11</sup>, Rui Pereira<sup>10</sup>, Saul Perlmutter<sup>7</sup>, David L. Rabinowitz<sup>15</sup>, Mickael Rigault<sup>5</sup>, David Rubin<sup>4</sup>, Karl Runge<sup>7</sup>, Clare Saunders<sup>7</sup>, Richard A. Scalzo<sup>2</sup>, Gerard Smadja<sup>10</sup>, Caroline Sofiatti<sup>7</sup>, Nao Suzuki<sup>6</sup>, Andrew Stocker<sup>14</sup>, Stefan Taubenberger<sup>8</sup>, Charling Tao<sup>9</sup>, Rollin Thomas<sup>7</sup>  
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**Contributing team(s):** The Nearby Supernova Factory

### 237.06 – The Untimely Demise of SN 2008S

Supernova (SN) 2008S in the "Fireworks Galaxy" (NGC 6946) has been enigmatic ever since its initial outburst was discovered in Feb 1, 2008. Initially classified a Type II in due to early spectral features, its subsequent spectral and photometric behavior over the first ~200 days led to two divergent explanations for the event. Citing photometric behavior atypical for any known explosion mechanisms, some have concluded this was "supernova imposter," such as a giant eruption in a massive Luminous Blue Variable star. Others report that its evolution was in fact consistent with the faintest Type-IIP SNe, which combined with the discovery of an intermediate-mass progenitor in mid-IR imaging, led to the conclusion that it was an electron-capture SN. Using a combination of ground-based, Hubble Space Telescope optical and near-infrared, and Spitzer Space Telescope mid-infrared imaging, we have traced the optical-through-infrared evolution of the SN from outburst to disappearance by 2014. We show that the limited intermediate-time optical data are consistent with radioactive <sup>56</sup>Co decay, however there are not enough late-time observations to assert with confidence whether or not the light curve supports a supernova hypothesis. We also show that the mid-infrared source identified as the progenitor is still present after the disappearance of the SN, suggesting either that this source is unrelated to the progenitor, or that the progenitor has returned to its pre-outburst state.

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### 237.07 – Understanding the Ultraviolet Flux from Supernovae

The conversion of observed magnitudes into flux densities for the creation of spectral energy distributions or integrating bolometric

fluxes depends on the spectral shape of the source and the characteristics of the filters. Such details are often neglected, though the effects can be significant. We demonstrate the complexities of conversion as they relate to ultraviolet observations of supernovae, though the principles have broader application. These complexities include spectral model testing, the meaning of effective wavelengths, the endpoints of integration, and extinction corrections. Using data from the Swift Optical Ultraviolet Supernova Archive (SOUSA) we will present integrated luminosity curves from example supernovae of all types. We will also show the unprecedented ultraviolet luminosity of ASASSN-15lh/SN2015L. The creation of ultraviolet/optical spectral energy distributions is helpful in predicting the observed brightness and detectability of these supernovae at higher redshifts with optical telescopes such as the Dark Energy Survey and the Large Synoptic Survey Telescope.

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### 237.08 – Studies of Template-based Photometric Classification of Supernovae

We study photometric classification of Type Ia (SNIa) and core collapse (SNcc) supernovae using a combination of simulated data from DES and real data from SDSS. We increase the number of core collapse templates from the eight commonly used to type SDSS supernovae (PSNID) to forty-five currently available in SNANA. These are implemented in the SNCosmo analysis package. Our goal is to study the accuracy in identifying all types of supernovae as a function of numbers and types of templates.

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### 237.09 – Late-time mid-IR emission from Type Ia and stripped-envelope core-collapse supernovae - possible sign of circumstellar interaction

The signs of circumstellar interaction in the late phase (>1 yr) of supernovae (SNe) can be studied in various wavelength regimes from X-ray to radio. These observations offer a chance to reveal information about the type and mass-loss history of the progenitor, the presence of a companion star, and the environment of the SN. While this phenomenon is well-known and well-studied concerning SN IIn, similar processes have not been observed to take place in other types of SNe.

We suggest that numerous objects belong to other types of SNe (SNe Ia, Ib/c or IIb) may also show detectable sign of circumstellar interaction. In these types of SNe, the source of late-time mid-infrared (mid-IR) excess may be some kind of interaction between the SN ejecta and the circumstellar matter (CSM) that originated from the pre-explosion mass-loss of the progenitor and/or its companion star. The observed mid-IR emission from these SNe, especially combined with data from other wavelength regimes, may be a convincing sign of CSM interaction.

Here we present some unpublished results based on the archive measurements of the Spitzer Space Telescope. Our study includes the analysis of late-time mid-IR emission from such well-known CSM-interacting SNe like SN Ia-CSM PTF11kx, SN Ibn 2001em, and SN IIb 1993J, as well as from some other interesting Type Ia and stripped-envelope SNe, where CSM interaction may also take place.

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### 237.10 – Using Twin Type Ia Supernovae to Improve Cosmological Distance Measurements

The Nearby Supernova Factory has collected spectrophotometric timeseries of many Hubble-flow type Ia supernovae. Using this dataset, we introduce a novel method of identifying "twin" Type Ia supernovae by matching spectral data. For this initial set of SNfactory twin supernovae, we find a dispersion in luminosity of

0.083  $\pm$  0.012 magnitudes between twins, implying a dispersion of 0.072  $\pm$  0.010 magnitudes in the absence of peculiar velocities. This shows that at least 3/4 of the variance in Hubble residuals in current supernova cosmology analyses is due to previously unaccounted-for astrophysical differences among the supernovae -- differences captured by spectrophotometric twinning. We discuss both the usage of this method and the data requirements to implement it.

**Author(s):** Kyle Boone<sup>11</sup>, Hannah Fakhouri<sup>11</sup>, Greg Scott Aldering<sup>6</sup>, Pierre Antilogus<sup>5</sup>, Cecilia Aragon<sup>6</sup>, Stephen J. Bailey<sup>6</sup>, Charles Baltay<sup>12</sup>, Kyle H. Barbary<sup>11</sup>, Derek Baugh<sup>8</sup>, Dan Birchall<sup>6</sup>, Sebastien Bongard<sup>5</sup>, Clement Buton<sup>9</sup>, Flora Cellier-Holzem<sup>5</sup>, Juncheng Chen<sup>8</sup>, Michael Childress<sup>2</sup>, Nicolas Chotard<sup>9</sup>, Yannick Copin<sup>9</sup>, Parker Fagrelis<sup>11</sup>, Ulrich Feindt<sup>4</sup>, Mathilde Fleury<sup>5</sup>, Dominique Fouchez<sup>1</sup>, Emmanuel Gangler<sup>3</sup>, Brian Hayden<sup>6</sup>, Alex G. Kim<sup>6</sup>, Marek Kowalski<sup>4</sup>, Pierre-Francois Leget<sup>3</sup>, Simona Lombardo<sup>4</sup>, Jakob Nordin<sup>6</sup>, Peter E. Nugent<sup>6</sup>, Reynald Pain<sup>5</sup>, Emmanuel Pecontal<sup>10</sup>, Rui Pereira<sup>9</sup>, Saul Perlmutter<sup>11</sup>, David L. Rabinowitz<sup>12</sup>, James Ren<sup>11</sup>, Mickael Rigault<sup>4</sup>, David Rubin<sup>6</sup>, Karl Runge<sup>6</sup>, Clare Saunders<sup>11</sup>, Richard A. Scalzo<sup>2</sup>, Gerard Smadja<sup>9</sup>, Caroline Sofiatti<sup>11</sup>, Mark Strovink<sup>11</sup>, Nao Suzuki<sup>6</sup>, Charling Tao<sup>8</sup>, Rollin Thomas<sup>6</sup>, Benjamin Weaver<sup>7</sup>

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**Contributing team(s):** Nearby Supernova Factory (SNfactory)

### 237.11 – Correlating Type Ia Supernova Properties with Their Local Environment Using HST Snapshots of Host Galaxies

Type Ia supernovae (SN Ia) are important tools for precision cosmology. But there are still uncertainties about how the host galaxy properties and local environment influence the luminosity, color and Hubble residuals of SN Ia. We investigate these questions by analyzing high angular resolution Hubble Space Telescope (HST) imaging of SDSS-II host galaxies. These are "snapshot" images obtained while the telescope was slewing to new targets, so the total exposure times are less than 30 minutes. ACS images were obtained in F475W and F625W filters, similar to SDSS g and r-bands. In total, we observed 61 host galaxies in Stripe 82 that had SN Ia discovered by the SDSS-II SN Survey. HST's resolution and low background allow for detailed analysis of both the region around the SN Ia and the galaxy as a whole. Co-added SDSS-II images of the hosts are used to supplement the HST data in regions of low surface brightness. From this data set we estimate the fractional pixel rank and photometric color of the SN Ia's location and correlate the local environment variables with SN Ia luminosity, light curve width, color and Hubble residual. We assess the impact of these correlations on the accuracy of SN Ia distance estimates and possible biases in measuring the Hubble constant and dark energy parameters.

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### 237.12 – The SuperNovae Analysis Application (SNAP): A new tool for rapid analysis of SNe light curves and model verification

The SuperNovae Analysis Application (SNAP) is a new tool for the analysis of SNe observations and validation of SNe models. SNAP consists of two data bases, an observational light curve data base and a theoretical light curve model data base, statistical comparison software, and a web interface available to the community. The observational light curves are primarily *Swift* UVOT core-collapse SNe and include all available observations from these observed SNe. The currently available theoretical models were developed at LANL. The web interface allows approved users to upload new SNe models or new SNe observations. The comparison software will validate new models against available SNe observations or rapidly give constraints on parameters for newly discovered SNe. With the advent of large computing abilities, more sophisticated SNe models are being

developed. SNAP will be a tool to determine the accuracy of these new models. SNAP will also be a useful tool in the era of large surveys where thousands of SNe are discovered annually. Frequently, the parameter space of a new SNe event is unbounded. SNAP will be a resource to constrain parameters and determine if an event needs follow up without spending resources to create new light curve models from scratch.

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**Contributing team(s):** SNAP Development Team

### 237.13 – Modeling Type II In Supernova Light Curves

We present near-by Type II In supernovae observed with *Swift*'s Ultraviolet/Optical Telescope (UVOT). Based on the diversity of optical light curve properties, this Type II subclass is commonly referred to as heterogeneous. At the time of discovery, our II In sample is  $\sim 2$  magnitudes brighter at ultraviolet wavelengths than at optical wavelengths, and ultraviolet brightness decays faster than the optical brightness. We use a semi-analytical supernova (SN) model to better understand our II In observations, and focus on matching specific observed light curves features, i.e peak luminosity and decay rate. The SN models are used to study the effects of initial SN conditions on early light curves, and to show the extent of the "uniqueness" problem in SN light curves. We gratefully acknowledge the contributions from members of the *Swift* UVOT team, the NASA astrophysics archival data analysis program, and the NASA *Swift* guest investigator program.

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### 237.14 – Effects of Metallicity on W7 model spectrum

The metallicity of progenitor systems of type Ia supernova can vary and are not well known. Variations in this can lead to differences in the observed spectra. To consider spectral variations caused by progenitor metallicity differences, we constructed a grid of model spectra of Type Ia supernova for metallicities from a thousandth to three times solar metallicity, using the W7 deflagration model, and spectral code PHOENIX. The grid covers days 8, 11, 14, 17, 21 post explosion because these effects should be most predominant in the early spectra. Variations are present in the spectra primarily in the UV as expected. We found an possible alternate identification for the feature that has been identified as the carbon 6580 observed in some normal type Ia. Our model spectra have a feature from carbon 6580 and a feature caused by a blend of silicon lines at 6690, 6667, and 6745. The carbon feature in the model is too slow and the silicon feature is at too low a velocity to match the observations. The fit of W7 to observations in this region of the spectra is poor so a better explosion model will be needed to better study these effects.

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**Institution(s):** 1. University of Oklahoma

### 237.15 – Fingerprinting Hydrogen in Core-Collapse Supernovae

This is a preliminary report on the mass of remaining hydrogen envelopes for stars massive enough to explode under core collapse. Using the stellar evolution code, MESA, our initial findings suggest that a significant fraction of massive stars with  $M_{\text{ZAMS}} = 20\text{--}60$   $M_{\odot}$  lose all but  $10^{-3}$   $M_{\odot}$   $\text{--} 10^{-1}$   $M_{\odot}$  as they near eventual core collapse. This result is dependent on the mass-loss prescription, degree of rotation, metallicity, rates of nuclear burning in the core, and the final stellar configuration. Nevertheless, each of our test cases include a few stars that retain trace amounts of surface hydrogen, which would then be detected as faint H in type IIb/IIc supernova spectra. We also compare our findings to the progenitor candidate identified for iPTF13bvn using the most recent photometric corrections. We agree with the previous conclusion found by Groh et al. (2013) that the progenitor had an initial mass of 32  $M_{\odot}$ , but now with an additional condition of 0.06  $M_{\odot}$  of hydrogen on its surface just prior to the explosion. We demonstrate through our study that not all Type Ib supernovae are fully devoid of hydrogen at the time of explosion, which has implications for the

nature of the progenitor star and thus provides impetus for a revised classification scheme for 'stripped envelope' supernovae. This work was supported in part by the NSF REU and DoD ASSURE programs under NSF grant no. 1262851 and by the Smithsonian Institution.

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**Institution(s):** 1. Harvard Smithsonian Center for Astrophysics, 2. The University of Texas at Austin

### 237.16 – Effects of magnetic fields on the nuclear burning propagation and the Type Ia SNe runaway

The consistency of Type Ia SNe allows for simple descriptions of the phenomena founded on basic physics and yet no theory is able to explain the observations entirely. In particular we are addressing an outstanding problem with current 3D simulations, in which Rayleigh-Taylor (RT) instabilities bring too much burned material to the outer layers thus mixing iron group elements towards the surface but those are not observed. Additionally light curves are reproduced well only in spherically symmetric explosions, while they break down when instabilities are present. We attempt to explain these discrepancies by introducing magnetic fields, which affects the rate of growth of unstable modes. Specifically it increases the growth rate of modes parallel to itself and suppress the transverse modes. This reduces the mixing in two possible ways: stronger burning causes faster pre-expansion, then plumes rise with the similar speed as the surrounding material is expanding; and RT instabilities are suppressed so much that they don't rise at all. Our preliminary models run in a rectangular domain inside a C/O white dwarf (WD) extending 120km along the stellar radius and is about 15km on the side. External magnetic fields between 1e4G and 1e9G are superimposed at various angles to the WD radius. A simple two-species nuclear network is employed in the form of fuel-product (C/O -> 56Ni). The front propagation is modeled as diffusion of the burned fraction of the C/O fuel. All simulations were done with Enzo - a 3D AMR MHD code for astrophysical and cosmological simulations, which was enhanced with additional physics for the nuclear burning. Future work will extend to full star simulations and more complex nuclear networks.

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### 237.17 – Thermonuclear Supernova Explosions From Hybrid White Dwarf Progenitors

Motivated by recent results in stellar evolution in which convective boundary mixing in SAGB stars can give rise to hybrid white dwarf (WD) stars with a C-O core inside an O-Ne shell, we simulate thermonuclear (Type Ia) supernovae from these hybrid progenitors. We use the FLASH code to perform multidimensional simulations in the deflagration to detonation transition (DDT) explosion paradigm from progenitor models produced with the MESA stellar evolution code that include the thermal energetics of the Urca process. We performed a suite of DDT simulations over a range of ignition conditions and compare to previous results from a suite of C-O white dwarfs. Despite significant variability within each suite, distinguishing trends are apparent in their Ni-56 yields and the kinetic properties of their ejecta. We comment on the feasibility of these hybrid WD explosions as the source of some classes of observed subluminal events. This research was supported in part by the U.S. Department of Energy under grant DE-FG02-87ER40317 and by resources at the Institute for Advanced Computational Science at Stony Brook University. The software used in this work was in part developed by the DOE-supported ASC/Alliances Center for Astrophysical Thermonuclear Flashes at the University of Chicago.

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### 237.18 – Neutrino event counts from Type Ia

### supernova models

Core collapse supernovae (SNe) are widely known to be among the universe's primary neutrino factories, releasing ~99% of their energy, or ~10<sup>53</sup> ergs, in the form of the tiny leptons. On the other hand, less than 4% of the energy of Type Ia SNe is released via neutrinos, hence making Ia SNe impossible to detect (through neutrino observations) at typical supernova distances. For this reason, neutrino signatures from these explosions have very rarely been modeled. We ran time-sliced fluences from non-oscillation pure deflagration and delayed detonation (DDT) Ia models by Odrzywolek and Plewa (2011) through SNOwGLOBES, a software that calculates event rates and other observed quantities of supernova neutrinos in various detectors. We determined Ia neutrino event rates in Hyper-K, a proposed water Cherenkov detector, JUNO, a scintillator detector under construction, and DUNE, a proposed argon detector, and identified criteria to distinguish between the two models (pure deflagration and DDT) based on data from a real supernova (statistically represented by a Poisson distribution around the expected result). We found that up to distances of 8.00, 1.54, and 2.37 kpc (subject to change based on oscillation effects and modified detector efficiencies), we can discern the explosion mechanism with ≥90% confidence in Hyper-K, JUNO, and DUNE, respectively, thus learning more about Ia progenitors.

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## 238 – Planetary Nebulae, Supernova Remnants Poster Session

### 238.01 – Identifying Close Binary Central Stars of PN From the Kepler K2 Mission

During the Kepler mission, De Marco et al (2015) reported observing 5 PN central stars. Of these, the light curves for 4 central stars exhibited signatures of close binary interactions during their evolution. While suggestive that a large fraction of PN evolve as a binary phenomenon, the sample is far too small to be compelling. We have acquired Kepler K2 data for campaigns 0 and 2 to monitor an additional 6 central stars, and we expect data for another 8-10 targets in campaign 7. We present preliminary results from Kepler K2 campaigns 0 and 2, describe our expectations for campaign 7, and discuss the challenges of using Kepler for these observations.

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### 238.02 – Atomic Data for Nebular Abundance Determinations: Photoionization and Recombination Properties of Xenon Ions

We present preliminary results of a study of the photoionization (PI) and recombination properties of low-charge Xe ions. The abundances of neutron(*n*)-capture elements (atomic number *Z* > 30) are of interest in planetary nebulae (PNe) since they can be enriched by slow *n*-capture nucleosynthesis (the ``s-process") in the progenitor asymptotic giant branch (AGB) stars. Xe is particularly valuable, because it is the most widely-observed ``heavy-s" species (*Z* > 40) in PNe. Its abundance relative to lighter *n*-capture elements can be used to determine s-process neutron exposures, and constrain s-process enrichment patterns as a function of progenitor metallicity. Using the atomic structure code AUTOSTRUCTURE (Badnell 2011, Comp. Phys. Comm., 182, 1528), we have computed multi-configuration Breit-Pauli distorted-wave PI cross sections and radiative recombination (RR) and dielectronic recombination (DR) rate coefficients for neutral through six-times ionized Xe, data which are critically needed for accurate Xe abundance determinations in ionized nebulae. We find good agreement between our computed direct PI cross sections and experimental measurements. Internal uncertainties are estimated for our calculations by using three different configuration interaction expansions for each ion, and by

testing the sensitivity of our results to the radial orbital scaling parameters. As found for other  $n$ -capture elements (Sterling & Witthoeft 2011, A&A, 529, A147; Sterling 2011, A&A, 533, A62), DR is the dominant recombination mechanism for Xe ions at nebular temperatures ( $\sim 10^4$  K). Following Sterling et al. (2015, ApJS, 218, 25), these data will be added to nebular modeling codes to compute ionization correction factors for unobserved Xe ions in PNe, which will enable elemental Xe abundances to be determined with much higher accuracy than is currently possible. This work is supported by NSF award AST-1412928.

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**Institution(s):** 1. University of West Georgia

### 238.03 – Atomic Data for Nebular Abundance Determinations: Photoionization, Recombination, and Collisional Excitation of Rubidium and Bromine Ions

We present results of an investigation into the photoionization (PI), recombination, and electron-impact excitation properties of low-charge Br and Rb ions. Br and Rb are among the relatively few neutron( $n$ )-capture elements (atomic number  $Z > 30$ ) that have been detected in planetary nebulae (PNe). Their abundances can reveal unique information regarding nucleosynthesis in asymptotic giant branch (AGB) stars, including slow  $n$ -capture ( $s$ -process) neutron densities and the dominant neutron source in more massive AGB stars (4-8 solar masses). However, the requisite atomic data needed for accurate Rb and Br nebular abundance determinations are unknown. Our work addresses this need, via a synthesis of theoretical and experimental methods. Using the AUTOSTRUCTURE atomic structure code (Badnell 2011, Comp. Phys. Comm., 182, 1528), we have computed multi-configuration Breit-Pauli distorted-wave PI cross sections, and rate coefficients for radiative recombination (RR) and dielectronic recombination (DR) for neutral through six-times ionized Br and Rb. To benchmark our calculations, we have measured absolute PI cross sections of  $\text{Br}^+$ - $\text{Br}^{4+}$  and  $\text{Rb}^+$ - $\text{Rb}^{5+}$  at the Advanced Light Source synchrotron radiation facility in Berkeley, CA. Breit-Pauli R-matrix calculations are in progress to facilitate analysis of the experimental data, including resonance identifications and determining the metastable populations of the primary ion beams. Finally, we are performing R-matrix calculations of effective collision strengths for electron-impact excitation of astrophysically detected Br and Rb ions. Our  $\text{Rb}^{3+}$  effective collision strength results have been applied to two PNe, with excellent agreement found for ionic abundances determined from different [Rb IV] lines. The combination of these atomic data will dramatically improve the accuracy of Br and Rb abundance determinations in astrophysical nebulae, providing new insight into heavy element nucleosynthesis in low- and intermediate-mass stars. This work is supported by NSF award AST-1412928.

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**Institution(s):** 1. Hobart and William Smith Colleges, 2. Lawrence Berkeley National Laboratory, 3. University of Connecticut, 4. University of Montana, 5. University of West Georgia, 6. Western Michigan University

### 238.04 – Heavy Element Abundances in Planetary Nebulae from Deep Optical Echelle Spectroscopy

We present the abundances of neutron( $n$ )-capture elements (atomic number  $Z > 30$ ) and iron determined from deep optical echelle spectroscopy of 14 Galactic planetary nebulae (PNe). The spectra were obtained with the 2D-coudé spectrograph on the 2.7-m Harlan J. Smith telescope at McDonald Observatory. The abundances of  $n$ -capture elements can be enhanced in PNe due to slow  $n$ -capture nucleosynthesis in the progenitor asymptotic giant branch (AGB) stars. The high spectral resolution of these data ( $R = 36,700$ ) allow most  $n$ -capture element emission lines to be resolved from other nebular and telluric features. We detect Kr in all of the observed PNe (with multiple ions detected in several objects), while Br, Rb, and Xe were each detected in 4--5 objects. Using the new Kr ionization

correction factors (ICFs) of Sterling et al. (2015, ApJS, 218, 25), we find [Kr/O] abundances ranging from 0.05 to 1.1 dex. We utilize approximate ICFs for the other  $n$ -capture elements, and find slightly lower enrichments for Br and Rb (-0.1 to 0.7 dex), while Xe is enhanced relative to solar by factors of two to 30. The [Xe/Kr] ratios range from -0.3 to 1.4 dex, indicating a significant range in neutron exposures in PN progenitor stars. Interestingly, the largest [Xe/Kr] ratio is found in the thick-disk PN NGC 6644, which has a lower metallicity than the other observed PNe. We detect iron emission lines in all but one target. Fe can be depleted into dust grains in ionized nebulae, and its abundance thus provides key information regarding dust-to-gas ratios and grain destruction processes. We find that [Fe/O] ranges from -1.3 to -0.7 dex in the observed PNe, a smaller spread of depletion factors than found in recent studies (Delgado-Inglada & Rodriguez 2014, ApJ, 784, 173) though this may be due in part to our smaller sample. These data are part of a larger study of heavy elements in PNe, which will provide more accurate determinations of  $n$ -capture element abundances than previous estimates in several PNe, thereby providing key new constraints to models of AGB nucleosynthesis and Galactic chemical evolution. This work was supported by NSF awards AST-0708245 and AST-901432.

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**Institution(s):** 1. Georgia Institute of Technology, 2. McDonald Observatory, 3. University of Texas, 4. University of Texas-San Antonio, 5. University of Washington, 6. University of West Georgia, 7. Wesleyan University

### 238.05 – Discovery and Characterization of Supernova Remnants in M101 with HST

We have begun a program to identify and characterize the supernova remnant (SNR) population in the face-on giant spiral galaxy M101 ( $d=6.8$  Mpc,  $0.1''=3.3$  pc), using Hubble Space Telescope imaging. Our Cycle 21 program leverages archival ACS/WFC deep H-alpha and continuum imaging for four fields by obtaining new WFC3 [S II] and [O III] imaging; also, one new field has been completely done with WFC3. The region covered extends to  $\sim 12$  kpc, but is asymmetrical with respect to the nucleus. Of the 93 SNR candidates known from ground-based imaging, 31 are within the new WFC3 coverage and all but two are confirmed. Additionally, we have identified 23 new strong SNR candidates and another 37 second-tier candidates within the WFC3 footprint. Thus, we have likely more than doubled the number of SNR candidates in the sampled region. We measure diameters for the sample and compare to other galaxy samples such as in M83 (which has more small diameter SNRs). At least 25 of the sources appear to have X-ray counterparts in deep Chandra data. Interestingly, no strong candidates for young, ejecta-dominated (Cas A-like) SNRs have been found in the sample to date. Scaling up to the entire galaxy, there should be well over 200 detectable SNRs in M101 if a full survey was performed.

We acknowledge support from STScI grant HST-GO-13361-01-A to the Johns Hopkins University.

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**Institution(s):** 1. Johns Hopkins Univ., 2. Middlebury College, 3. STScI

### 238.06 – An Archival Chandra Study of the Young Core-Collapse Supernova Remnant 1E 0102.2-7219 in the Small Magellanic Cloud

We report on the initial results from our detailed spatially-resolved spectral analysis of the young O-rich supernova remnant (SNR) 1E 0102.2-7219 in the Small Magellanic Cloud, using the deep 273 ks archival Chandra data. We examined the radial and azimuthal variations in elemental abundances (O, Ne, Mg) and plasma parameters (electron temperature, ionization timescale). We briefly discuss the implications of our results on the geometrical structure of the remnant and its circumstellar medium.

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**Institution(s):** 1. Istanbul University, 2. University of Texas at Arlington

### 238.07 – An Archival X-ray Study of the Large Magellanic Cloud Supernova Remnant N132D

We present the results of an analysis of the archival XMM-Newton EPIC data (203ks for pn and 556/574ks for MOS1/MOS2) and the Chandra X-ray Observatory ACIS data (89ks) of the brightest X-ray supernova remnant (SNR) in the Large Magellanic Cloud (LMC) N132D. N132D has been classified as an "O-rich" remnant based on the UV and optical spectra which show emission from C, O, Ne, Mg, and Si. These spectra of the central optical knots do not show any emission from elements with Z higher than Si, yet the nucleosynthesis models predict significant quantities of these higher Z elements. Our spectral analysis of the deep XMM data clearly shows emission lines from S, Ar, Ca, and Fe, with indications of other possible features between Ca and Fe. We use a combination of the high resolution images from Chandra and the sensitive spectra from XMM to disentangle the emission from swept-up interstellar material and a possible hot ejecta component. We interpret these results in the context of a 3,000 year old remnant from a massive progenitor that has exploded into a cavity created by the progenitor.

This research was supported by the NASA Astrophysics Data Analysis Program (ADAP) through grant number NNX11AD17G.

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### 238.08 – New Extended GeV Sources in the Galactic Plane Found in a Search of the Pass 8 Data from Fermi-LAT

Spatially resolving pulsar wind nebulae (PWNe) and supernova remnants (SNRs) at GeV energies enables accurate representation of spectra, aids identification of multiwavelength counterparts, and probes possible substructure within the gamma-ray sources. Using 6 years of Fermi-LAT Pass 8 data above 10 GeV, we searched for spatially extended sources near the Galactic plane. The improved angular resolution and photon acceptance of the Pass 8 event reconstruction significantly aids in characterizing source extension and assessing spectral and morphological properties, a key consideration for studies of PWNe and SNRs in the gamma-ray band. Selecting photons above 10 GeV strikes a balance between keeping photon statistics high and diffuse gamma-ray emission low, and also carries benefits of a near constancy with energy of the point spread function of the LAT. More than 30 significantly extended sources are detected, many of which are resolved at GeV energies for the first time.

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**Contributing team(s):** Fermi LAT Collaboration

### 238.09 – The Dual Associations of Fermi Source 3FGL J2015.6+3709

The Large Area Telescope (LAT) is the main instrument onboard the Fermi Gamma-Ray Space Telescope, which surveys the entire gamma-ray sky eight times each day. More than 3000 gamma-ray sources have been detected by the LAT since its launch in 2008. Until recently, source 3FGL J2015+3709 was associated with the blazar B2013+370 on the basis of GeV variability. However, our updated analysis reveals a second association with the pulsar wind nebula (PWN) VER J2016+371. The blazar and PWN are separated by only 5.8 arcminutes. An analysis of 6.5 years of Pass 8 data reveals that above 30 GeV, the gamma-ray source shows an abrupt spectral hardening, and the localization shifts to agree with that of the PWN.

This analysis extends the spectrum of VER J2016+371 to lower energies than previously reported. Both the PWN and blazar contribute to the source detected by the LAT catalog, indicating that the previous single-object association is insufficient in representing a complete picture of the source.

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**Institution(s):** 1. NASA Goddard Space Flight Center

### 238.10 – Resolving the hadronic accelerator IC 443 with Fermi-LAT and VERITAS

Supernova remnants (SNRs) close to molecular clouds are ideal astrophysical laboratories to study cosmic ray acceleration and injection into the Galaxy. The Galactic SNR IC 443 is among the brightest and best-studied of such systems, detected as an extended gamma-ray source at both GeV and TeV energies. Previous observations with the AGILE and Fermi-LAT gamma-ray space telescopes have shown a low-energy cutoff at <200 MeV indicating relativistic protons are responsible for gamma-ray emission. Observations by the MAGIC and VERITAS ground-based gamma-ray telescopes show a steepening spectrum at TeV energies. Now, with updated Fermi-LAT observations using 7 yr of Pass 8 data above 1 GeV, the gamma-ray morphology of IC 443 is revealed as an inhomogeneous shell. Multi-wavelength observations have mapped the detailed physical conditions across the interaction site between the SNR and cloud, allowing us to separately study gamma-ray emission regions on scales less than 10 pc. We find an excellent correlation between GeV gamma-rays and the TeV morphology determined by VERITAS. The combination of new VERITAS and Fermi-LAT observations of IC 443 allows an unprecedented study of the environmental dependence of cosmic-ray diffusion in and around a hadronic accelerator.

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**Contributing team(s):** LAT Collaboration, VERITAS Collaboration

### 238.11 – STIS Spectra of the Remnant of SN 1885 in M31

We present Hubble Space Telescope (*HST*) ultraviolet and optical spectra of the remnant of Supernova 1885 (S And) taken with the Space Telescope Imaging Spectrograph (STIS). S And is a probable Type Ia supernova that is seen in absorption against the bulge of the Andromeda galaxy, M31. The STIS optical spectra, covering 2900–5700 Å, were taken using six 0.2'' wide slit positions through the remnant in two orientations providing insight to the three dimensional structure of S And. The spectra show broad Ca II H & K absorption extending out to at least 11,500 km/s consistent with previous *HST* images of S And in Ca II. There is noticeable enhancement of Ca II absorption between expansion velocities of 2,000 and 5,000 km/s suggestive of a Ca II-rich shell. The spectra also show strong asymmetric Ca I 4227 Å absorption extending out to 12,400 km/s along with weak Fe I 3720 Å absorption confined to a shell between 2,000 and 9,000 km/s on both the near and far sides of the remnant. These STIS spectra exhibit features similar to the spectrum taken with the Faint Object Spectrograph (FOS) on *HST* in 1996, with the notable differences in the width of Fe I 3720 Å absorption as well as weaker and more asymmetric Ca I 4227 Å absorption. STIS NUV-MAMA observations, covering 1570–3180 Å, taken in one orientation, show broad absorption shortward of 3000 Å consistent with model predicted spectra. These spectral observations, together with previous images, indicate a less than 10% departure from spherical symmetry in Ca-rich ejecta.

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**Institution(s):** 1. Dartmouth College, 2. Florida State University, 3. University of Colorado

### 238.12 – X-Ray Ejecta and CSM Distributions in the

## Galactic Core-Collapse SNR G292.0+1.8

Based on our deep Chandra data we present the initial results from our detailed study of the shocked ejecta and circumstellar medium in the textbook-type Galactic core-collapse supernova remnant G292.0+1.8. We utilize an adaptive-mesh technique to construct spatial distribution maps of individual ejecta elements (O, Ne, Mg, and Si), and their thermodynamic plasma parameters (e.g., electron temperature, ionization timescale, and thermal pressure). Our maps show significantly asymmetric distributions of overabundant ejecta elements and their thermal condition. We also map the complex spatial structure of the shocked circumstellar medium in G292.0+1.8, and compare it with that observed in mid-infrared. We briefly discuss the implications of these results.

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**Institution(s):** 1. UT Arlington

## 239 – Evolved Stars, Cataclysmic Variables, and Novae Poster Session

### 239.01 – Photometry of the Variable Bright Red Supergiant Betelgeuse from the Ground and from Space with the BRITe Nano-satellites

Robert B. Minor, Edward Guinan, Richard Wasatonic  
Betelgeuse (Alpha Orionis) is a large, luminous semi-regular red supergiant of spectral class M1.5-2Iab. It is the 8<sup>th</sup> brightest star in the night sky. Betelgeuse is 30,000 times more luminous than the Sun and 700 times larger. It has an estimated age of  $\sim 8 \pm 2$  Myr. Betelgeuse explodes in a Type II supernova (anytime within the next million years). When it explodes, it will shine with about the intensity of a full moon and may be visible during the day. However, it is too far away to cause any major damage to Earth.

Photometry of this pre-supernova star has been ongoing at Villanova for nearly 45 years. These observations are being used to define the complex brightness variations of this star. Semi-regular periodic light variations have been found with periods of 385 days up to many years. These light variations are used to study its unstable atmosphere and resulting complex pulsations. Over the last 15 years, it has been observed by Wasatonic who has accumulated a large photometric database.

The ground-based observations are limited to precisions of 1.5%, and due to poor weather, limit observations to about 1-2 times per week. However, with the recent successful launch of the BRITe Nano-satellites (<http://www.brite-constellation.at>) during 2013-14, it is possible to secure high precision photometry of bright stars, including Betelgeuse, continuously for up to 3 months. Villanova has participated in the BRITe guest investigators program and has been awarded observing time and data rights many bright stars, including Betelgeuse. BRITe blue and red observations of Betelgeuse were carried out during the Nov-Feb 2013-14 season and the 2014-15. These datasets were given to Villanova and have been combined with coexistent photometry from Wasatonic. Although BRITe's red data is saturated, the blue data is useable. The BRITe datasets were combined with our ground-based V, red, and near-IR photometry. Problems were uncovered with some of the BRITe data, but they were resolved for the most part. We present and discuss the results obtained so far.

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**Institution(s):** 1. Villanova University

### 239.02 – Out on a Limb: Updates on the Search for X-ray Emission from AGB Stars

X-rays from asymptotic giant branch (AGB) stars are rarely detected, however, few modern X-ray observatories have targeted AGB stars. In 2012, we searched a list of 480 galactic AGB stars and found a total of 13 targeted or serendipitous observations with few detections (Ramstedt et al. 2012). Since this initial search new programs have successfully targeted and detected X-ray emission from a handful of AGB stars. The X-ray emission, when detected, reveals high temperature plasma ( $\geq 10$  MK). This plasma might be heated by a

large-scale magnetic field or indicate the presence of accretion onto a compact companion. In this poster, we update our search for X-ray emission from AGB stars with a review of their characteristics, potential origins, and impact of X-ray emission in this late stage of stellar evolution.

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### 239.03 – Searching for Cool Dust in the Mid-to-Far Infrared: The Mass Loss Histories of the Hypergiants $\mu$ Cep, VY CMa, IRC +10420, and $\rho$ Cas

The most massive cool stars near the empirical upper limit of luminosity on the HR Diagram shed mass during brief, intense periods of enhanced mass loss. Their circumstellar environments show extensive and complex ejecta in scattered light at visual wavelengths. In the infrared, thermal emission from cooler dust in their ejecta can be used as a tracers of their mass loss histories. We combine high-resolution adaptive optics imaging from MMT/MIRAC (8 - 12  $\mu$ m) with the new capabilities in far-infrared imaging of SOFIA/FORCAST and Herschel/PACS to probe further into the past for evidence of earlier mass loss for four famous objects: the red supergiants  $\mu$  Cep and VY CMa and the yellow hypergiants IRC +10420 and  $\rho$  Cas. We find evidence for a variable mass loss rate over several thousand years for  $\mu$  Cep, while in contrast the lack of extended cold dust beyond VY CMa's visible ejecta indicates that its high mass loss episodes are recent. Despite its history of episodic mass loss,  $\rho$  Cas has no resolved circumstellar ejecta. The new long wavelength photometry from FORCAST, however, confirms the presence of a slowly expanding dust shell from its 1946 event

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### 239.04 – A Runaway Red Supergiant in M31

A significant percentage of OB stars are runaways, so we should expect a similar percentage of their evolved descendants to also be runaways. However, recognizing such stars presents its own set of challenges, as these older, more evolved stars will have drifted further from their birthplace, and thus their velocities might not be obviously peculiar. Several Galactic red supergiants (RSGs) have been described as likely runaways, based upon the existence of bow shocks, including Betelgeuse. Here we announce the discovery of a runaway RSG in M31, based upon a 300 km s<sup>-1</sup> discrepancy with M31's kinematics. The star is found about 21' (4.6 kpc) from the plane of the disk, but this separation is consistent with its velocity and likely age ( $\sim 10$  Myr). The star, J004330.06+405258.4, is an M2 I, with  $M_V = -5.7$ ,  $\log L/L_\odot = 4.76$ , an effective temperature of 3700 K, and an inferred mass of 12-15  $M_\odot$ . The star may be a high-mass analog of the hypervelocity stars, given that its peculiar space velocity is probably 400-450 km s<sup>-1</sup>, comparable to the escape speed from M31's disk. K. A. E.'s work was supported by the NSF's Research Experience for Undergraduates program through AST-1461200, and P. M.'s was partially supported by the NSF through AST-1008020 and through Lowell Observatory.

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### 239.05 – HST/COS Observations of the UV-Bright Star Y453 in the Globular Cluster M4 (NGC 6121)

Post-AGB stars represent a short-lived phase of stellar evolution during which stars cross the optical color-magnitude diagram from the cool, red tip of the asymptotic giant branch (AGB) to the hot, blue tip of the white-dwarf cooling curve. Their surface chemistry reflects the nuclear-shell burning, mixing, and mass-loss processes characteristic of AGB stars, and their high effective temperatures allow the detection of elements that are unobservable in cool giants. Post-AGB stars in globular clusters offer the additional advantages of known distance, age, and initial chemistry. To better understand the

AGB evolution of low-mass stars, we have observed the post-AGB star Y453 in the globular cluster M4 (NGC 6121) with the Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope. The star, which has an effective temperature of at least 60,000 K, shows absorption from He, C, N, O, Ne, Si, S, Ti, Cr, Mn, Fe, Co, Ni, and Ga. While the star's C and O abundances are consistent with those measured in a sample of nitrogen-poor RGB stars in M4, its N abundance is considerably enhanced. The star's low C abundance suggests that it left the AGB before the onset of third dredge-up. This work was supported by NASA grant HST-GO-13721.001-A to the University of Wisconsin, Whitewater. P.C. is supported by the Canadian Space Agency under a contract with NRC Herzberg Astronomy and Astrophysics.

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### 239.06 – An Almost Complete Radio Survey of Magnetic Cataclysmic Variables

This poster presents the results of a radio survey using the Jansky Very Large Array (JVLA) of 129 Magnetic Cataclysmic Variables (MCVs) north of declination -35 deg. 103 hours of observations were performed during the JVLA observing sessions 2013B and 2015A, when the array was mostly in its highest spatial-resolution configurations (i.e., A and B). Most targets were observed twice for 2-5 minutes at each of three frequencies (C, X, and K-bands), although a few targets were also observed at a fourth frequency (Q-band). 22 of the 129 MCVs were detected at one or more frequencies. Of these 22 detections, 15 are new. This number nearly triples the number of MCVs that are known radio sources. Most detections are at the C and X-band frequencies, although three sources were detected at the K-band frequency. One of the K-band frequency detections is the known rapidly-rotating radio source AE Aqr, while the other two are the polars, AI Tri and ST LMi. Of the 22 detected sources, two-thirds are polars (15) and all are believed to be nearby (<200 pc). Except for a few stronger sources, most detections are in the range of 100-200  $\mu$ Jy, which at a distance of 150 pc corresponds roughly to a luminosity of  $2 \times 10^{24}$  erg/s at the X-band frequency. The results of this survey are encouraging in that more MCVs are likely to be detected as the time on-source increases, since the flux from MCVs is highly variable.

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### 239.07 – Revisiting the HST Fine Guidance Sensor Parallax of SS Cygni

Recently, our results for the HST FGS parallax of SS Cyg (Harrison et al. 2000) have been called into question due to a recent radio parallax for this object (Miller-Jones et al. 2013). We have re-analyzed the data for our FGS program on SS Cyg and derive a revised parallax of  $7.3 \pm 0.2$  mas (137 pc). This parallax is 17% larger than that originally published. We discuss the new analysis effort, and the reasons for the change in our result. We believe we have identified why the radio parallax (8.77 mas) disagrees with the FGS results: We find that if we allow for a roll of two degrees in the HST coordinate system, we obtain the discrepant VLBA radio parallax. It is impossible, however, for the error in the roll of HST to be more than a few tenths of a degree, or else the FGS would not lock-on to the program targets. This roll leads to the large, and erroneous VLBA parallax for SS Cyg. We note that the radio parallax for the black hole system V404 Cyg (Miller-Jones et al. 2009) is also much larger than the spectroscopic parallax of its secondary star. In addition, we closely examine the attempt by Nelan & Bond (2013) to reconcile the FGS data set with the radio result. We identify what we believe to be significant issues with their analysis. Finally, we present a quantitative abundance analysis for SS Cyg, RU Peg, and GK Per derived from moderate resolution K-band spectroscopy. We find

severe carbon deficiencies (10 to 20% of the solar value) in the secondary stars of all three objects. We describe the Python program "kmoog" which generates synthetic spectra, and autonomously compares them to observational data.

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### 239.08 – FUSE and HST FUV Spectroscopic Analysis of the Old Novae V533 Her, DI Lac and RR Pic

The old novae V533 Her (Nova Her 1963), DI Lac (Nova Lac 1910) and RR Pic (Nova Pic 1891) are in (or near) their quiescent stage following their nova explosions and continue to accrete at a high rate in the aftermath of their explosions. All three systems appear to be accreting at high rates long after their novae. They exhibit continua that are steeply rising into the FUV as well as absorption lines and emission lines of uncertain origin. All three have FUSE spectra which offer not only higher spectral resolution but also wavelength coverage extending down to the Lyman Limit. We have matched these FUSE spectra with existing archival HST STIS and IUE spectral coverage, and adopted the newly determined interstellar reddening corrections of Selvelli and Gilmozzi (2013). The dereddened FUV spectra have been modeled with our grids of optically thick accretion disks and hot white dwarf photospheres. We present the results of our modeling analysis and discuss implications for the poorly understood quiescent states of old novae including the role of irradiation in enhancing the rate of accretion far into quiescence. This work is supported by NASA grants NNX13AF11G and NNX13AF12G to Villanova University.

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### 239.09 – The Evolutionary Behavior of Old Novae in their Quiescent Stage: DN Gem, T Aur and HR Lyr

There is currently a poor understanding about how a nova explosion affects the rate of mass transfer in a cataclysmic binary system and the subsequent evolutionary behavior of the accreting white dwarf during post-nova quiescence. In order to shed light on this fundamental question, we have carried out a synthetic spectral analysis of the archival HST and IUE far ultraviolet spectra of the post-novae, DN Gem (Nova Gem 1912), T Aur (Nova Aur 1891) and HR Lyr (Nova Lyr 1919). We have utilized the best available input parameters from the literature for the white dwarf masses, orbital inclinations and distances of each system while adopting the newly determined interstellar reddening corrections, E(B-V), of Selvelli and Gilmozzi (2013). Our synthetic spectral analysis utilized optically thick, steady state accretion disk models and white dwarf model atmospheres that we constructed using TLUSTY and SYNSPEC (Hubeny 1988, Hubeny and Lanz 1995). We report the results of our model fitting including the mass transfer rates and other physical properties 115 years (DN Gem), 124 years (T Aur) and 96 years (HR Lyr) after their respective nova explosions.

This work is supported by NASA grants NNX13AF12G to Villanova University and a summer undergraduate research assistantship from the NASA-DSGC.

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### 239.10 – Optical Spectroscopy of the Classical Novae V339 Del (2013) and V5668 Sgr (2015 No. 2)

We report the results of optical spectroscopy of the gamma-ray classical novae V339 Del (2013) and V5668 Sgr (PNV J18365700-2855420/Nova Sgr 2015 No. 2) supplemented by UV and X-ray observations obtained with Swift. Our spectra were obtained with the Steward Observatory Bok 2.3 m telescope (+B&C), the MDM 2.4 m Hiltner telescope (+OSMOS), the 6.5 m MMT (+BlueChannel), and the 2 x 8.4 m Large Binocular Telescope (+MODS1 and PEPSI) between 2013 August and 2015 September. The PEPSI spectra cover all or part of the 384-907 nm spectral region at a resolution of up to 270,000 (1 km/s). This is the highest resolution available on any

8-10 m class telescope. V339 Del was discovered on 2015 August 14.58 by Itagaki at V about 6.8. This nova reached a peak magnitude of about 4.3 making it one of the brightest novae of this century. Because of its exceptional brightness it has been observed at a variety of wavelengths and by a host of observatories both on the ground and in space. V5668 Sgr was discovered on 2015 March 15.634 by Seach at a magnitude of 6.0. It subsequently reached a maximum brightness of about 4.0 in late March. High resolution PEPSI spectra obtained in early April show dramatic variations in the multi-component P Cygni-type line profiles. V5668 Sgr was observed to form dust in June thereafter fading to about 13th magnitude. Our recent observations show that it has now evolved into the nebular phase. SS acknowledges partial support from NSF and NASA grants to ASU. CEW acknowledges support from NASA.

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### 239.11 – Simultaneous Photometry and Spectroscopy of the Deeply Absorbing Polar MASTER OT J132104.04+560957.8

We present photometry and time-resolved spectroscopy of the suspected polar MASTER OT J132104.04+560957.8 (J1321) taken at the Large Binocular Telescope (LBT) simultaneously with the LBC camera and MODS spectrograph in binocular mode. Our V-band photometry confirmed a primary and secondary maximum first identified by Littlefield et al. In the spectra we see unusually deep Balmer and helium absorption features for about 10-15% of a 91 minute orbital period. The absorption lines first appear to the red of the emission peaks then shift bluewards, ultimately dominating the line profile at zero radial velocity. Towards the end of the absorption phase, weak absorption reappears to the blue of the emission lines. When the system is bright the spectra show a broadly-peaked continuum with a maximum around 500nm. We do not see absorption during the secondary bright red phase. Around the minima the continuum is blue and resembles a more typical polar spectrum with strong Balmer, neutral helium and ionized helium emission lines. The Doppler tomograms of J1321 are fuzzy and blobby and resemble those of the asynchronous polar BY Cam. The highly variable width of the secondary maximum remains a mystery along with the lack of a discernible irradiated secondary in the tomograms. We use our observations to constrain the properties of the white dwarf's magnetic field as well as the accretion flow structure. We also discuss evidence of J1321 being in a prolonged low-mass-transfer state in all observations prior to 2007.

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### 239.12 – Strong [Fe X] Emission and Deep Optical Eclipses of the Classical Nova V5593 Sgr 2012 No. 5

V5593 Sgr was discovered by T. Kojima on 2012 July 16.512 UT at a magnitude of ~12.6. A low-resolution spectrum obtained by M. Fujii on 2012 July 18.572 UT confirmed that the object was indeed a Classical Nova. The AAVSO V-band light curve showed that the nova peaked near 11th mag on July 23-24 UT and subsequently declined in brightness with a  $t_2$  of about 27 days making it a moderately fast nova. We obtained optical spectroscopy of V5593 Sgr between 2012 July 26 and 2013 February 19 UT with the SMARTS/CTIO 1.5 m telescope (+RC spectrograph) and then between 2014 August 25 and 2015 June 17 UT using the MDM Observatory 2.4 m Hiltner telescope (+CCDS), the 8.4 m Large Binocular Telescope (+MODS1), and the 6.5 m MMT (+BlueChannel). The SMARTS spectra confirmed the Fe II classification but showed that by 2013 February 19 UT the Fe II lines became much weaker and strong He II 468.5 nm and [Fe VII] 608.7 nm became prominent. A spectrum obtained on 2014 August 25 UT exhibited Balmer, He II, and [Fe VII] emission lines, but also for the first time, the presence of strong [Fe X] 637.4 nm emission with an observed intensity ratio with respect to H $\alpha$  of about 1.5. Other identified emission lines in our spectra

included O VI, [Ca V], [Ca VI], [Ca VII], [Fe VI], [Fe XI], and [Fe XIV]. Surprisingly, [O III] emission was weak or absent. By 2015 June, a spectrum showed that the observed [Fe X]/H $\alpha$  intensity ratio had decreased to about 0.74. Contemporaneous optical photometry was obtained with the SMARTS/CTIO 1 m telescope (+ANDICAM) between 2014 March 19 and 2015 September 28 UT in the BVRIJHK bands. In agreement with our spectra in quiescence, V5593 Sgr is very red with (B-V) ~ 1 mag and (V-K) ~ 5 mag. The photometry shows ellipsoidal-like modulations with a peak-to-peak amplitude exceeding 2 mag in R and I. The modulation is seen in B through K; however, the amplitude is lower in JHK. Brief eclipses occur at the minimum of the ellipsoidal variation with a depth of at least 5 mag in R and I. The eclipse is seen in all bands covered by our observations. Two or more candidate periods may be consistent with the data. We will discuss these results in the context of other classical novae including GQ Mus and V723 Cas.

**Author(s):** Sumner Starrfield<sup>2</sup>, R. Mark Wagner<sup>4</sup>, Frederick M. Walter<sup>5</sup>, Charles E. Woodward<sup>6</sup>, Greg Schwarz<sup>1</sup>, Joachim Krautter<sup>3</sup>  
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### 239.13 – HST Observations of the Ejecta of Recurrent Nova T Pyxidis

Fermi's identification of classical novae as a new class of gamma-ray sources has raised the question of the role of shocks and particle acceleration in these eruptions. It has also highlighted similarities between the physical processes in novae and those in higher-energy explosions such as supernovae. High-resolution radio interferometry of several recent outbursts at early times indicates that some shocks result from collisions between early, slow outflows and later, faster, collimated flows. We will discuss our Hubble Space Telescope imaging and spatially-resolved spectra of the ejecta of the recurrent nova T Pyxidis at several late epochs following its most recent 2011 outburst. We will use the spatial size, expansion rate, Doppler shifts and emission line ratios to constrain the geometry, kinematics and plasma conditions of the complex features seen in the newest ejecta, and attempt to connect the origins of these structures with the outflows seen in radio data at earlier times.

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### 239.14 – Towards Bayesian Machine Learning for Estimating Parameters of Accretion Disk Models for SPH Simulations

Accretion disks are ubiquitous in Active Galactic Nuclei, in protostellar systems forming protoplanets, and in close binary star systems such as X-ray binaries, Cataclysmic Variables, and Algols, for example. Observations such as disk tilt are found in all of these different accreting system types, suggesting a common physics must be present. To understand the common connections between these different system types, which can help us understand their unique evolutions, we need to better understand the physics of accretion. For example, viscosity is typically a constant value in the disk of a system that is in a specific state such as a quiescent state. However, viscosity can't be constant throughout the disk, especially at the boundaries. To learn more about viscosity and other common parameters in these disk, we use Bayesian Inference and Markov Chain Monte Carlo techniques to make predictions of events to come in the numerical simulations of these accreting disks. In this work, we present our techniques and initial findings.

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## 240 – Star Associations, Star Clusters - Galactic & Extra-galactic Poster Session

### 240.01 – Photometric and Structural Parameters of

## Globular Clusters Towards the Galactic Bulge: Results from VVV and More

Globular clusters (GCs) located towards the Galactic bulge have been systematically excluded from most ground- and space-based photometric surveys due to severe total and differential extinction. Recent discoveries based on near-infrared imaging imply that these clusters hold valuable keys to Galactic formation and evolution, including double horizontal branches and density profiles which differ significantly from results based on optical integrated light. We present results based on wide-field near-infrared PSF photometry of bulge GCs from the Vista Variables in the Via Lactea (VVV) survey, leveraged together with results from a plethora of other sources: Near-IR photometry of well-studied GCs, deep space-based optical imaging, and recent observations from ground-based adaptive optics facilities. The results include new calibrations of distance- and reddening-independent photometric metallicity indicators, the first broad tests of multiple sets of evolutionary models against homogenous photometry in the near-IR, and the first number density-based structural parameters for many poorly studied bulge GCs.

**Author(s):** Roger Cohen<sup>2</sup>, Francesco Mauro<sup>1</sup>, Christian Moni Bidin<sup>3</sup>, Douglas Geisler<sup>2</sup>

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### 240.02 – Na-O abundances in M53: A Mostly First Generation Globular Cluster

We present the Fe, Ca, Ti, Ni, Ba, Na, and O abundances for a sample of 53 red giant branch (RGB) stars in the globular cluster (GC) NGC 5024 (M53). The abundances were measured from high signal-to-noise medium resolution spectra collected with the Hydra multi-object spectrograph on the WIYN 3.5-meter telescope. M53 is of interest because previous studies based on the morphology of the cluster's horizontal branch suggested that it might be composed primarily of first generation (FG) stars and differ from the majority of other GCs with multiple populations, which have been found to be dominated by second generation (SG) stars. Our sample has an average  $[Fe/H] = -2.07$  with a standard deviation of 0.07 dex. This value is consistent with previously published results. The alpha-element abundances in our sample are also consistent with the trends seen in Milky Way halo stars at similar metallicities, with enhanced  $[Ca/Fe]$  and  $[Ti/Fe]$  relative to solar. We find that the Na-O anti-correlation is not as extended as other GCs with similarly high masses. The fraction of SG to FG stars in our sample is approximately 1:3 and the SG is more centrally concentrated. These findings further support that M53 might be a mostly FG cluster and could give further insight into how GCs formed the light element abundance patterns we observe in them today.

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**Institution(s):** 1. Indiana Univeristy

### 240.03 – NGC 6273: Towards Defining A New Class of Galactic Globular Clusters?

A growing number of observations have found that several Galactic globular clusters exhibit abundance dispersions beyond the well-known light element (anti-)correlations. These clusters tend to be very massive, have  $>0.1$  dex intrinsic metallicity dispersions, have complex sub-giant branch morphologies, and have correlated  $[Fe/H]$  and s-process element enhancements. Interestingly, nearly all of these clusters discovered so far have  $[Fe/H] \sim -1.7$ . In this context, we have examined the chemical composition of 18 red giant branch (RGB) stars in the massive, metal-poor Galactic bulge globular cluster NGC 6273 using high signal-to-noise, high resolution ( $R \sim 27,000$ ) spectra obtained with the Michigan/Magellan Fiber System (M2FS) and MSpec spectrograph mounted on the Magellan-Clay 6.5m telescope at Las Campanas Observatory. We find that the cluster exhibits a metallicity range from  $[Fe/H] = -1.80$  to  $-1.30$  and is composed of two dominant populations separated in  $[Fe/H]$  and  $[La/Fe]$  abundance. The increase in  $[La/Eu]$  as a function of  $[La/H]$  suggests that the increase in  $[La/Fe]$  with  $[Fe/H]$

is due to almost pure s-process enrichment. The most metal-rich star in our sample is not strongly La-enhanced, but is  $\alpha$ -poor and may belong to a third "anomalous" stellar population. The two dominant populations exhibit the same  $[Na/Fe]$ - $[Al/Fe]$  correlation found in other "normal" globular clusters. Therefore, NGC 6273 joins  $\omega$  Centauri, M 22, M 2, and NGC 5286 as a possible new class of Galactic globular clusters.

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**Institution(s):** 1. Indiana University, 2. Smithsonian Astrophysical Observatory, 3. The Observatories of the Carnegie Institution for Science, 4. University of California, Los Angeles, 5. University of Michigan

### 240.04 – Uncovered: Progenitors of globular clusters showing off their multiple stellar populations

Stars in star clusters are thought to form in a single burst from a common progenitor cloud of molecular gas, resulting in so-called simple stellar populations. However, old, massive globular clusters—with ages greater than 10 billion years—often host multiple stellar populations, indicating that more than one star-forming event may have occurred during their lifetimes. The most popular scenario for their formation invokes colliding stellar winds from late-stage, asymptotic-giant-branch stars. If this were correct, the initial globular cluster masses should be at least 10 times more massive than their current masses of typically a few  $\times 10^5$  Msun. However, large populations of clusters with masses greater than a few  $\times 10^6$  Msun are not found in the local Universe. Here we present *Hubble Space Telescope* observations of three 1–2 billion-year-old, massive star clusters in the Magellanic Clouds which show unequivocal evidence of burst-like star-formation activity that occurred a few  $\times 10^8$  years after their initial formation era. The spatial distributions of the younger stellar generations suggest that they may have originated from ambient gas clouds accreted by the clusters while orbiting in the disks of their host galaxies rather than from colliding stellar winds. Simple models imply that such clusters could indeed accrete sufficient gas reservoirs to form these stars. This may eventually give rise to the appearance of multiple stellar populations in globular clusters.

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### 240.05 – Bayesian Analysis of Multiple Populations in Galactic Globular Clusters

We use GO 13297 Cycle 21 Hubble Space Telescope (HST) observations and archival GO 10775 Cycle 14 HST ACS Treasury observations of Galactic Globular Clusters to find and characterize multiple stellar populations. Determining how globular clusters are able to create and retain enriched material to produce several generations of stars is key to understanding how these objects formed and how they have affected the structural, kinematic, and chemical evolution of the Milky Way. We employ a sophisticated Bayesian technique with an adaptive MCMC algorithm to simultaneously fit the age, distance, absorption, and metallicity for each cluster. At the same time, we also fit unique helium values to two distinct populations of the cluster and determine the relative proportions of those populations. Our unique numerical approach allows objective and precise analysis of these complicated clusters, providing posterior distribution functions for each parameter of interest. We use these results to gain a better understanding of multiple populations in these clusters and their role in the history of the Milky Way. Support for this work was provided by NASA through grant numbers HST-GO-10775 and HST-GO-13297 from the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS5-26555. This material is based upon work supported by the National Aeronautics and Space Administration under Grant NNX11AF34G issued through the Office of Space Science. This project was supported by the National Aeronautics & Space

Administration through the University of Central Florida's NASA Florida Space Grant Consortium.

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#### **240.06 – Searching for Multiple Populations in NGC 6791**

We present further analysis of the CN and CH molecular band strengths in NGC 6791 from low resolution SEGUE spectra as a means to detect chemical variations in the cluster. We attempt to measure the C and N abundances for the stars in our sample based on index measurements analyzed with the help of synthetic spectra produced by the Synthetic Spectrum Generator (SSG), which makes use of MARCS model atmospheres. These measurements combined with analysis of the CH and CN band strengths of globular and open clusters of varying metallicity taken from the SEGUE database suggest a saturation of the CH band occurring at metallicities above  $[Fe/H] \sim -0.7$  that is not predicted by the models. This saturation effect limits the usefulness of the CH and CN bands in determining the C and N abundances in open clusters. However, the models continue to accurately predict the CN band strengths at high metallicities and are used to statistically determine the likelihood of two populations existing in NGC 6791. The statistical analysis confirms NGC 6791 is most likely to have only one CN population.

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#### **240.07 – A Comparison of the Detailed Chemical Abundances of Globular Clusters in the Milky Way, Andromeda, and Centaurus A Galaxies**

We present a homogeneous analysis of high resolution spectra of globular clusters in three massive galaxies: the Milky Way, M31, and NGC 5128. We measure detailed abundance ratios for alpha, light, Fe-peak, and neutron capture elements using our technique for analyzing the integrated light spectra of globular clusters. For many of the heavy elements we provide a first look at the detailed chemistry of old populations in an early type galaxy. We discuss similarities and differences between the galaxies and the potential implications for their star formation histories.

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**Institution(s):** 1. Observatories of the Carnegie Institution for Science

#### **240.08 – Globular Cluster Population of the HST Frontier Field Galaxy J07173724+3744224**

We present preliminary results of a study of the globular cluster population of the elliptical galaxy J07173724+3744224 ( $z \sim 0.2$ ). This galaxy is located in the field-of-view of the Hubble Space Telescope Frontier Field observations of galaxy cluster MACSJ0717.5+3745. Measurements of the spatial and color radial distributions of the globular cluster population are given. We also present an estimate of the total number of globular clusters and the globular cluster specific frequency of the host galaxy.

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#### **240.09 – Large scale structure of the globular cluster population in Coma**

A search for globular cluster candidates in the Coma Cluster was carried out using Hubble Space Telescope data taken with the Advanced Camera for Surveys. We combine different observing

programs including the Coma Treasury Survey in order to obtain the large scale distribution of globular clusters in Coma. Globular cluster candidates were selected through careful morphological inspection and a detailed analysis of their magnitude and colors in the two available wavebands, F475W (Sloan g) and F814W (I). Color Magnitude Diagrams, radial density plots and density maps were then created to characterize the globular cluster population in Coma. Preliminary results show the structure of the intergalactic globular cluster system throughout Coma, among the largest globular clusters catalogues to date. The spatial distribution of globular clusters shows clear overdensities, or bridges, between Coma galaxies. It also becomes evident that galaxies of similar luminosity have vastly different numbers of associated globular clusters.

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**Institution(s):** 1. Australian Astronomical Observatory, 2. Gemini Observatory, 3. Virginia Polytechnic Institute and State University

#### **240.10 – A VLA Search for Intermediate-Mass Black Holes in M81's Globular Clusters**

Nantais et al. (2011) used the Hubble Space Telescope to localize probable globular clusters in M81, a spiral galaxy at a distance of 3.6 Mpc. Theory predicts that such clusters can host intermediate-mass black holes (IMBHs) with masses of 100 - 100,000 solar masses. We used the NRAO Karl G. Jansky Very Large Array (VLA) to search for the radiative signatures of IMBH accretion from 206 clusters in a mosaic of M81. The wavelength was 5.5 cm and the resolution was 1.5 arcsec (26 pc). None of the individual clusters are detected, nor is a weighted-mean stack of their images that achieved a 1-sigma rms of 430 nanoJy/beam. Applying a formalism developed for globular clusters in the Milky Way, the stack's radio-luminosity upper limit corresponds to a mean 3-sigma IMBH mass of less than 41,000 solar masses. The associated sphere of influence has a radius of less than 20 mas (0.35 pc) and crosschecks based on stellar dynamics must await the advent of NIR telescopes in the 30 m class (e.g., Do et al. 2014). The NRAO is a facility of the NSF, operated under cooperative agreement by AUI.

**Author(s):** J. M. Wrobel<sup>3</sup>, James Miller-Jones<sup>1</sup>, M. J. Middleton<sup>2</sup>  
**Institution(s):** 1. Curtin University, 2. Institute of Astronomy, 3. NSF

#### **240.12 – Are the Youngsters Home? A Search for Young Clusters in the Merger Remnant NGC 2655**

We are studying star clusters in NGC 2655, a shell elliptical galaxy that is likely a post-merger remnant and may yet still be forming new stars. Our project consists of two parts. The first goal is to put together a pipeline for taking raw images and transforming them into a final calibrated set of data. The algorithms we have developed will be useful for all astronomers who use the Large Binocular Cameras (LBCs) at the Large Binocular Telescope (LBT) located on Mount Graham in Arizona. The LBCs are two widefield f/1.45 cameras each mounted at prime focus for each mirror of the LBT. The LBCs each have a 23' x 25' field of view (FOV) and optimized for 0.3-0.6 microns on the left mirror and 0.5-1.0 microns on the right mirror.

The second goal is to effectively take a population census of young star clusters (YSCs) and Globular Clusters (GCs) in a galaxy undergoing a transformation from two spiral galaxies into an elliptical galaxy. NGC 2655 may be a future version of our Milky Way after it collides and merges with the Andromeda Galaxy. Stars are born in groups and clusters. When mergers occur between spiral galaxies, vast reservoirs of gas are turned into stars and these stars all form together in large clusters with masses ranging from  $10^4$  to  $10^7$   $M_{\odot}$ . As seen in major mergers like the Antennae and NGC 3256, thousands of such star clusters are formed during and after a galaxy merger. However, NGC 2655 is clearly an elliptical galaxy with strong indications of having undergone a recent major merger. Thus, it represents a transition object, allowing us to study both the GC and possibly YSC populations. Although similar studies have been undertaken for a handful of other similar transition objects (i.e. NGC 1316), they have all been done using imagers with rather small FOVs ( $\sim 2-6'$ ). The large FOV of the

LBCs allow us to capture not only the entire galaxy, but a large region surrounding the galaxy, making it possible to obtain a better census of GCs and YSCs without relying on extrapolating the properties from small FOVs.

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### 240.13 – Bright Young Star Clusters in NGC5253 with LEGUS

Using UV-to-H broad and narrow-band HST imaging, we derive the ages and masses of the 11 brightest star clusters in the dwarf galaxy NGC5253. This galaxy, located at ~3 Mpc, hosts an intense starburst, which includes a centrally-concentrated dusty region with strong thermal radio emission (the 'radio nebula'). The HST imaging includes data from the Cycle 21 Treasury Program LEGUS (Legacy ExtraGalactic UV Survey), in addition to narrow-band H-alpha (6563 Å), P-beta (12820 Å), and P-alpha (18756 Å). The bright clusters have ages ~1-15 Myr and masses ~1E4 - 2.5E5 Msun. Two of the 11 star clusters are located within the radio nebula, and suffer from significant dust attenuation. Both are extremely young, with a best-fit age around 1 Myr, and masses ~7.5E4 and ~2.5E5 Msun, respectively. The most massive of the two 'radio nebula' clusters is 2-4 times less massive than previously estimated and is embedded within a cloud of dust with A<sub>V</sub>~50 mag. The two clusters account for about half of the ionizing photon rate in the radio nebula, and will eventually supply about 2/3 of the mechanical energy in present-day shocks. Additional sources are required to supply the remaining ionizing radiation, and may include very massive stars.

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**Institution(s):** 1. Caltech, 2. Durham University, 3. IAC, 4. IAP, 5. IBM, 6. INAF - University of Bologna, 7. Johns Hopkins University, 8. Louisiana State University, 9. New Mexico State University, 10. Stockholm University, 11. STScI, 12. SUNY - Genesee, 13. Texas University, 14. Toledo University, 15. Univ. of Massachusetts, 16. University of Alabama, 17. University of Amsterdam, 18. University of Arizona, 19. University of Bologna, 20. University of California, 21. University of Cambridge, 22. University of Exeter, 23. University of Geneva, 24. University of Heidelberg, 25. University of Virginia, 26. University of Wyoming, 27. University of Wisconsin, 28. Uppsala University, 29. Vassar College

### 240.14 – Applying Machine Learning to Star Cluster Classification

Catalogs describing populations of star clusters are essential in investigating a range of important issues, from star formation to galaxy evolution. Star cluster catalogs are typically created in a two-step process: in the first step, a catalog of sources is automatically produced; in the second step, each of the extracted sources is visually inspected by 3-to-5 human classifiers and assigned a category. Classification by humans is labor-intensive and time consuming, thus it creates a bottleneck, and substantially slows down progress in star cluster research.

We seek to automate the process of labeling star clusters (the second step) through applying supervised machine learning techniques. This will provide a fast, objective, and reproducible classification. Our data is HST (WFC3 and ACS) images of galaxies in the distance range

of 3.5–12 Mpc, with a few thousand star clusters already classified by humans as a part of the LEGUS (Legacy ExtraGalactic UV Survey) project. The classification is based on 4 labels (Class 1 – symmetric, compact cluster; Class 2 – concentrated object with some degree of asymmetry; Class 3 – multiple peak system, diffuse; and Class 4 – spurious detection). We start by looking at basic machine learning methods such as decision trees. We then proceed to evaluate performance of more advanced techniques, focusing on convolutional neural networks and other Deep Learning methods. We analyze the results, and suggest several directions for further improvement.

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**Institution(s):** 1. University of Massachusetts, Amherst

### 240.15 – The Cluster Destruction Rate and the Mass Functions of Luminous Infrared Galaxies

We present an HST ACS/WFC analysis of the age and mass distribution of bright, optically-visible clusters in local luminous infrared galaxies (LIRGs). These galaxies host the most extreme star-forming galaxies in the local Universe, with their observed activity triggered by the interaction or merger of gas-rich galaxies. We constructed extinction-corrected color-color diagrams and compare the observed colors with predictions from the Bruzual & Charlot (2003) Simple Stellar Population Models in order to estimate the ages and masses of individual clusters. We find that, for an instantaneous starburst and Salpeter IMF, the estimated cluster ages for the sample are consistent with the cluster destruction rate derived for the Antennae Galaxies (Fall et al. 2005). For LIRGs with detailed dynamical modeling, we find that their oldest clusters have ages consistent with the time since pericentric passage. The derived cluster mass function for the sample is also consistent with SFR-normalized mass functions for a wide range of star-forming galaxies in the Local Universe, indicating the general similarity among the cluster populations of different galaxies. This study is part of the Great Observatories All-Sky LIRG Survey (GOALS).

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**Institution(s):** 1. University of Virginia

**Contributing team(s):** Great Observatories All Sky LIRG Survey (GOALS)

### 240.16 – Tidal Tales: Comparison of Star Formation in Tidal Tails of Minor Mergers

While major mergers and their tidal debris are well studied, they are less common than minor mergers (mass ratios <0.3) and likely played a role in forming most large galaxies, including the Milky Way. Tidal debris regions have large reservoirs of neutral gas but a lower gas density and may have higher turbulence. Star formation tracers such as young star cluster populations, star cluster complexes, and H-alpha, CO, molecular hydrogen, and CII emission were studied to determine the different factors that may influence star formation in tidal debris. These tracers were compared to the reservoirs of gas available for star formation to estimate the star formation efficiency (SFE). In our pilot study using two of the sample of 15 minor mergers, we find that the star formation rate (SFR) of minor merger tidal debris can reach up to 50% of the total star formation in the system which is comparable to prior simulations of star formation in major mergers. The SFE of tidal tails in minor mergers can range over orders of magnitude on both local and global scales. From the tidal debris environments in this study, this variance appears to stem from the formation conditions of the debris. Further work on the 13 additional minor mergers in this sample will shed more light on the factors influencing star formation in low density environments.

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### 240.17 – The Formation of Cluster Populations Through Direct Galaxy Collisions

Much progress has been made on the question of how globular clusters form. In particular, the study of extragalactic populations of young, high-mass clusters (“super star clusters”) has revealed a class of objects can evolve into globular clusters. The process by which these clusters form, and how many survive long enough to become globular clusters, is not wholly understood. Here, we use new data on the colliding galaxy system Arp 261 to investigate the possibility that young, massive clusters form in greater numbers during direct galaxy collisions, compared to less direct tidal collisions.

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**Institution(s):** 1. East Tennessee State University, 2. Iowa State University, 3. University of Wisconsin -- Barron County

#### 240.18 – The Clustering of Young Stellar Cluster Populations in Nearby Galaxies

We present measurements of clustering among star clusters for several galaxies drawn from the Legacy ExtraGalactic UV Survey (LEGUS), in order to establish whether the clustering strength depends on properties of the cluster population. We use the two point autocorrelation function to study clustering as a function of spatial scale, age, concentration index (CI), and mass. We separate the clusters into different classes, defined by their (a)symmetry and number of peaks, comparing the trends of the autocorrelation functions between all the cluster classes. For one galaxy, NGC 628, we find that younger star clusters are more strongly clustered over small spatial scales and that the clustering disappears rapidly for ages as young as 40 Myr. We present here a similar analysis for the other galaxies. We also measure the power-law slope and amplitude of the autocorrelation functions and discuss the results.

**Author(s):** Kathryn Grasha<sup>1</sup>, Daniela Calzetti<sup>1</sup>  
**Institution(s):** 1. University of Massachusetts - Amherst

#### 240.19 – Quantifying the Components of the Field OB Star Population

Massive stars have long been thought to form in clusters. However, recent observations suggest some massive stars form in extremely sparse environments. Could these massive stars form alone? Clarifying the nature of field OB stars is central to this question. Defining these as OB stars that are isolated from other OB stars, the field comprises three distinct populations: “tip-of-the-iceberg stars”, which are in small, but normal, clusters that only have one OB star; runaway stars; and any stars that form in situ in the field. The relative frequencies of each category are unknown. To study the population and obtain estimates of the frequencies, we examine 134 field OB stars from the Runaways and Isolated O-Type Star Spectroscopic Survey of the SMC (RIOTS4; Lamb et al. 2015) in the bar region of the Small Magellanic Cloud. These stars are at least 28 pc in projection away from other OB stars. We use OGLE-III (Udalski et al. 2008) *I*-band images to search for small, potential clusters around our target stars, using friends-of-friends and nearest-neighbor algorithms. We estimate the relative frequencies of tip-of-the-iceberg stars and isolated stars, some of which may have formed in situ.

Thanks to Radek Poleski for help with the OGLE-III database. This work was supported by the NSF grants AST-0907758 and AST-1514838.

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#### 240.20 – Study of the Cygnus Star-Forming Field

The star-forming complexes in Cygnus extend nearly 30 deg in Galactic longitude and 20 deg in latitude, and most probably include star-formation sites located between 600 and 4000 pc. We combine the catalog by Heiles (2000) with uvby $\beta$  photometric data from the catalog of Paunzen (2015) to collate a sample of O and B-type stars with precise homogeneous distances, color excess and available polarimetry. This allows us to identify star-forming sites at different

distances along the line of sight and to investigate their spatial correlation to the interstellar matter. Further, we use this sample to study the orientation of the polarization as revealed by the polarized light of the bright early-type stars and analyze the polarization-extinction correlation for this field. Since dust grains align in the presence of a magnetic field cause the observed polarization at optical wavelengths, the data contain information about the large-scale component of the Galactic magnetic field. In addition, wide-field astrophotography equipment was used to image the Cygnus field in Hydrogen-alpha, Hydrogen-beta and the [OIII] line at 500.7 nm. This allows us to map the overall distribution of ionized material and the interstellar dust and trace large-scale regions where the physical conditions change rapidly due to supernova shock fronts and strong stellar winds. Acknowledgments: This work was supported by NSF grant AST- 1516932 and the Wisconsin Space Grant Consortium, NASA Space Grant College and Fellowship Program, NASA Training Grant #NNX14AP22H.

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#### 240.21 – Open-Cluster Population of Sh 2-109

The prominent nebula Sh 2-109 that dominates the Cygnus star-forming field is probably a complex of several overlapping H II regions. Since in this direction the line of sight is along the local Orion spiral arm, the isolation of individual stellar and interstellar structures is difficult. This study is focused on the massive stellar content of Sh 2-109 with the purpose of providing new insights on its structure. We use the catalog of optically visible open clusters and candidates (Dias et al. 2014) to study the properties of the open-cluster population within the boundaries of the Sh 2-109 star-forming region. We also utilize photometric uvby $\beta$  data for the massive stars in Sh 2-109. This data set includes more than 10 young open clusters. Since the intermediate-band uvby $\beta$  photometry allows the derivation of stellar physical parameters with high precision, we provide homogeneous distance and age estimates to the OB-associations identified toward Sh 2-109. Based on all the data we map the structure of the field in order to further study its morphology and energetics. Acknowledgments. This work was supported by NSF grant AST- 1516932.

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#### 240.22 – Extinction in young massive clusters

Up to ages of ~100 Myr, massive clusters are still swamped in large amounts of gas and dust, causing considerable and uneven levels of extinction. At the same time, large grains (ices?) produced by type II supernovae profoundly alter the interstellar medium (ISM), thus resulting in extinction properties very different from those of the diffuse ISM. To obtain physically meaningful parameters of stars (luminosities, effective temperatures, masses, ages, etc.) we must understand and measure the local extinction law. We have developed a powerful method to unambiguously determine the extinction law everywhere across a cluster field, using multi-band photometry of red giant stars belonging to the red clump (RC) and are applying it to young massive clusters in the Local Group. In the Large Magellanic Cloud, with about 20 RC stars per arcmin<sup>2</sup>, for each field we can easily derive an accurate extinction curve over the entire wavelength range of the photometry. As an example, we present the extinction law of the Tarantula nebula (30 Dor) based on thousands of stars observed as part of the Hubble Tarantula Treasury Project. We discuss how the incautious adoption of the Milky Way extinction law in the analysis of massive star forming regions may lead to serious underestimates of the fluxes and of the star formation rates by factors of 2 or more.

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#### 240.23 – A Hectochelle Radial Velocity Survey of Cep OB3b: An ONC like cluster at late gas dispersal phase

Cep OB3b is a young (~3-5 Myr), late gas dispersal cluster of roughly 3000 members broken into two sub-clusters (Eastern and Western) at a distance of 700pc; it is a rare example of nearby cluster in the

late stages of gas dispersal and appears to be a more evolved analog to the Orion Nebular Cluster. As part of an ongoing multi wavelength study, we focus on Hectochelle data from the MMT to measure the radial velocities of 499 stars. After removing binaries, outliers, and imposing a minimum R value to the cross correlation, we obtain radial velocities of 57 previously identified members, with an average error of 1.7 km/s. There is no observed variation in radial velocity across the cluster in right ascension or declination. The preferred mechanism for this type of kinematic evolution is that any initial kinematic structure from formation may have been erased and that minimal or no rotation is present in the cluster. However, the Eastern sub-cluster, containing the most massive star in the field, an O7 star, has a higher velocity dispersion than the Western sub-cluster, which contains several B stars. We will compare these results to CO maps of the residual gas in the cluster and discuss possible reasons for this difference. Finally, we will assess whether the cluster is bound or in a state of expansion.

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#### 240.24 – K2 observations of young star clusters

In operation since 2014, the K2 mission is now acquiring high cadence, high precision, long time baseline on thousands of stars in the ecliptic plane. Unlike its predecessor the Kepler mission, K2 is observing a number of young to intermediate age star clusters. This provides the chance to not only look for relatively young planets, but to also study starspot evolution, accretion, and inner circumstellar disk dynamics on several month timescales. I will provide an overview of our K2 cluster photometry pipeline and highlight the variable processes evident in the first few campaigns.

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**Institution(s):** 1. NASA Ames Research Center

#### 240.25 – An Initial Census of Eclipsing Binaries in the Pleiades and Hyades in Field 4 of the K2 Mission

We have identified four new eclipsing binary members of the Pleiades and Hyades in the K2 Field 4 data. For one of those stars, where radial velocities are available, we report a complete SB1/EB orbital fit to the data. For the other EB candidates, we describe the information we have derived from the K2 light curve and what is known about the stars from the published literature.

**Author(s):** John R. Stauffer<sup>3</sup>, Keivan Stassun<sup>4</sup>, Suzanne Aigrain<sup>2</sup>, Lynne Hillenbrand<sup>1</sup>, Trevor J. David<sup>1</sup>, Luisa M. Rebull<sup>3</sup>

**Institution(s):** 1. Caltech, 2. Oxford University, 3. Spitzer Science Center, 4. Vanderbilt University

**Contributing team(s):** K2 Young Clusters team

#### 240.26 – An Updated look at the Initial-Final Mass Relation with Five Open Clusters

The Initial-Final Mass Relation (IFMR) maps a stars ZAMS mass to it's white dwarf mass. The IFMR tells us how much material a star ejects back into the ISM over the course of its lifetime, and is also crucial for deriving minimum ages of the galactic components from studies of the coolest white dwarf stars. We have taken deep multislit observations of M34, M35, M67, NGC6633, and NGC7063 using the Keck-II telescope. We have applied models to spectroscopically confirmed white dwarfs which have zeroed in on each star's effective temperature and surface gravity. Cooling ages for these white dwarfs have in turn been determined, and subtracting this from the cluster's age has given us each white dwarfs main sequence lifetime. Isochrones in turn have been invoked to get each white dwarfs initial (ZAMS) mass. Analyzing data from five clusters of various ages has enabled us to sample a range of ZAMS masses, populating the initial mass parameter space which allows for a more precise IFMR.

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**Institution(s):** 1. Texas A&M, 2. University of Oklahoma

#### 240.27 – BINOCS: The Dynamical Evolution of Binary Populations in Star Clusters

Studies of the internal dynamics of stellar clusters is conducted primarily through N-Body simulations. A key input into these simulations is the fraction and mass distribution of binary stars. The internal dynamics of stellar clusters is conducted primarily through N-Body simulations. A key input into these simulations is the fraction and mass distribution of binary stars. Currently the N-body input relations are taken from "field" binary stars studies, but to truly understand how clustered environments evolve, binary data from within star clusters is needed, including detailed mass information. The detailed information on binaries masses, primary and secondary, in star clusters has been limited to bright high mass stars that are reachable using decade-long radial velocity surveys. We introduce a new binary detection method, Binary INformation from Open Clusters Using SEDs (BINOCS) that covers the wide mass range needed to improve cluster N-body simulation inputs and comparisons. Using newly-observed multi-wavelength photometric catalogs (0.3 - 8 microns) of the key open clusters with a range of ages, we can show that the BINOCS method determines accurate binary component masses for unresolved cluster binaries through comparison to available RV-based studies. Using this method, we present results on the dynamical evolution of binaries from 0.4 - 2.5 solar masses within nine prototypical clusters, spanning 30 Myr to 7 Gyr, and show how the binary populations evolve, and discover significant variations in the "dynamical age" of a clusters as a function of the stellar mass range studied.

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**Institution(s):** 1. Texas Christian Univ. (TCU)

#### 240.28 – Dolidze-35: Results for a Possible Open Cluster

Dolidze-35 is an under-observed northern hemisphere open cluster. It is noted in WEBDA as "No data available for this cluster". As such, we chose this cluster as an undergraduate class project to investigate its existence. We present SDSS-ugriz magnitudes for the possible cluster and cross these with existing JHK data obtained from 2MASS. Selection of possible members is aided by the proper motion study of Krone-Martins (2010).

**Author(s):** Deborah J. Gullette<sup>1</sup>, Richard A. Borges<sup>1</sup>, Elizabeth Juelfs<sup>1</sup>, J. Allyn Smith<sup>1</sup>, Mary E. Olive<sup>1</sup>, Christopher P. McDonald<sup>1</sup>, Sarah M Williams<sup>1</sup>, Eden M. Cohen<sup>1</sup>, Jason D. Gawe<sup>1</sup>, Bambi A. McCole<sup>1</sup>, Jacob M. Robertson<sup>1</sup>, Tyler Wilson<sup>1</sup>, William J. Young<sup>1</sup>, Spencer L. Buckner<sup>1</sup>, Nic R. Allen<sup>1</sup>, H. Hope Head<sup>2</sup>

**Institution(s):** 1. Austin Peay State University, 2. NSO

#### 240.29 – Neutron Capture Elements in the Open Cluster Chemical Abundance & Mapping (OCCAM) Survey

The Open Cluster Chemical Abundance & Mapping (OCCAM) survey is a systematic survey of Galactic open clusters using data primarily from the SDSS-III/APOGEE-1 survey. The high-resolution (R=22,500), near-infrared (H-band) APOGEE-1 survey allows for cluster membership probability determination and analysis of light and iron-peak elements. Neutron capture elements, however, prove to be elusive in the IR region covered by APOGEE. In an effort to fully study detailed Galactic chemical evolution, we conducted a high resolution (R~60,000) spectroscopic abundance analysis of neutron capture elements for OCCAM clusters in the optical regime to complement the APOGEE results. We present results for ten open clusters using data obtained at McDonald Observatory with the 2.1m Otto Struve telescope and Sandiford Echelle Spectrograph. We see abundance trends for Ba II, La II and Eu II that are consistent with Galactic abundance patterns for these elements. Ce II appears to be slightly enhanced in all program stars with a median value of ~0.1 dex and a spread of 0.5 dex for the entire sample.

**Author(s):** Julia O'Connell<sup>3</sup>, Peter M. Frinchaboy<sup>3</sup>, Matthew D. Shetrone<sup>4</sup>, Steven R. Majewski<sup>5</sup>, Gail Zasowski<sup>1</sup>, Fred R. Hearty<sup>2</sup>

**Institution(s):** 1. Johns Hopkins University,, 2. Pennsylvania State University,, 3. Texas Christian University, 4. University of Texas, 5. University of Virginia,

## 240.30 – WIYN Open Cluster Study: Lithium in Red Giants of the Open Cluster NGC 2158

We present lithium abundances of photometric candidate member giant stars of the open cluster NGC 2158 derived from WIYN Hydra spectra. We address membership criteria, as well as discuss the morphology of Li in both V magnitude and B-V color.

**Author(s):** Daniel M Krolkowski<sup>1</sup>, Aaron J. Steinhauer<sup>1</sup>, Constantine P. Deliyannis<sup>2</sup>, Bruce A. Twarog<sup>3</sup>, Barbara J. Anthony-Twarog<sup>3</sup>

**Institution(s):** 1. State University of New York, College at Geneseo, 2. University of Indiana, 3. University of Kansas

## 241 – Pulsars, Neutron Stars and Black Holes Poster Session

### 241.01 – Atmospheres of Quiescent Low-Mass Neutron Stars

Observations of the neutron stars in quiescent low-mass X-ray binaries are important for determining their masses and radii which can lead to powerful constraints on the dense matter nuclear equation of state. The interpretation of these sources is complex and their spectra differ appreciably from blackbodies. Further progress hinges on reducing the uncertainties stemming from models of neutron star atmospheres. We present a suite of low-temperature neutron star atmospheres of different chemical compositions (pure H and He). Our models are constructed over a range of temperatures [ $\log(T/1\text{ K})=5.3, 5.6, 5.9, 6.2, 6.5$ ] and surface gravities [ $\log(g/1\text{ cm/s}^2)=14.0, 14.2, 14.4, 14.6$ ]. We generated model atmospheres using **zcode** - a radiation transfer code developed at Los Alamos National Laboratory. In order to facilitate analytic studies, we developed three-parameter fits to our models, and also compared them to diluted blackbodies in the energy range of 0.4-5 keV (CXO/MGE). From the latter, we extract color-correction factors ( $f_c$ ), which represent the shift of the spectra as compared to a blackbody with the same effective temperature. These diluted blackbodies are also useful for studies of photospheric expansion X-ray bursts. We provide a comparison of our models to previous calculations using the McGill Planar Hydrogen Atmosphere Code (McPHAC). These results enhance our ability to interpret thermal emission from neutron stars and to constrain the mass-radius relationship of these exotic objects.

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### 241.02 – Modeling Pulsar Trajectories to Determine Birth Locations

Neutron stars are the remnants of massive stars after their deaths in supernova explosions. They typically have higher velocities than their progenitor stellar population due to either kicks from supernova asymmetries or from remnant velocities of compact binaries after they are disrupted by explosions. Velocities are large enough that pulsars will typically move large distances from their birth sites. By determining the present day location and velocity, we project back to twice the pulsars characteristic age to constrain the location of the progenitor star (within the uncertainty of the unknown line-of-sight velocity component). We use precision measurements of the proper motion and parallax determined with the Very Long Baseline Array as input to trajectory modeling that includes deceleration in the Galactic potential. Using a python implementation utilizing *astropy* and *galpy*, we verify the results of Vlemmings et al. (2004, ApJ, 610, 402) on two pulsars, B2020+28 and B2012+51, which found that the

two objects very likely originated in the same star cluster and whose progenitor stars could have been in the same binary system. We have applied the trace back algorithm to other pulsars using the most recent astrometric measurements to identify their birth locations. Results on these objects will be reported.

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### 241.03 – The Optimization of GBT Pulsar Data for the GBNCC Pulsar Survey

The Green Bank Telescope collects data from the Green Bank Northern Celestial Cap (GBNCC) pulsar survey in order to find new pulsars within its sensitivity and also, to confirm previously found pulsars within its sensitivity range. The collected data is then loaded into the CyberSKA website database where astronomers are tasked with rating the data sets based on its potential to be a pulsar from 0(unclassified), 1(class 1 pulsar), 2(class 2 pulsar), 3(class 3 pulsar), 4(radio frequency interference), 5(not a pulsar), 6(know pulsar), 7(harmonic of a known pulsar). This specific research done was to use previously classified pulsars to create a python script that will automatically identify the data set as a pulsar or a non-pulsar. After finding the recurring frequencies of radio frequency interference (RFI), the frequencies were then added to a pipeline to further discern pulsars from RFI.

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**Contributing team(s):** Green Bank NRAO, GBNCC

### 241.04 – Precision Pulsar Timing at the DSN

Millisecond pulsars are a class of radio pulsars with extremely stable rotations. The excellent timing stability of millisecond pulsars can be used to study a wide variety of astrophysical phenomena. In particular, observations of a large sample of these pulsars can be used to detect the presence of low-frequency gravitational waves. We have developed and are now commissioning a precision pulsar timing backend for the Deep Space Network (DSN), which will allow the use of short gaps in tracking schedules to observe and time pulses from an ensemble of millisecond pulsars. The NASA Deep Space Network (DSN) operates clusters of large dish antennas (up to 70-m in diameter), located roughly equi-distant around the Earth, for communication and tracking of deep-space spacecraft. The backend system is capable of removing entirely the dispersive effects of propagation of radio waves through the interstellar medium in real-time. We will describe our development work, initial results, and prospects for future observations scheduled over the next few years.

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### 241.05 – Multiwavelength Observations of the Redback Pulsar J1048+2339, Coincident with the Fermi-LAT Source 3FGL J1048.6+2338

We report on pulsar timing and multiwavelength observations of the redback millisecond pulsar J1048+2339, which was discovered in an Arecibo search for periodic radio pulsations targeting the Fermi-LAT source 3FGL J1048.6+2338 (Cromartie et al. 2015, in prep). This discovery calls into question the association of the Fermi-LAT source with the BL Lac active galactic nucleus NVSS J104900+233821 appearing in the 3FGL source catalog. Fourteen months of radio timing data from Arecibo allowed us to derive precise astrometric and orbital parameters for the pulsar. J1048+2339 is in a binary system with a companion whose minimum mass is 0.3 solar masses and exhibits radio eclipses over half the orbital period. We have identified an optical counterpart with intensity modulations matching the pulsar's orbital period. We also present preliminary results from searches for gamma-ray pulsations using the radio ephemeris.

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**Contributing team(s):** Fermi-LAT Collaboration

#### **241.06 – Shedding Light on the Eclipses of PSR 1748-2446A**

The last seven years have seen a wealth of new black widow and redback pulsars, or spider pulsars. These spider pulsars are binary millisecond pulsars characterized by their tight orbits and low companion masses, and often exhibit eclipses. The mechanism that produces the radio eclipse in these systems is still unknown and progress has not been made on this problem in over a decade. However, with a wealth of new systems and data, it makes sense to revisit this question. We analyzed polarization data from PSR 1748-2446A, or Terzan 5A, and observed previously unknown behavior around the eclipse. We found that the linearly polarized eclipse is significantly longer than the total intensity eclipse and that there is rapid variation in rotation measure around ingress and egress of the eclipse. We also found during one epoch that exhibited many short eclipses around the ingress of the eclipse, there was an associated burst of linear polarization at the ingress of the eclipse.

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#### **241.08 – High-Cadence Timing Observations of an Exoplanet-Pulsar System, PSR B1257+12**

The pulsar B1257+12 was regularly observed and timed by Aleksander Wolszczan from its discovery in 1992 up to 2008. It is the first example of an exoplanet-pulsar system, and is modeled to consist of three planets. At the time, long term timing programs lacked the sensitivity to measure effects that low mass, short orbital period bodies would have on the pulse arrival times (TOA's) and its timing residuals. Newer technology, like the PUPPI backend at Arecibo, allows for the exploration of an untouched planet parameter space. The project consisted of conducting precise timing using PUPPI, taking two hour long observations at 327 MHz, 430 MHz, and L-Band Wide (LBW) frequencies for 25 days. The data is processed in order to obtain standard profiles and TOA's that would be introduced into TEMPO2, allowing data point manipulation by fitting them for known pulsar parameters to acquire post fit residuals with expected precisions below 1  $\mu$ s. The observations yielded residuals ranging between 0.40  $\mu$ s and 1.89  $\mu$ s for 430 MHz and 327 MHz, while LBW resulted in values higher than 4.0  $\mu$ s, which is attributed to the many radio frequency interference (RFI) bands present in the data. Combining the newly and previously acquired data revealed a decrease in the dispersion measure (DM), from 10.16550 pc/cm<sup>3</sup> to 10.15325 pc/cm<sup>3</sup>, since the pulsar was last observed, which allowed a correction for the effects of interstellar scintillation, which are most noticed at 327 MHz.

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#### **241.09 – VLA Observations of the Magnetar PSR J1745-2900 and Sgr A\***

We present radio continuum light curves of the magnetar PSR J1745-2900 located  $\sim 3$  arcseconds from Sgr A\*, as well as light curves of Sgr A\*, obtained with multi-epoch VLA observations between 2012 and 2014. During this period, a powerful X-ray outburst from SGR J1745-2900 occurred on 2013-04-24. Enhanced radio emission is delayed with respect to the X-ray peak by about seven months. In addition, the flux density of the emission from the magnetar fluctuates by a factor of 2 to 4 at frequencies between 21 and 41 GHz, and its spectral index varies erratically. As for Sgr A\*, monitoring data shows a constant flux density and spectral index during this period, in spite of the variability of Sgr A\* expected to be induced by the passage of the G2 cloud. We argue that the excess fluctuating emission from the magnetar arises from the interaction of a shock generated from the X-ray outburst with the orbiting ionized gas at the Galactic center. This continuum emission is in addition to pulsed emission from the pulsar. In this picture, variable synchrotron emission is produced by ram pressure variations due to inhomogeneities in the dense ionized medium of the Sgr A West bar. The pulsar, with its high transverse velocity, is moving through a

highly blue-shifted ionized medium. This implies that the magnetar is at a projected distance of  $\sim 0.1$  pc from Sgr A\*, and that the orbiting ionized gas is at least partially responsible for a large rotation measure detected toward the magnetar.

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#### **241.10 – A New High-Frequency Search for Galactic Center Millisecond Pulsars using DSS-43**

The primary 70-meter Deep Space Network antenna (DSS-43) in Canberra, Australia was equipped with a new high-frequency (18-28 GHz) receiver system in May 2015 for use in a search for Galactic Center (GC) millisecond pulsars. The primary motivation for this search is that a pulsar in the Galactic Center region (especially one that is gravitationally bound to the massive black hole at the GC) would provide unprecedented tests of gravity in the strong-field regime and would offer an entirely new tool for probing the characteristics of the Galactic Center region. Preparation for the GC pulsar search has involved the development of a single-pulse search pipeline that integrates tools from both Fortran and Python as well as the implementation of this pipeline on high performance CPUs. The original version of the search pipeline was developed using Vela Pulsar data from DSS-43, and a more refined version that relies upon chi-squared fitting techniques was ultimately developed using Crab Pulsar data. Future work will involve continued testing of the single-pulse search pipeline using data from the rotating radio transient (RRAT) J1819-1458, the characterization of RRAT pulses using high time resolution data from the new receiver system on DSS-43, and ultimately the analysis of high-frequency data using the existing pipeline to search for millisecond pulsars in the Galactic Center.

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#### **241.11 – Resonant Compton Physics for Magnetar Astrophysics**

Various telescopes including RXTE, INTEGRAL, Suzaku, and Fermi have detected steady non-thermal X-ray emission in the 10 - 200 keV band from strongly magnetic neutron stars known as magnetars. Magnetic inverse Compton scattering is believed to be the leading candidate for the production of this intense X-ray radiation. Scattering at ultra-relativistic energies leads to attractive simplifications in the analytics of the magnetic Compton cross section. We have recently addressed such a case by developing compact analytic expressions using correct spin-dependent widths acquired through the implementation of Sokolov & Ternov basis states, focusing specifically on ground-state-ground-state scattering. Compton scattering in magnetar magnetospheres can cool electrons down to mildly relativistic energies. Moreover, soft gamma-ray flaring in magnetars may involve strong Comptonization in expanding clouds of mildly relativistic pairs. Such environs necessitate the development of more general magnetic scattering cross sections, in which the incoming photons acquire substantial incident angles relative to the field in the rest frame of the electron leading to arbitrary Landau excitations of the intermediate and final states. Due to the rapid transitions of the excited-state to the ground-state, the initial electron is still assumed to be in the ground state. The cross sections treat the plethora of harmonic resonances associated with various cyclotron transitions between Landau states. Polarization and spin dependence of the cross section for the four scattering modes is compared to the cross section obtained with spin-averaged widths. We present numerical results to show the comparisons to highlight the role of the spin-dependent widths of the resonances. The findings presented here will have applications to various neutron star problems, including computation of Eddington luminosities and polarization mode-switching rates in transient

magnetar fireballs.

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### 241.12 – The Local Black Hole Mass Function Derived from the $M_{\text{BH}}$ -Pitch Angle and the $M_{\text{BH}}$ -Sersic Index Relations

We determined the local supermassive black hole mass function (BHMF) for all galaxy types with complementing the local BHMF for spiral galaxies derived by Davis et al. (2014). We used the empirical relation between supermassive black hole mass and the Sersic index for early type (E/So) galaxies from the same parent sample with Davis et al. (2014), which is selected from galaxies in the Carnegie-Irvine Galaxy Survey (CGS) which is a very complete sample of the nearby galaxies. The observational simplicity of our approach and direct measurements from the statistically tightest correlations with black hole mass, which are the Sersic index for E/So galaxies and pitch angle for spiral galaxies, make it straightforward to estimate an accurate local BHMF. Integrating over the best-fitting mass function, the local mass density of SMBHs from early- and late-type galaxies combined is  $\rho = 3.61^{+3.80}_{-1.75} \times 10^5 \text{ M}_{\odot} \text{ Mpc}^{-3}$ . The errors are estimated from Monte Carlo simulations which include uncertainties in the empirical relations and measurement errors in both Sersic index and Pitch angle. Assuming supermassive black holes form via baryonic accretion, we find that  $0.013^{+0.013}_{-0.006}$  per cent of baryons are contained in SMBHs at the centers of galaxies in the local universe.

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### 241.13 – Contemporaneous Optical and X-ray Observations of the V404 Cygni Outburst

The 12 solar mass black hole V404 Cygni began a series of renewed flaring on June 15<sup>th</sup>, 2015, as detected by Swift and Fermi, when material from its small binary companion began to fall into the black hole. The source was observed for several hours in four optical bands on June 19<sup>th</sup> by 0.9m Southeastern Association for Research in Astronomy (SARA) telescope on Kitt Peak in Arizona. Several x-ray flares from Swift were detected during the same time period. We present the contemporaneous data and look for simultaneous flaring in the optical and x-ray.

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### 241.14 – Survey for Radio Nebulae Around Ultraluminous X-ray Sources

The nature of ultraluminous X-ray sources (ULX) is an ongoing debate. As such sources appear to violate the Eddington Limit for the expected masses of stellar remnants, ULX may represent a class of super-Eddington objects, "intermediate" mass black holes (IMBH) emitting at sub-Eddington levels, or a diverse population including examples of both. Most initial efforts to search for radio emission associated with ULX did so with high angular resolution in hopes of applying the "fundamental plane of black hole activity" which relates X-ray luminosity, radio luminosity, and black hole mass. The predicted radio flux densities for such compact radio emission are quite low meaning that even non-detections leave open much of the mass range associated with IMBH. However, a small number of ULX have been associated with extended radio emission and these radio nebulae have sizes and energetics that differentiate them from more common classes of extended objects such as HII regions and supernova remnants. We report here on the results of a cohesive study to identify and characterize ULX radio nebula associated with unbiased samples of ULX. This study has two prongs: one relying upon archival Very Large Array data and one using new, dedicated Jansky Very Large Array observations. Several new candidate ULX radio nebulae are identified and characterized, and along with limits from non-detections we discuss implications for the overall

population of ULX.

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### 241.15 – Driving of Accretion Disk Variability by the Disk Dynamo

Variability is a universal feature of emission from accreting objects, but many questions remain as to how the variability is driven and how it relates to the underlying accretion physics. We use a long, semi-global MHD simulation of a thin accretion disk around a black hole to perform a detailed study of the fluctuations in the internal disk stress and the affect these fluctuations have on the accretion flow. In this poster, we show that low frequency fluctuations in the effective  $\alpha$ -parameter in the disk are due to oscillations of the disk dynamo. Additionally, we show that fluctuations in the effective  $\alpha$ -parameter drive "propagating fluctuations" in mass accretion rate through the disk that qualitatively resemble the variability from astrophysical black hole systems. In particular, we show that several of the ubiquitous phenomenological properties of black hole variability, including log-normal flux distributions, RMS-flux relationships, and radial coherence are present in the mass accretion rate fluctuations of our simulation.

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### 241.16 – Kinetic Study of Radiation-Reaction-Limited Particle Acceleration During the Relaxation of Force-Free Equilibria

Many powerful and variable gamma-ray sources, including pulsar wind nebulae, active galactic nuclei and gamma-ray bursts, seem capable of accelerating particles to gamma-ray emitting energies efficiently over short time scales. This might be due to prodigal dissipation in a highly magnetized outflow. In order to understand the generic behavior of relativistic plasma with high magnetization, we consider a class of prototypical force-free equilibria which are shown to be unstable to ideal modes (East et al 2015 PRL 115, 095002). Kinetic simulations are carried out to follow the evolution of the instability and to study the basic mechanisms of particle acceleration, especially in the radiation-reaction-limited regime. We find that the instability naturally produces current layers and these are sites for efficient particle acceleration. Detailed calculations of the gamma ray spectrum, the evolution of the particle distribution function and the dynamical consequences of radiation reaction will be presented.

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### 241.17 – Sowing Black Hole Seeds: Forming Direct Collapse Black Holes With Realistic Lyman-Werner Radiation Fields in Cosmological Simulations

Luminous quasars detected at redshifts  $z > 6$  require that the first black holes form early and grow to  $\sim 10^9$  solar masses within one Gyr. Our work uses cosmological simulations to study the formation and early growth of direct collapse black holes. In the pre-reionization epoch, molecular hydrogen ( $\text{H}_2$ ) causes gas to fragment and form Population III stars, but Lyman-Werner radiation can suppress  $\text{H}_2$  formation and allow gas to collapse directly into a massive black hole. The critical flux required to inhibit  $\text{H}_2$  formation,  $J_{\text{crit}}$ , is hotly debated, largely due to the uncertainties in the source radiation spectrum,  $\text{H}_2$  self-shielding, and collisional dissociation rates. Here, we test the power of the direct collapse model in a non-uniform Lyman-Werner radiation field, using an updated version of the SPH+N-body tree code Gasoline with  $\text{H}_2$  non-equilibrium abundance tracking,  $\text{H}_2$  cooling, and a modern SPH implementation. We vary  $J_{\text{crit}}$  from 30 to  $10^4 J_{21}$  to study the effect on seed black holes, focusing on black hole formation as a function of environment, halo mass, metallicity, and proximity of the Lyman-Werner source. We discuss the constraints on massive black hole occupation fraction

in the quasar epoch, and implications for reionization, high-redshift X-ray background radiation, and gravitational waves.

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### 241.18 – A Particular Appetite: Cosmological Hydrodynamic Simulations of Preferential Accretion in the Supermassive Black Holes of Milky Way Size Galaxies

With the use of cosmological hydrodynamic simulations of Milky Way-type galaxies, we identify the preferential source of gas that is accreted by the supermassive black holes (SMBHs) they host. We examine simulations of two Milky Way analogs, each distinguished by a differing merger history. One galaxy is characterized by several major mergers and the other has a more quiescent history. By examining and comparing these two galaxies, which have a similar structure at  $z=0$ , we assess the importance of merger history on black hole accretion. This study is an extension of Bellovary et. al. 2013, which studied accretion onto SMBHs in massive, high redshift galaxies. Bellovary found that the fraction of gas accreted by the galaxy was proportional to that which was accreted by its SMBH. Contrary to Bellovary's previous results, we found that though the gas accreted by a quiescent galaxy will mirror the accretion of its central SMBH, **a galaxy that is characterized by an active merger history will have a SMBH that preferentially accretes gas gained through mergers.** We move forward by examining the angular momentum of the gas accreted by these Milky Way-type galaxies to better understand the mechanisms fueling their central SMBH.

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### 241.20 – Searching For Gaps in AGN Disks Using Data From the Sloan Digital Sky Survey

There is good evidence for two different types of Black Holes (BH): Stellar Mass BHs (SBH) and Super Massive BHs (SMBH). SBHs have masses between  $10 - 10^2$  solar masses ( $M_\odot$ ) and they can be found all over the galaxy, while SMBHs have masses between  $10^5 - 10^{10} M_\odot$  and can be found in the center of most galaxies. Many models predict an intermediate mass black hole (IMBH) population, most likely in stellar clusters. Evidence is poor for IMBH in galaxies, prompting McKernan, Ford et al. 2012; Gultekin & Miller 2012 to suggest searching for IMBH in disks around SMBH. Sufficiently massive IMBHs in disks will open a gap that may be detectable in optical/UV spectra as a decrement. Using spectra from  $>130$  very bright galaxies in the Sloan Digital Sky Survey (SDSS), we searched for decrements versus a simple continuum model. We did not find obvious decrements, and now we are currently trying new strategies that can attest this assertion.

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### 241.21 – AGN from HeII: AGN host galaxy properties & demographics

We present an analysis of HeII emitting objects classified as AGN. In a sample of 81,192 galaxies taken from the seventh data release (DR7) of the Sloan Digital Sky Survey in the redshift interval  $0.02 < z < 0.05$  and with  $r < 17$  AB mag, the Baldwin, Philips & Terlevitch 1981 method (BPT) identifies 1029 objects as active galactic nuclei. By applying an analysis using HeII  $\lambda$  4686 emission lines, based on Shirazi & Binchmann 2012, we have identified an additional 283 active galactic nuclei, which were missed by the BPT method. This represents an increase of over 25 %. The characteristics of the HeII selected AGN are different from the AGN found through the BPT; the colour - mass diagram and the colour histogram both show that HeII selected AGN are bluer. This new selection technique can help inform galaxy black hole coevolution scenarios.

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### 241.22 – Investigating saturated versus unsaturated driving of stellar modes by gravitational waves

Gravitational waves (GWs) emitted by massive black hole binaries (MBHBs) can be absorbed by nearby stars. As a consequence of resonance between the GW frequency and quadrupolar modes in stars, observable changes in luminosity are expected as the star absorbs and subsequently discharges energy. While it has previously been shown that GWs can do work on nearby compact stars, resonant heating of normal stars has not yet been fully explored. By modeling such stars as driven, damped harmonic oscillators, we examine which stars and stellar oscillations can become saturated (versus unsaturated) for physically plausible binary-oscillator pairings. Using such models, we can compute the total energy deposited in any given toy model star. Energy deposition can then be used to compute the luminosity and structural changes expected in realistic stars.

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### 241.23 – A Search for Fast Radio Bursts in GALFACTS data

Fast Radio Bursts (FRBs) are transient radio sources whose high dispersion measures suggest they are of extra-galactic origin. They are particularly difficult to detect because, unlike other fast radio transients, they are non-recurring events. At present, 11 such bursts have been detected, 10 by the Parkes Radio Telescope and one by Arecibo Observatory. The G-ALFA Continuum Transit Survey (GALFACTS) is the highest resolution, full-Stokes, radio-continuum survey of the foreground sky. The Arecibo radio telescope is the largest single-aperture telescope in the world, offering the superior point-source sensitivity necessary to detect additional FRBs. GALFACTS utilizes Arecibo's ALFA receiver, an L-band 7-beam feed array, to produce a high-time (1 ms), low-spectral (MHz) resolution (HTLS) data stream between 1225 and 1525 MHz. We used ``Red\_Transient'', a robust search pipeline developed by A.A. Deshpande, to de-disperse the HTLS data with the intention of detecting FRBs in the  $\sim 30\%$  of the total sky surveyed by GALFACTS. Concurrently, the student produced a similar search pipeline to calibrate HTLS data and validate detections by ``Red\_Transient''. Here, we present the results of initial processing runs on the first several days of GALFACTS observations. Currently, no FRB detections have been found. However, the detection of pulses from the known pulsar J1916+1312 indicates that ``Red\_Transient'' is capable of detecting fast transient signals present in the data stream.

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## 242 – Dust Poster Session

### 242.01 – Characterizing Dust Attenuation in Local Star Forming Galaxies

The dust attenuation for a sample of  $\sim 10000$  local ( $z \leq 0.1$ ) star forming galaxies is constrained as a function of their physical properties. We utilize aperture-matched multi-wavelength data available from the *Galaxy Evolution Explorer* and the *Sloan Digital Sky Survey* to ensure that regions of comparable size in each galaxy are being analyzed. We characterize the dust attenuation through the slope of the UV flux density and the Balmer decrement ( $H\alpha/H\beta$ ). The observed linear relationship between these quantities is similar to the local starburst relation. We derive a selective attenuation curve over the range  $1250 \text{ \AA} < \lambda < 8320 \text{ \AA}$  and find that a single attenuation curve is effective for characterizing the majority of galaxies in our sample. We do not see evidence to suggest that a  $2175 \text{ \AA}$  feature is significant in the average attenuation curve.

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## 242.02 – Extinction Mapping of Nearby Galaxies with LEGUS

Using 5-band (NUV (2750 Å), U, B, V, I) photometry from the Legacy ExtraGalactic Ultraviolet Survey (LEGUS), we generate extinction maps for nearby (within 10 Mpc) galaxies at resolutions of a few arcseconds. Dust is commonly used as a tracer for cold dense gas, either through IR and NIR emission maps or through extinction mapping. Extinction mapping has been used to trace dust column densities in the Milky Way, the Magellanic Clouds, and M31. The maps for M31 use IR and NIR photometry of red giant branch stars, which is more difficult to obtain for more distant galaxies. Our method uses the extinctions derived for individual massive stars using the isochrone-matching method described by Kim et al. (2012). With our 5-band photometry, which extends into the UV, we are able to trace even small amounts of extinction. These maps are then compared to HI and CO maps of the same galaxies with the goal of constraining the dust-to-gas mass ratio, which we can then correlate with the gas phase metallicity from other observations. This poster will demonstrate the technique on a few galaxies, but the project will subsequently be expanded to cover the full LEGUS sample of nearly 50 galaxies. These maps can then be used to correct massive star and cluster photometry and HII region H $\alpha$  observations for the effects of extinction in order to better characterize star formation rates and massive stellar populations for other projects, such as initial mass function studies and ionization balance studies for HII regions and the diffuse ionized gas.

**Author(s):** Lauren Kahre<sup>2</sup>, Rene A.M. Walterbos<sup>2</sup>, Elena Sabbi<sup>3</sup>, David A. Thilker<sup>1</sup>, Leonardo Ubeda<sup>3</sup>

**Institution(s):** 1. Dept. of Physics and Astronomy, The John's Hopkins University, 2. New Mexico State University, 3. Space Telescope Science Institute

**Contributing team(s):** LEGUS Science Team

## 242.03 – Covariance between Star Formation Rates and Dust Mass of KINGFISH Galaxies

We present the initial results for a study of the potential covariance between galaxy physical parameters (e.g., the star formation rate and dust mass) derived from the infrared spectral energy distributions (SEDs) of galaxies. With the emergence of powerful facilities and instruments in the millimeter and sub-millimeter wavelengths, which complement data from infrared space telescopes like Herschel, scientists have been able to observe the infrared SEDs of faraway galaxies (with redshifts between 2 and 5). These SEDs are being used to derive both star formation rates (SFR) and dust masses, the latter related to gas masses. The relationship between SFRs and gas masses determine the fundamental scaling laws of star formation (the Schmidt Kennicutt Law). Thus, it is fundamental to ascertain whether derivation of these quantities from IR SEDs may be affected by covariance. We will use the Spitzer and Herschel data from the nearby survey: Key Insights on Nearby Galaxies: A Far-IR Survey with Herschel (KINGFISH), which includes 61 nearby galaxies observed between 3.6 and 500 micron.

**Author(s):** Randall Rojas Bolivar<sup>2</sup>, Daniela Calzetti<sup>2</sup>, Daniel A. Dale<sup>3</sup>, David Cook<sup>1</sup>

**Institution(s):** 1. Caltech, 2. University of Massachusetts, 3. University of Wyoming

## 242.04 – Herschel Dust Measurements of SDSS Supernovae Host Galaxies

We use Herschel Spectral and Photometric Imaging Receiver (SPIRE) far-infrared observations of Supernova host galaxies to study the cosmological distant measurement from Hubble diagrams. We investigate the dust content of SN host galaxy from the Sloan Digital Sky Survey (SDSS) using the far-infrared stacks of Herschel in the Equatorial Stripe using , Herschel Multi-Tiered Extragalactic Survey (HELMS), and the Herschel Stripe 82 Survey (HERS). Cosmic dust may contribute to much more obscuring of standard candles than previously thought. Measuring the average flux values

of stacks from dim Type-Ia supernovae provides a measure of the dust content of galaxies as a function of deviation of those sources from the Hubble diagram given a standard cosmology. Using the optical to far infrared stacked data of the galaxies we also measure the physical properties of the standard candles as a function of dust content.

**Author(s):** Donald Trinh<sup>1</sup>, Asantha R. Cooray<sup>1</sup>, Hooshang Nayyeri<sup>1</sup>

**Institution(s):** 1. University of California, Irvine

**Contributing team(s):** Herschel Hermes and h-atlas collaboration

## 242.05 – ZFOURGE: UV to FIR Luminosities and Dust Attenuation Determined from ~4000 K-Selected Galaxies at $1 < z < 3$

We analyze the UVJ color-color selection technique and the IRX- $\beta$  dust relation at  $1 < z < 3$  using data from the Fourstar Galaxy Evolution Survey (ZFOURGE). We build a set of composite SEDs by combining the precise photometric redshifts from a K-band selected sample of ZFOURGE data with public photometry from the Chandra Deep Field South, the Cosmological Evolution Survey, and the Ultra Deep Field. Infrared fluxes are determined from Spitzer/MIPS 24 micron and Herschel/PACS 100 and 160 micron data. From a sample of 4000 K-band selected galaxies, we identify 38 composite SEDs that span the range in UVJ colors and IR to UV flux ratios. These composites lie on the UVJ plane as predicted by their SED shapes. We also find significant deviation from local IRX- $\beta$  relations. Blue star-forming composites show a slightly elevated IRX value, while red star-forming composites are offset from local relations by as much as 1 dex. We find that the resulting dust attenuation at 1600 Angstroms is over-estimated for these red star-forming galaxies, implying a lower intrinsic SFR than previously inferred, e.g. using the Meurer99 relation.

**Author(s):** Ben Forrest<sup>1</sup>, Kim-Vy Tran<sup>1</sup>

**Institution(s):** 1. Texas A&M University

**Contributing team(s):** ZFOURGE Collaboration, CANDELS-H Collaboration

## 242.06 – Improving the Pan-STARRS/2MASS 3-D dust map: Regularization for increased resolution and fidelity.

The Green et al. (2015) 3-D map of interstellar dust uses photometry of nearly 1 billion stars from Pan-STARRS1 and 2MASS to infer the distribution of dust in the Milky Way. The current map treats each angular pixel (~ 6 arcmin) independently, and estimates the dust in 30 distance bins. However, dust structures cut across pixels and the fit could be improved by coupling the dust density in neighboring pixels. This also has the advantage that fewer stars would be required per pixel, allowing finer angular resolution. We propose a simple way to do this, and show that it allows the use of smaller angular pixels and produces sharper resolution in the distance direction for a test case in Orion. We intend to incorporate similar regularization into the next full-sky 3-D dust map.

**Author(s):** Douglas P. Finkbeiner<sup>1</sup>, Gregory Green<sup>1</sup>, Albert Lee<sup>1</sup>, Edward Ford Schlafly<sup>2</sup>

**Institution(s):** 1. Harvard-Smithsonian Center for Astrophysics, 2. MPTA

## 242.07 – Dust Reddening Variation in the Milky Way

Various studies of dust extinction have shown that reddening curves vary from cloud to cloud. However, most of these results use relatively small numbers of stars in limited regions of interest. We describe a generalized technique for estimating the angular variation in the reddening law across the Milky Way at mid-to-high galactic latitudes, inferred from the photometry of millions of stars from Pan-STARRS 1. We find pixels where stars are primarily extinguished by a single dust-cloud, and determine a most likely de-reddening vector from shifts of the stellar locus in color space. We present maps for some target clouds, and compare a variety of reddening laws with our results.

The maps should help us better understand the general properties of

dust in the Milky Way, as well as provide more accurate extinction correction in the relevant regions. The stellar locus fitting technique can also corroborate detailed studies of reddening based on APOGEE spectra (Schlafly et al.) and more rigorous analyses of the line-of-sight extinction (Green et al.)

**Author(s):** Albert Lee<sup>1</sup>, Douglas P. Finkbeiner<sup>1</sup>, Gregory Green<sup>1</sup>, Edward Ford Schlafly<sup>2</sup>

**Institution(s):** 1. Harvard University, 2. Max Planck Institute for Astronomy

#### 242.08 – Milky Way Dust in 3D using Pan-STARRS 1

We present a three-dimensional map of dust reddening in the Milky Way, covering three quarters of the sky out to a distance of several kiloparsecs, at an angular resolution of  $\sim 7'$ . We combine stellar photometry from Pan-STARRS 1 and 2MASS with prior information on the spatial distribution, metallicity and luminosity of stars to infer the distance, reddening and type of 800 million stars. Using this information, we infer how dust reddening increases with distance along 2.4 million sightlines north of  $\delta = -30^\circ$ .

Our map reveals a wealth of structure within the ISM, from angular scales of  $\sim 7'$  to large cloud complexes. Comparison with the 2D Planck reddening maps shows agreement to within 0.05 mag in  $E(B-V)$  out to a cumulative reddening of 0.5 mag. We expect this map to have a wide range of applications, from correcting for reddening in observations, to studies of Galactic structure, to distance determinations to molecular clouds in the Milky Way.

Our map has now been released, and is available at <http://argonaut.skymaps.info>. We provide an online tool for exploring the map, an API through which users can query the map remotely, and the full data cube for users who desire access to the entire map.

**Author(s):** Gregory Green<sup>1</sup>, Edward Ford Schlafly<sup>2</sup>, Albert Lee<sup>1</sup>, Douglas P. Finkbeiner<sup>1</sup>

**Institution(s):** 1. Harvard Univ., 2. MPIA

#### 242.09 – Interstellar Extinction and its Variation in the Galaxy

Dust reddening is an important diagnostic of the interstellar medium and the dust grain size distribution, as well as a pervasive observational nuisance. Detailed studies of the dust extinction curve and its variation have hitherto been largely limited to samples of hundreds of specially chosen stars. We use spectroscopy from APOGEE in combination with photometry from Pan-STARRS1, 2MASS, and WISE to characterize the dust extinction curve throughout much of the nearest few kiloparsecs of the Galactic plane using tens of thousands of stars. We make new measurements of the dust extinction curve and its variation, finding that the extinction curve in the optical through infrared is well characterized by a one-parameter family of curves, described, for instance, by  $R(V)$ . Our data show little evidence of any need for further parameters. The local curvature of the extinction curve increases with decreasing  $R(V)$  throughout most of the optical and infrared: the extinction curve in the infrared is not more "universal" than in the optical, in contrast to several widely-used extinction curve parameterizations. We find that the shape of the dust extinction curve is rather uniform, with  $\sigma(R(V)) = 0.2$ , and with less than two percent of sight lines having  $R(V) > 4$ . However, significant spatially coherent variations in  $R(V)$  do exist. The primary variations are on scales much larger than individual molecular clouds, indicating that grain growth in dense molecular cloud environments is not the primary driver of  $R(V)$  variations in dust at large. Indeed, we find no correlation between  $R(V)$  and dust column density out to  $E(B-V) \approx 2$ .

**Author(s):** Edward Ford Schlafly<sup>3</sup>, Hans-Walter Rix<sup>3</sup>, Douglas P. Finkbeiner<sup>2</sup>, Gregory Green<sup>2</sup>, Albert Lee<sup>2</sup>, Aaron M. Meisner<sup>1</sup>

**Institution(s):** 1. Berkeley National Laboratory, 2. Harvard/CfA, 3. MPIA

#### 242.10 – Investigation of Reddening in Fields of the SMASH Survey

We present dust extinction maps derived from eight fields in the Survey of the MAGellanic Stellar History (SMASH), a survey that is imaging  $480 \text{ deg}^2$  of the southern sky in DES-ugriz with the CTIO 4-m Blanco telescope and the Dark Energy Camera (DECam). We derive the extinction due to dust using fits to the stellar locus of stars brighter than  $g=21$  in color-color diagrams, and explore the spatial distribution of the extinction within each of the fields. We compare our results to the extinction map of Schlegel, Finkbeiner, & Davis (1998), and find generally good agreement. We describe plans to measure the three-dimensional distribution of extinction in these fields using fainter stars and background galaxies as tracers. Juelfs was supported by the NOAO/KPNO Research Experiences for Undergraduates (REU) Program which is funded by the National Science Foundation Research Experiences for Undergraduates Program (AST-1262829).

**Author(s):** Elizabeth A. Juelfs<sup>1</sup>, Knut A. Olsen<sup>2</sup>

**Institution(s):** 1. Austin Peay State University, 2. NOAO

**Contributing team(s):** SMASH team

### 243 – AGN, QSO, Blazars Poster Session

#### 243.01 – Describing the Gas Kinematics and Excitation of the Inner Kiloparsec of the Post-Starburst Quasar SDSS J170328.95+614109.9

Post-Starburst Quasars (PSQs) are hypothesized to represent a stage in the evolution of massive galaxies in which both star formation and nuclear activity have been triggered and are visible simultaneously before one or the other fades. We present preliminary results for the study of the kinematics and excitation of the gas present in the PSQ J1703+6141 in order to understand which are the excitation mechanisms in the central region of this object (starburst or/and AGN?). For this purpose we have used optical Integral Field Spectroscopy (IFS) obtained with the GMOS-IFU at Gemini North telescope and performed IDL codes to analyze the spectra. We have found that the [OIII] emission line can be observed all around the object and that it presents a higher blueshift to the South West direction. On the other hand, the H $\beta$  line is better observed around the nucleus and it presents an apparent rotation. Also, the ratio between these two emission lines is typical of a Seyfert galaxy according to the BPT diagram and typical of an AGN based on the study of Lamareille et al. 2004, that uses the ratio between [OII] $\lambda$ 3727 and H $\beta$  for the study instead of [NII]/H $\alpha$  like the BPT diagram does. Ionization models are necessary to analyze the gas excitation and to distinguish what are the main mechanisms working in the central region of this PSQ. Also, further studies will be conducted to analyze the stellar kinematics and the history of star formation in the central kpc of this PSQ.

**Author(s):** Pamela Soto Pinto<sup>2</sup>, David Sanmartin<sup>1</sup>

**Institution(s):** 1. SOAR, 2. Universidad de Concepción

#### 243.02 – The Keck OSIRIS Nearby AGN Survey: distribution and kinematics of molecular gas in the nuclear regions of Seyfert 1s and Seyfert 2s

We present results from the analysis of the nuclear molecular gas distribution in the Keck OSIRIS Nearby AGN (KONA) survey. The survey takes advantage of the integral field unit OSIRIS plus laser and natural guide star adaptive optics on the Keck Observatory to probe down to scales of 5-30 parsecs in a sample of 40 local Seyfert galaxies. With these K-band data we measure the two-dimensional distribution and kinematics of the nuclear stars, molecular gas, and ionized gas within the central few hundred parsecs. Results verify those from previous smaller samples in which Seyferts are found to have both geometrically and optically thick nuclear disk of molecular gas, as traced by the 1-0 S(1) H $_2$  2.12  $\mu\text{m}$  emission. A comparison of the flux distribution of the nuclear gas disks in Seyfert 1s versus 2s was completed. Seyfert 1s have, on average, a half-width-half-maximum value of  $29 \pm 16$  pc, while Seyfert 2s have, on average, a half-width-half-maximum value of  $41 \pm 25$  pc. A comparison of the characteristics of the nuclear kinematics in Seyfert 1s and Seyfert 2s will also be presented.

**Author(s):** Kiana Kade<sup>1</sup>, Erin K. Hicks<sup>1</sup>  
**Institution(s):** 1. University of Alaska Anchorage

### **243.03 – The Effect of Special Reduction Procedures of IFU Observations from Gemini-NIFS on Dynamical Measurements of Nearby AGN**

We present a preliminary analysis of the inflows and outflows in the narrow-line regions of nearby ( $z < 0.1$ ) AGN using observations from the Gemini-North telescope's Near-Infrared Integral Field Spectrograph (NIFS). In addition to the standard reduction procedure for NIFS data cubes, these observations were treated for multiple sources of noise and artifacts from the adaptive optics observations and the NIFS instrument. This procedure included the following steps: correction of the differential atmospheric refraction, spatial resampling, low-pass Butterworth spatial filtering, removal of the "instrumental fingerprint", and the Richardson-Lucy deconvolution. We compare measurements from NIFS data cubes with and without the additional correction procedures to determine the effect of this data treatment on our scientific results.

**Author(s):** Crystal L Pope<sup>1</sup>, D. Michael Crenshaw<sup>1</sup>, Travis C. Fischer<sup>2</sup>  
**Institution(s):** 1. Georgia State University, 2. Goddard Space Flight Center

### **243.04 – Feeding and Feedback in Nearby AGN based on IFU Observations**

We present evidence for feeding and feedback in the circumnuclear regions of nearby AGN based on observations with the Near-Infrared Field Spectrograph (NIFS) on the Gemini North 8-meter telescope. Mrk 509 shows evidence for infalling gas along a check-mark feature that is likely due to the disruption of a merging gas-rich dwarf galaxy. Mrk 3 shows outflows of ionized gas in the [S II] emission line along a backwards S shaped narrow-line region (NLR) that may result from the ionization of a previous fueling flow. Kinematics of the warm molecular gas indicate outflows as well as other components that are outside of the ionizing bicone. Mrk 573 shows evidence for in situ acceleration of ionized gas from arcs of emission-line gas in its NLR, as well as complicated molecular gas kinematics. We compare the NIFS observations with those from the Hubble Space Telescope and ground-based long slit spectra of the host galaxies from the Apache-Point Observatory 3.5-meter telescope to investigate the geometries of feeding and feedback in nearby AGN.

**Author(s):** D. Michael Crenshaw<sup>1</sup>, Travis C. Fischer<sup>2</sup>, Steven B. Kraemer<sup>4</sup>, Henrique R. Schmitt<sup>3</sup>, Crystal L Pope<sup>1</sup>, Camilo Machuca<sup>1</sup>, Mitchell Revalski<sup>1</sup>  
**Institution(s):** 1. Georgia State Univ., 2. NASA's Goddard Space Flight Center, 3. Naval Research Laboratory, 4. The Catholic University of America

### **243.05 – Modeling Host Disk Kinematics of Nearby Active Galactic Nuclei**

Previous work by our group has shown that, although the kinematics of many active galactic nuclei (AGN) can be modeled by biconal outflow, most AGN have kinematics that are too convolved with other forms of motion to be modeled so simply, such as the rotation of the host disk. To disentangle these rotational components from the outflowing ionized gas due to AGN "feedback" in the narrow-line region (NLR) and understand the AGN's relationship with the host galaxy at extended distances, we present this study on two Seyfert 2 galaxies, Markarian 3 and Markarian 573, based on two-dimensional long-slit spectra taken with the ARC 3.5m telescope at Apache-Point Observatory. The two targets were observed multiple times at varying position angles (in order to trace the kinematics of the host disk at multiple points) and their total kinematics were analyzed and modeled using DiskFit, a publicly available code that fits given velocity fields. We compare the results of DiskFit to observed velocities and consider the applications of this technique to the kinematic fitting of other nearby AGN with convolved motions.

**Author(s):** Camilo Machuca<sup>1</sup>, D. Michael Crenshaw<sup>1</sup>, Travis C. Fischer<sup>2</sup>  
**Institution(s):** 1. Georgia State University, 2. NASA's Goddard Space Flight Center

### **243.06 – Mass Outflow in the Narrow Line Region of Markarian 573**

We present our progress toward determining the mass outflow rate in the narrow emission line region (NLR) of the Seyfert 2 galaxy Markarian 573. Mass outflows in Active Galactic Nuclei (AGN) drive gas away from the central supermassive black hole (SMBH) into the circumnuclear environment, and may play an important role in regulating the growth of the SMBH, and its coevolution with the host galaxy bulge. Recent work by Crenshaw et al. (2015, ApJ, 799, 83) found that the mass outflow rate in the NLR of NGC 4151 is too large for the outflowing mass to have originated only from the central region, indicating a significant amount of gas is picked up by the outflow as it travels away from the nucleus. Using archival spectra taken with the Hubble Space Telescope (HST) Space Telescope Imaging Spectrograph (STIS), we are working to determine the mass outflow rates in a sample of 10 Seyfert galaxies to determine if correlations exist between their outflows and other properties including galaxy luminosity. To accomplish this, we will analyze the emission line spectra using photoionization models to determine the mass of the outflowing gas. Combining this information with previous kinematic modeling from Fischer et al. (2013, ApJS, 209, 1), we can determine the mass outflow rates and kinetic luminosities as a function of radius from the nucleus. These quantities will provide a direct comparison between observation and theoretical feedback models, allowing us to determine the significance of these outflows in regulating AGN feedback.

**Author(s):** Mitchell Revalski<sup>1</sup>, D. Michael Crenshaw<sup>1</sup>, Travis C. Fischer<sup>2</sup>, Steven B. Kraemer<sup>4</sup>, Henrique R. Schmitt<sup>3</sup>  
**Institution(s):** 1. Georgia State University, 2. NASA Goddard Space Flight Center, 3. Naval Research Laboratory, 4. The Catholic University of America

### **243.07 – Kinematic and Physical Constraints on the Outflows in NGC 3516**

We analyse the 2011 COS spectrum of the Seyfert 1 galaxy NGC 3516, which has a significant increase in signal-to-noise over the STIS 2000 spectrum. The COS spectrum shows clear changes in one of the intrinsic absorption troughs (component 5) and the presence of a new absorption trough. We interpret the change as bulk motion across the line-of-sight with transverse velocities greater than 870 km s<sup>-1</sup>. Also, due to the improved signal, we identify a previously undetected trough due to an excited state of Si II for component 1. In combination with the resonance trough of Si II and photoionization modelling, we directly determine the distance of the outflow to be 27 pc.

**Author(s):** Jay P. Dunn<sup>2</sup>, Rozhin Parvaresh<sup>2</sup>, D. Michael Crenshaw<sup>3</sup>, Steven B. Kraemer<sup>4</sup>, Jack Gabel<sup>1</sup>  
**Institution(s):** 1. Creighton University, 2. Georgia Perimeter College, 3. Georgia State University, 4. The Catholic University of America

### **243.08 – Do Radio Jets Contribute to Driving Ionized Gas Outflows in Moderate Luminosity Type 2 AGN?**

This poster examines the role of AGN-driven feedback in low to intermediate power radio galaxies. We begin with [OIII] measurements of ionized gas outflows in 29 moderate AGN-luminosity  $z \sim 0.3$ -0.7 dust-obscured Type 2 AGN. We aim to examine the relative role of the AGN itself, of star-formation and of nascent radio jets in driving these outflows. The strength of the AGN and star formation are based on the [OIII] luminosities, and the far-IR luminosities respectively. For the radio jets, we present multi-frequency radio (X, S, and L-bands) JVA imaging of our sample, which allows us both to constrain the overall radio power, but also look for signatures of young radio sources, including Giga-hertz Peaked Spectrum (GPS) sources, as well as small-scale jets. While radio jet-driven outflows are well known for powerful radio-loud galaxies, this study allows us to constrain the degree to which this

mechanism is significant at more modest radio luminosities of  $L_{5\text{GHz}} \sim 10^{22-25} \text{ W/Hz}$ .

**Author(s):** Julia Fowler<sup>2</sup>, Anna Sajina<sup>2</sup>, Mark Lacy<sup>1</sup>  
**Institution(s):** 1. NRAO, 2. Tufts University

### 243.09 – New Chandra Observations of NGC 4151: Modelling the X-Ray Absorption

We present the results of the a new spectral analysis of the Seyfert 1.5 galaxy NGC 4151, using data obtained from the simultaneous UV/X-Ray observations with Hubble STIS Echelle and Chandra HETG in 2014. Past observations of NGC 4151 show high variability in the continuum flux, and our data found the galaxy in a very low flux state, in both X-Ray and UV. We propose an X-Ray model consistent of an intrinsic broken powerlaw continuum, attenuated by absorber components with a range of ionization and column densities. Preliminary analysis of the UV data rules out the possibility of a larger column density, as proposed by Kraemer et. al (2005) for a similar low flux state dataset from 2000. Instead, we suggest the presence of an additional, highly ionized absorber. In our model, the three main components of absorption span a range of radial distances, with the nearer ones filtering the ionizing radiation incident on the further ones. The changes in absorption appear to be principally due to the changes in ionization state/opacity of the individual components.

**Author(s):** Jullianna Denes Couto<sup>2</sup>, Steven Kraemer<sup>2</sup>, T. Jane Turner<sup>3</sup>, D. Michael Crenshaw<sup>1</sup>  
**Institution(s):** 1. Georgia State University, 2. The Catholic University of America, 3. University of Maryland Baltimore County

### 243.10 – Intrinsic Absorption in Quasars (AAL & BAL) and its Relation to Outflows, BH Mass, Accretion Rate, Spin, Orientation, and Radio Properties

Despite the fact that quasars are fueled by matter falling into supermassive black holes, this process spews out considerable mass and energy. We investigate the nature of these outflows in the form of both broad and narrow absorption lines using data taken as part of the Sloan Digital Sky Survey (SDSS). Although these outflows are seen to have ejection speeds of up to 60,000 km/s, it is still unclear how they affect the quasar's host-galaxy and its evolution. We look for correlations of these outflows with the radio properties of the quasars, which can potentially reveal a physical connection between the quasar's accretion physics and its outflows. We also investigate how relaxing the traditional criteria for defining both radio loud and broad absorption line quasars impacts our understanding of these classes and quasars in general. Our ultimate goal is to understand how outflows from quasars change as a function of line-of-sight orientation, mass, accretion, and spin of the black holes that fuel them.

**Author(s):** Robert Bernard Stone<sup>1</sup>, Gordon T. Richards<sup>1</sup>  
**Institution(s):** 1. Drexel University

### 243.11 – Constraining the Accretion Mode in LINER 1.9s

The accretion mode and the dominant power source in low-ionization nuclear emission-line regions (LINERs), a class of active galactic nuclei (AGN), are still elusive. We focus on a sample of 22 LINER 1.9s (Ho et al. 1997), a subclass of LINERs that show broad H $\alpha$  lines, a signature of blackhole-powered accretion, to test the hypothesis that the ionizing continuum emitted by a radiatively inefficient accretion flow (RIAF) could lead to the LINER ultraviolet (UV) emission-line ratios. Optical line-ratio diagrams are a weak diagnostic tool in distinguishing between possible power sources (Sabra et al. 2003). We search the Mikulski Archive for Space Telescopes (MAST) for UV spectra of the objects in the above sample and also perform photoionization simulations using CLOUDY (Ferland et al. 2013). Unfortunately, only one object (NGC 1052; Gabel et al. 2000) of the 22 LINER 1.9s has UV spectra that cover many emission lines; the rest of the objects either do not have any UV spectra, the spectral coverage is inadequate, or the spectra have very low signal-to-noise ratios. Our photoionization simulations set

up two identical grids of clouds with a range of densities and ionization parameters. We illuminate one grid with radiation emitted by a thin accretion disk (AD) and we illuminate the other grid with radiation from a RIAF. We overplot the UV emission-line ratio predictions for AD and RIAF illumination, together with the available line ratios for NGC 1052. Initial results show that UV lines could be used as diagnostics for the accretion mode in AGN. More UV spectral coverage of LINER 1.9s is needed in order to more fully utilize the diagnostic powers of UV emission line ratios.

**Author(s):** Bassem Sabra<sup>2</sup>, Elias Der Sahaguian<sup>2</sup>, Elie Badr<sup>1</sup>  
**Institution(s):** 1. IMEC, 2. Notre Dame University-Louaize

### 243.12 – The Properties of Low-Luminosity AGN: Variability, Accretion Rate, Black Hole Mass and Color

We present the results from a study of ~5000 Broad-Line selected AGN from the Sloan Digital Sky Survey DR7. Galaxy and AGN templates have been fit to the SDSS spectra to isolate the AGN component. The sources have absolute magnitudes in the range  $-23 < M_i < -18$  and lie at redshifts less than  $z \sim 0.8$ . A variability analysis reveals that the anti-correlation between luminosity and variability amplitude continues to the faintest AGN in our sample (Gallastegui-Aizpun & Sarajedini 2014), though the underlying cause of the relation is still poorly understood. To address this, we further explore the connection between AGN luminosity and variability through measurement of the H $\beta$  line width to determine black hole mass and accretion rate. We find that AGN with the highest variability amplitudes at a given luminosity appear to have lower accretion rates compared to low amplitude variables. We also investigate correlations with AGN color and accretion rate among these low-luminosity AGN.

**Author(s):** Juan Oleas<sup>1</sup>, Stephanie Podjed<sup>1</sup>, Vicki Sarajedini<sup>1</sup>  
**Institution(s):** 1. University Of Florida

### 243.13 – Simulations of Accretion Disk Wind Models

The kinematics of the broad emission line region (BELR) in quasars is largely unknown, however there is strong evidence that outflows may be a key component. For example, in approximately 15% of quasars we observe broad, blue-shifted absorption features which may be ubiquitous based on line-of-sight arguments. We use a new mathematical description of an outflowing disk-wind with an initial rotational component to predict surface brightness distributions of this wind at different orientations. These surface brightness distributions will allow us to simulate gravitational microlensing of BELR light, with a view to mapping the structure and better understanding the kinematics of these flows.

**Author(s):** Craig L Brooks<sup>1</sup>, Suk Yee Yong<sup>4</sup>, Matthew O'Dowd<sup>2</sup>, Rachel L. Webster<sup>4</sup>, Nicholas Bate<sup>3</sup>  
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### 243.14 – Recovering the radial temperature structure of accretion disks around thermal active galactic nuclei

We demonstrate how the mean radial temperature structure of an accretion disk of an active galactic nucleus (AGN) can be recovered from the observed spectral energy distribution of AGNs after correction for reddening and contaminating host galaxy starlight. Contrary to the predictions of classical accretion disk models (Lynden-Bell 1969), the temperature of the part of the disk dominating the ultraviolet emission of AGNs falls off with a shallower temperature gradient than the predicted  $-3/4$  power of the radius. The derived temperature gradient becomes progressively flatter in the inner disk. We discuss the implications for AGN physics of the temperature structure we derive.

**Author(s):** Sathvik Nair<sup>1</sup>, C. Gaskell<sup>3</sup>, Jerry Hong<sup>2</sup>  
**Institution(s):** 1. Leland High School, 2. Palo Alto High School, 3. Univ. Calif. Santa Cruz

### 243.15 – The Effect of Realistic Radial Temperature

## Gradients on Predicted Accretion Disk Sizes of Active Galactic Nuclei: Improving Agreement with Estimated Disk Sizes.

Multi-wavelength reverberation mapping (Sergeev et al. 2005) indicated that accretion disks in active galactic nuclei (AGNs) are several times larger than predicted by standard accretion disk theory (Lynden-Bell 1969). Gravitational microlensing studies of high-redshift AGNs have found a similar size discrepancy (Pooley et al. 2006, 2007). We find that real AGN accretion disks have a flatter radial temperature gradient than predicted by standard accretion disk theory. We investigate quantitatively how this flatter temperature gradient increases the predicted sizes of emitting regions as a function of wavelength. We find that, while our flatter temperature gradient improves the fit to multi-wavelength reverberation mapping observations and reduces the disk-size-discrepancy problem, it does not eliminate it. This supports the proposal of Gaskell (2015) that much of the size discrepancy problem is due to underestimating AGN luminosities by neglecting the substantial internal extinction of AGNs.

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## 243.16 – Cadence Requirements for AGN Accretion Studies with LSST

We test various samplings of mock AGN lightcurves to determine minimum cadence requirements for future technologies like the Large Synoptic Survey Telescope (LSST). AGN lightcurves exhibit stochastic behavior, with variability seen in ground-based optical surveys on timescales from days to years. Significant variability structure on timescales up to a few days was revealed by the high time resolution (~30 minutes) of Kepler Satellite. Now it is apparent that under-sampling by ground based instruments may be leaving out a big chunk of the AGN accretion picture. To probe Kepler AGN, recent studies have investigated the suitability of sophisticated models like CARMA processes to better understand dominant mechanisms driving observed variability across these timescales. By testing models against AGN photometry, we gain insights about accretion physics, intrinsic differences between AGN sub-types, and physical scales pertaining to orbits or casually connected matter flows. We investigate cadence, time window, and regularity requirements that accurately recover parameters of our model lightcurves constructed with a CARMA process and observations such that ground based telescopes can optimally collect data for AGN science.

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## 243.17 – Can emission line profiles from perturbed accretion disks mimic those from the broad line region of a black hole in a supermassive binary?

Both observations and simulations from the last decade suggest a link between the evolution of galaxies and their central supermassive black holes. An important ingredient in these evolutionary models is galactic interaction and mergers. Consequently, we expect to see dual active galactic nuclei at the early stages of an interaction and close, bound binary black holes after the parent galaxies have merged. While binary active galactic nuclei have been detected at large separations, it has proven difficult to detect close, bound binaries. Our team has been carrying out an observing campaign to find binary black holes with sub-parsec separations. Thus, we have been studying a sample of 88 quasars from the Sloan Digital Sky Survey whose broad H $\beta$  lines are offset from their nominal wavelength by a few thousand km/s. These offsets suggest orbital motion of one of the black holes and the gas that is bound to it. In this work, we play devil's advocate by exploring an alternative interpretation of the broad emission lines. We ask whether lines formed in a perturbed, non-axisymmetric disks can have profiles similar to those observed. Two categories of non-axisymmetric disks are explored - one with a prominent spiral arm and one that is elliptical. To make the model as general as possible, the radial emissivity of the disk was allowed to

have a broken power-law profile. For certain combinations of model parameters, these models can match the observed profile shapes. A subset of these model parameters can mimic the sinusoidal procession of the peak velocity we would expect to see in a binary system on an observable time scale. However, the predominate, observed statistical trend between the Pearson Skewness and the peak position is not reproduced; instead, other trends are predicted by the models that we do not observe.

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## 243.18 – Implications of Profile Variability in Searches for Supermassive Black Hole Binaries

Modern galaxy evolution scenarios suggest that supermassive black hole binaries (SBHBs) are an inevitable result of merging galaxies that host black holes in their centers. Though candidates of wide-separation dual active galactic nuclei have been detected, there is no reliable evidence for the expected close, bound binaries at separations of one parsec or less. We are searching for close SBHBs among  $z < 0.7$  SDSS quasars with offset broad emission lines. Specifically, we test the idea that, if one of the black holes is active, the orbital motion within the binary will cause its broad emission lines to exhibit periodic radial velocity shifts. Among the most significant caveats to this approach is that the variability of the broad H $\beta$  profile may mimic radial velocity changes. Cases where the flux increases in one side of the line profile and decreases in the other are of particular concern. In order to test the extent of this problem, we introduce simulated profile variability into the observed spectra of the binary candidates and then make radial velocity measurements on the H $\beta$  lines. We will present the results of this simulation to assess how often we will measure false radial velocity shifts as a result of changes in the shape of the broad H $\beta$  profile.

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## 243.19 – Searching for the Nearest Extragalactic Binary Black Hole: A Spectroscopic Study of NGC 4736

In 1995 and 1996, Maoz et al. concluded that the nearby galaxy NGC 4736 ( $d=16$  million light years) is in the late stages of a merger event. After further investigation, in 2005, Maoz et al. observed UV variability in the nuclear region of NGC 4736, revealing a second unknown source in the nucleus. Since late stage mergers are an ideal location to search for binary black holes (BBH), members of our team hypothesized that the second source could be a second black hole, making this a potential BBH system. This is important since observational evidence for their existence remains sparse, even though BBH are predicted by many theories and potentially play an important role in galaxy evolution. In January of 2008, NGC 4736 was observed with the GMOS-N instrument on Gemini North. Optical longslit spectra of the nuclear region were obtained with spatial resolution of  $0.1454''/\text{pixel}$  and a spectral resolution of  $R \sim 1700$ . At this resolution, the two nuclear sources are spatially resolved at a projected separation of  $2.5''$ . As a result, we can classify the nature of the second source by looking at the optical line ratios following Ho et al. (1997). High signal-to-noise spectra of the unknown source displayed strong emission of [SII] and [NII], but an extremely weak [OIII] emission line. The unknown source has a calculated [NII]/[H $\alpha$ ] ratio of 1.37 and an upper limit of 0.6 for the [OIII]/[H $\beta$ ] ratio. Placing the unknown source on the BPT-NII diagram (Baldwin et al., 1981), we tentatively conclude that it is a low-luminosity second black hole potentially making NGC 4736 the nearest BBH system. The result will enable future high-spectral and spatial resolution observations of a low-luminosity system in extremely late stages of merging, which will be a significant step forward in validating models of galaxy mergers and AGN activity.

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### 243.20 – Constraining the orbits and masses of a supermassive binary black hole system

As galaxy mergers are common, and most galaxies have black holes at their center, we expect that the number of merging black holes should be high. However, only a few such systems have been observed. This could happen if black holes in a binary system merge too quickly to be able to see them, or if one of the black holes escapes. We do know about one system where the two black holes are in the process of merging. The radio galaxy 0402+379 was discovered by Maness et al. (2004), to have two core components with flat spectra. With a projected separation of 7.3 pc, this system is the most compact supermassive binary black hole, which makes it one of the best candidates to study. Understanding the motion of the merging black holes, and the dynamics of this system are important to understanding the evolution and formation of galaxies. It is also expected that as the separation between the black holes decreases, emission of gravitational waves will grow stronger, which makes supermassive binary black holes (SBBHs) one of the most promising sources for gravitational radiation detection.

We present the latest results from 2015 in a campaign of multi-frequency observations at 8, 15 and 22 GHz, using the Very Long Baseline Array (VLBA), combined with the previous observations from 2003, 2005 and 2009. These observations, along with the previous studies over a time span of 22 years, enable us to study the evolution of the separation between the core components. We also use these observations to constrain the motion, orbit, and the mass of the compact sources.

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### 243.21 – The Binary Black Hole Model for Mrk 231 Can Not Explain the Observed Emission Lines

Quasars are known for their strong, broad emission lines and their broad-band continua peaking in the extreme UV. While there are observable and interesting differences from object to object, the emission-line equivalent widths and ratios are, overall, quite uniform over a broad range of luminosity. This result is consistent with photoionization of the broad-line region by continuum emission from an accretion disk, where the luminosity and number of photoionizing photons generally scale with the black hole mass and accretion rate.

Mrk 231 is a nearby quasar with an unusually red continuum, generally explained by heavy reddening from dust (e.g., Veilleux et al. 2013, Leighly et al. 2014). Yan et al. 2015 recently proposed that Mrk 231 is a black-hole binary system with very little intrinsic reddening, in which the large black hole experiences advection dominated accretion, emitting little continuum, while the accretion disk of the small black hole emits as an ordinary quasar, dominating the observed weak UV continuum and the photoionizing flux.

Using Cloudy photo-ionization modeling, recombination broad lines in the relatively unreddened near-IR, and CIV and CIII] lines in the reddened UV, we show that the observed line emission is not consistent with the binary black hole hypothesis. The observed near-IR recombination line flux is too strong to be produced by the weak continuum of the putative small black hole. Moreover, the lack of intrinsic reddening in the binary model implies a small intrinsic CIV/IR line ratio from the observed lines, which would in turn require a very low ionization parameter that would under-predict the observed near-IR recombination line flux.

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### 243.22 – Searching for Super Massive Binary Black

### Holes in the VLBA Calibrator Survey

Due to its incredible resolving power, the Very Long Baseline Array (VLBA) allows astronomers to view radio emission from celestial objects in incredible detail. This makes the VLBA the best instrument for studying the dynamics of active galactic nuclei, or compact regions at the centers of galaxies where black holes are thought to reside. Since most galaxies harbor supermassive black holes at their centers, and some galaxies merge with others, supermassive binary black hole systems arise. Though a number of these systems have been found, only one system contains black holes within 10 pc apart. During the summer, we analyzed new observations from the VLBA Calibrator Survey (VCS) on approximately 2200 sources in the hopes of detecting more close supermassive binary black hole candidates. Here we present the results from reducing and categorizing these sources. We also discuss the importance of the VCS and its role in enabling observations of the most distant celestial objects.

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### 243.23 – Uncovering Binary Supermassive Black Holes in Merging Galaxy Pairs

It is now well known that virtually all galaxies host a central supermassive black hole (SMBH) and that galaxy interactions are ubiquitous. Theory predicts these interactions would funnel gas toward the central regions of galaxies, potentially triggering gas accretion onto the SMBH, causing them to appear as binary active galactic nuclei (AGN). However, despite decades of searching and strong theoretical reasons that they should exist, observationally confirmed cases of binary AGNs are extremely rare, and most have been discovered serendipitously. Since galaxy mergers are likely to be characterized by dusty environments, it is possible that the optical signatures of a significant number of binary AGNs are obscured. Observations from the *Wide-field Infrared Survey Explorer (WISE)* may hold the key for increasing the rate of discovery of binary AGN in late-stage mergers. Starting with a sample of ~4,000 galaxy pairs, we searched for mid-IR signatures of binary AGNs. In this poster, we report on the detection frequency of binary AGNs identified through mid-infrared observations and explore its dependence on merger stage.

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### 243.24 – Testing Mergers as a Trigger for Quasars: Host Galaxy Morphologies

What makes a galaxy become active? It is often thought that galaxy mergers trigger the most luminous active galaxies (AGN)—quasars—but lower-luminosity AGN are started by milder processes. In our prior work, we analyzed a range of lower-luminosity AGN at redshifts of  $0.5 < z < 0.7$  and found no trend of rising merger incidence with luminosity.

To reach the high luminosities thought to require mergers, we have now imaged 20 quasars to expand the range of the sample, using the Hubble's Wide Field Camera 3 in the H-band. We have used the Starfit software to remove the nuclear point sources and show the host galaxies beneath, allowing a comparison of galaxy properties. We now reveal the host morphologies and quantify their disturbances.

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### 243.25 – Combining Chandra Observations and Near-Infrared Imaging to Search for Dual AGNs Among Double-Peaked [O III] SDSS AGN

When galaxies merge, gas accretes onto both central supermassive black holes. Thus, one expects to see close pairs of active galactic nuclei (AGNs), or dual AGNs, in a fraction of galaxy mergers. However, finding them remains a challenge. We studied a sample of

double-peaked SDSS [O III] AGNs using Keck 2 Laser Guide Star Adaptive Optics assisted imaging to find that 30% of double-peaked SDSS AGNs have two spatial components within a 3" radius. However, the identity of the companion object is not revealed with imaging; X-ray observations can confirm these galaxy pairs as systems containing two AGNs. We performed Chandra X-ray ACIS-S observations on 12 double-peaked candidate dual AGNs with a possible near-infrared companion 1-3" away. Using our observations and 8 archival observations of additional candidate dual AGNs, we compare the distribution of X-ray photons to our spatially double near-IR images, measure X-ray luminosities and hardness ratios, and estimate column densities. Additionally, we can compare our near-IR spatially double candidates with 7 double-peaked [O III] SDSS AGNs that are spatially single in our near-IR imaging and have archival Chandra ACIS-S observations. By assessing what fraction of double-peaked emission line SDSS AGNs are true dual AGNs, we can better determine whether double-peaked [O III] is an efficient dual AGN indicator and constrain the statistics of dual AGNs

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### 243.26 – SSC Model Fits to Simultaneous Fermi and CAO observations of BL Lac's

The Challis Astronomical Observatory (CAO) has been surveying a sample of blazar-type AGN since 2010. The CAO blazar sample includes 3 sources - comprising 30 FSRQs, 15 BL Lacs, one radio galaxy and four unclassified sources - covering a redshift range  $0.02 < z < 2$ . Observations are carried out in BVRI filters. Here we describe photometric results on a small sample emphasizing BL Lacs. We combine the CAO data with Fermi/LAT data and explore the suitability of fits to the data using the uniform conical jet model of Potter and Cotter (MNRAS, 2012, 423, 756-765).

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### 243.27 – Unveiling Unidentified Fermi Sources

The Fermi  $\gamma$ -ray Space Telescope (Fermi) has surveyed the entire sky at the highest-energy band of the electromagnetic spectrum. The majority of Fermi sources have counterpart identifications from multi-wavelength large-area surveys, particularly in the radio and x-ray bands. However, around 35% of Fermi sources remain unidentified, a problem exasperated by the low resolution of the telescope. Understanding the nature of unidentified Fermi sources is one of the most pressing problems in  $\gamma$ -ray astronomy. The South Pole Telescope (SPT) has completed a survey covering a 2500 square degrees of the southern extragalactic sky with arcminute resolution at millimeter wavelengths. The mm wavelength is the most efficient means to identify blazars and unidentified Fermi sources. Our analysis shows that the SPT point source catalog provides candidate associations for 40% of the unidentified Fermi sources, showing them to be flat-spectrum radio quasars which are extraordinarily bright at millimeter (mm) wavelengths.

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**Contributing team(s):** The South Pole Telescope

### 243.28 – Spectral Evolution in High Redshift Quasars from the Final BOSS Sample

We report on a study of the spectral variations in a sample of 102,150 quasars from the Baryon Oscillation Spectroscopic Survey (BOSS) of the Sloan Digital Sky Survey (SDSS-III). After mitigating selection effects and Malmquist bias over the redshift range  $2.1 \leq z \leq 3.5$ , we create high signal-to-noise composite spectra binned by luminosity, spectral index, and redshift. We use these composite spectra to inspect the variations in quasar properties as a function of each of these three parameters. We confirm the traditional Baldwin effect (i.e. the anti-correlation of CIV equivalent width and luminosity) and

identify physical trends associated with spectral index and redshift. In this poster, we will present these results with a particular focus on the clear spectroscopic signature that we find in redshift evolution.

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### 243.29 – Luminous, High-z, Type-2 Quasars are Still Missing

We argue that the expected population of luminous, high-z, type-2 quasars are still missing and we consider a method of uncovering this elusive population through a combination of WISE, Spitzer, and SDSS data. While large numbers of type-2 (obscured) AGNs have now been identified (both via spectroscopy and through color-based arguments in the optical, IR, and X-ray), the vast majority of these are low-luminosity objects at  $z < 1$ , whereas only handfuls of bonafide type-2 quasars are confirmed at redshifts  $z \sim 2$  with bolometric luminosities that are comparable to the typical luminosity of SDSS type-1 quasars. Although some analyses find the density of high-z, type-2 candidates to be three times that of the type-1 population (at similar bolometric luminosity), our revisiting of the problem through an archival spectroscopic search reveals that the confirmed high-z, type-2 population ( $\sim 0.2/\text{sq deg}$ ) is only  $\sim 1/3$  of the high-z, type-1 quasar population ( $\sim 0.7/\text{sq. deg}$ ) to a depth of WISE W4 < 8. As most interpretations of the "unified model" predict similar numbers type-1 and type-2 quasars, this conspicuous lack of luminous type-2 quasars at high-redshift constitutes a major unsolved problem. We explore a candidate selection algorithm that utilizes the sky area of AllWISE, the depth/resolution of large-area Spitzer-IRAC surveys, and optical data from the SDSS in order to uncover these missing type-2 quasars.

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### 243.30 – Extended X-ray and Radio Structures around high-redshift ( $z \sim 0.5-2$ ) 3CRR sources

X-rays probe the emission mechanisms, energetics, and feedback of powerful radio jets. Chandra observations of the 3CRR radio sources reveal extended emission in 31 objects. Chandra X-ray images were aligned with the radio contours to locate X-ray emission associated with the various radio structures as well as X-ray emission unassociated with the radio contours that may be detected due to hot gas emitting X-ray radiation in a cluster of galaxies containing the quasar. The radio-associated X-ray data are analysed by fitting the spectra and calculating the median flux for the emission within each radio knot or hotspot. The radio and X-ray fluxes for each radio structure (knot, hotspot, lobe) are then fit with synchrotron and Inverse Compton scattering models to estimate the physical conditions and energetics of the emitting plasma.

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### 243.31 – On Building a 3D Model of the M87 Jet

Optical and radio images of the M87 jet show a huge variety of parsec-scale bends and helical distortion from HST-1 to knot C. The sinusoidal pattern in the outer jet is observed in both bands, suggesting a possible double helical structure. We developed a mathematical model that converts the observed 2D projection of the jet to a 3D configuration by using three inputs: the viewing angle (estimated from 20 years of HST monitoring of the jet), distances and relative angles between bends measured from the HST optical and VLA/VLBA radio images of the M87 jet. Our model is written in Python, combining nonlinear optimization methods and computer graphics to describe and demonstrate the jet geometry. We are extensively testing the scripts to compare stability of the model, optimization techniques, and model with the data of galactic jets,

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### 243.32 – The Spectacular Radio-Near-IR-X-Ray Jet of 3C 111

Relativistic jets from active galactic nuclei (AGN) are powerful phenomena that transport prodigious amounts of energy and mass from the core of a galaxy out to kiloparsec or even megaparsec distances. While most spatially-resolved jets are seen in the radio, an increasing number have been discovered to emit in the optical/near-IR and/or X-ray bands. Here we discuss a spectacular example of this class, the 3C 111 jet, housed in one of the nearest, double-lobed FR II radio galaxies known. The jet itself extends over 100 kpc on each side, making it one of the longest to be seen in the radio, near-IR/optical and X-ray bands; its length and straight nature makes it ideal for studying jet physics over many kiloparsecs. We discuss new, deep Chandra and HST observations that reveal both near-IR and X-ray emission from several components of the 3C 111 jet, as well as both the approaching and receding hotspots. We also discuss new VLA observations of the jet. The near-IR and X-ray emission in the jet is restricted to several knots, and there are important differences between the morphologies seen in the radio, near-IR bands, and X-ray bands. We analyze the broad-band spectral energy distributions of the jet components. We compare competing models of emission as they relate to frequency-dependent relativistic beaming. Synchrotron emission seems to fit adequately the observed emissions of all knots and hotspots.

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### 243.33 – Supersonic inflation of the radio lobes of NGC 1052: evidence for non-thermal particle acceleration

We analyze archival Chandra data of the nearby AGN NGC 1052 to determine the nature of the interaction of the radio lobes with the ambient hot gas. NGC 1052 is typically classified as a Seyfert galaxy, but has a radio bright core and extended diffuse radio lobes on kpc scales. We report the detection of X-ray bright shells around the radio lobes, suggestive of compression of the ISM by the supersonic inflation of the lobes. We determine the temperature and density of the gas in these shells and of the ambient ISM. We find that the temperature of the ISM is 0.8 keV, and that of the shells around the E and W radio lobes are 0.72 and 0.69 keV, respectively fitting a single temperature APEC model. The statistical quality of the fits is low, so systematic uncertainties dominate our ability to distinguish temperature variations between regions. NGC 1052's outburst is relatively young ( $9 \times 10^{13}$  sec) and comparatively low power ( $1.9 \times 10^{41}$  erg/sec). Interestingly, the density jump between the shells and the ambient ISM is larger than the maximum compression allows by the Rankine-Hugoniot conditions, suggesting that the emission from the shells is not thermal. We propose that the bubbles are highly supersonic (Mach number  $>5$ ) and that the emission of the shell is due to synchrotron radiation from a population of ultrarelativistic electrons created by the powerful shock. If this interpretation is correct, NGC 1052 would be only the second AGN in which this process has been observed. This work was supported in part by the NSF REU and DoD ASSURE programs under NSF grant no. 1262851 and by the Smithsonian Institution.

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### 243.34 – Population Studies of Quasars in Infrared and X-Ray Light

We present newly assembled multiwavelength datasets for studying the luminosity evolution, density evolution, and luminosity functions of quasars in infrared and X-ray light, as well as preliminary results for these parameters in infrared. We use infrared and X-ray data from NASA's Wide-Field Infrared Survey Explorer Chandra X-ray satellites respectively, in combination with optically identified quasars from the Sloan Digital Sky Survey. We present results for the infrared population parameters, including luminosity evolution which suggests that quasars have evolved more slowly in infrared than in other bands. We also demonstrate new techniques for recovering the intrinsic luminosity-luminosity correlations in datasets with different wavebands in the presence of artificial correlations introduced by survey limits and similar redshift evolutions.

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### 243.35 – Solving the puzzle of discrepant quasar variability on monthly time scales implied by SDSS and CRTS datasets

SDSS imaging survey has provided a time-resolved photometric dataset which greatly improved our understanding of the quasar optical continuum variability: data for monthly and longer time scales are consistent with a damped random walk. Recently, newer data obtained by CRTS (Catalina Real-Time Transient Survey) provided puzzling evidence for enhanced variability, compared to SDSS results, on monthly time scales. Quantitatively, SDSS results predict about 0.06 mag rms variability for timescales below 50 days, while CRTS data show about a factor of two larger rms for spectroscopically confirmed SDSS quasars. Our analysis presented here has successfully resolved this discrepancy as due to slightly underestimated photometric error estimates provided by the CRTS image processing pipelines. The photometric error correction factors, derived from detailed analysis of non-variable SDSS standard stars that were re-observed by CRTS, are about 20-30%, and result in a quasar variability behavior fully consistent with earlier SDSS results.

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### 243.36 – Initial Results from a COS Survey of PG Quasars

We investigate 27 low-redshift ( $z < 0.3$ ) quasars in the far ultraviolet with high signal-to-noise spectra from the Cosmic Origins Spectrograph on the *Hubble Space Telescope*. One quarter of these galaxies are found to have O VI (1032, 1038 Å) or N V (1239, 1243 Å) doublet absorption features, often with corresponding Ly  $\alpha$  and Ly  $\beta$  absorption. Some of these profiles are indicative of outflowing, highly-ionized gas. We find both narrow and broad, blended features. We will present the results from preliminary fits of the absorption profiles.

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**Institution(s):** 1. Rhodes College, 2. University of Maryland

### 243.37 – Bayesian and Profile Likelihood Approaches to Time Delay Estimation for Stochastic Time Series of Gravitationally Lensed Quasars

The gravitational field of a galaxy can act as a lens and deflect the light emitted by a more distant object such as a quasar. If the galaxy is a strong gravitational lens, it can produce multiple images of the same quasar in the sky. Since the light in each gravitationally lensed image traverses a different path length and gravitational potential from the quasar to the Earth, fluctuations in the source brightness are observed in the several images at different times. We infer the time delay between these fluctuations in the brightness time series data of each image, which can be used to constrain cosmological parameters. Our model is based on a state-space representation for

irregularly observed time series data generated from a latent continuous-time Ornstein-Uhlenbeck process. We account for microlensing variations via a polynomial regression in the model. Our Bayesian strategy adopts scientifically motivated hyper-prior distributions and a Metropolis-Hastings within Gibbs sampler. We improve the sampler by using an ancillarity-sufficiency interweaving strategy, and adaptive Markov chain Monte Carlo. We introduce a profile likelihood of the time delay as an approximation to the marginal posterior distribution of the time delay. The Bayesian and profile likelihood approaches complement each other, producing almost identical results; the Bayesian method is more principled but the profile likelihood is faster and simpler to implement. We demonstrate our estimation strategy using simulated data of doubly- and quadruply-lensed quasars from the Time Delay Challenge, and observed data of quasars Q0957+561 and J1029+2623.

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**Institution(s):** 1. *Harvard University*, 2. *Harvard-Smithsonian Center for Astrophysics*, 3. *Imperial College London*

### 243.38 – Jansky VLA Imaging of Heavily Obscured, Luminous Quasars at Redshifts $z \sim 2$

We present JVLA A and B array observations in X-band (8-12 GHz) of a sample of radio powerful, bolometrically luminous, but optically obscured quasars. The quasars were selected using a cross-match between WISE mid-IR sources brighter than 7 mJ at 22  $\mu$ m and NVSS and/or FIRST radio surveys, with a further constraint that the sources were optically faint. The survey aims to select young quasars with young radio sources at redshifts  $z \sim 1-3$ . Ultimately, we wish to study the role that radio jets play in quasar driven feedback. Our VLA observations provide fundamental information on radio source size, structure, power and spectral index, all of which shed light on the properties of the young radio source. We will present images and data on 155 objects from our primary sample WISE-NVSS sample of 156.

The majority of sources are found to be compact, steep-spectrum, and sub-galactic in scale, with a significant minority of resolved doubles, triples, and core-jets. Using radio data at other wavelengths taken from the literature, we use SED fits to identify or constrain the turn-over frequencies. Combining size and turn-over frequency, the majority of the sources are found to be CSS, GPS or HFPs, consistent with young radio source ages.

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### 243.39 – The Pan-STARRS1 $z > 6$ quasar survey: More than 100 quasars within the first Gyr of the universe

Quasars are the most luminous non-transient sources in the Universe. As such, they are ideal probes of the redshift range  $z=6-7$ , a critical phase in cosmic history, when the Universe is emerging from the dark ages. Over the last three years we have exploited the Pan-STARRS1 survey, more than doubling the number of known  $z > 5.5$  quasars (tripling the number of  $z > 6$  quasars in the southern sky, and discovering 4 of the 9 quasars known at  $z > 6.5$ ). This search significantly extended the sampled parameter space in terms of quasar luminosities and redshift coverage. Pioneering studies already demonstrate the instrumental role of QSOs in probing the very early phases of galaxy formation and black hole growth within 1 Gyr from the Big Bang: a) billion solar masses black holes are already in place, b) they are surrounded by massive reservoirs of cold gas, and c) the neutral fraction of the intergalactic medium rapidly drops after  $z \sim 6$ , thus marking the end of the epoch of reionization. Our significantly enlarged sample marks the transition phase from studies of individual sources to statistical studies of the high- $z$  quasar population. We present some of the comprehensive multiwavelength characterization of the high- $z$  quasar population and their environment (our on-going efforts include deep NIR spectroscopy, ALMA, NOEMA, HST, Spitzer, and JVLA observations).

**Author(s):** Fabian Walter<sup>2</sup>, Eduardo Banados<sup>1</sup>, Bram Venemans<sup>2</sup>, Roberto Decarli<sup>2</sup>, Emanuele Farina<sup>2</sup>, Chiara Mazzucchelli<sup>2</sup>, Xiaohui Fan<sup>3</sup>, Kenneth C. Chambers<sup>4</sup>  
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### 243.40 – Quasars in the Time Domain: Supermassive Black Hole Binaries and Extreme Objects

Quasar variability can offer insights into the physics of AGN, as it is driven by the variations in the accretion rate, changes in obscuration, and/or instabilities and propagation effects of the relativistic jets. Large synoptic sky surveys such as CRTS (crts.caltech.edu) offer new possibilities in this domain.

We use the data set of CRTS light curves of  $\sim 335,000$  known, spectroscopically confirmed quasars. They have up to a few hundred data points each, with baselines of up to 10 years. This is an unprecedented data set for the studies of quasar variability.

We have previously identified a characteristic time scale of stochastic quasar variability,  $\sim 54$  days (restframe), which anticorrelates with luminosity and black hole mass. While the origin of this phenomenon is not yet understood, it may lead to new insights into the physics of AGN accretion disks and quasars in general. While most quasars show such a characteristic time scale and trends, a subset exhibit a time scale that is significantly different than expected given their physical parameters. We have also found a number of other objects that show extreme variability (in RMS amplitude, or other measures). For a number of these objects we have now detected significant spectroscopic changes that correlate with the photometric variability. We will describe some of the more interesting cases.

An even more interesting is the recent detection of periodically variable quasars, which are interpreted as a signature of close (milliparsec scale) supermassive black hole binaries (SMBH) en route to a merger. This population may offer new insights into the assembly of SMBH and their physics in the gravitational wave regime. We have initiated a spectroscopic monitoring program of these objects, and have already detected some spectroscopic changes for some of them. We will describe these results and their possible interpretations.

**Author(s):** Matthew Graham<sup>1</sup>, Stanislav G. Djorgovski<sup>1</sup>, Daniel Stern<sup>2</sup>, Andrew J. Drake<sup>1</sup>, Ashish A. Mahabal<sup>1</sup>, Eilat Glikman<sup>3</sup>  
**Institution(s):** 1. *Caltech*, 2. *JPL/Caltech*, 3. *Middlebury College*

### 243.41 – Blazar Demographics Using Multiwavelength Data

Blazars are ideal laboratories to study relativistic jets in AGN, which are thought to be an important channel for feeding energy into galaxies and clusters. We present multi-wavelength SEDs of 2214 blazars with known redshifts, based on the Roma-BZCAT data across 12 frequency bands ranging from radio to gamma-ray. We confirm the anti-correlation between radio luminosity and synchrotron peak frequency, (part of what defines the "blazar sequence"), although with greater scatter than seen previously in studies of far fewer blazars. We describe an empirical estimator of luminosities in those 12 frequency bands using only the radio luminosity at 1.4 GHz and the redshift as inputs. Using this estimator, we study the demographics of blazars by comparing Monte-Carlo simulations to blazar surveys at several different frequencies and flux limits. We recover the observed evolutionary parameter for both low-frequency peaked ( $V/V_{\text{max}} \approx 0.6$ ) and high-frequency peaked ( $V/V_{\text{max}} \approx 0.4$ ) blazars, proving that selection effects cause the high-frequency-peaked sources to appear to anti-evolve even though the same underlying evolution was assumed in the simulation. We also show that if instead we randomly assign fluxes independent of radio luminosity, the simulated blazar samples disagree strongly with the observed ones. These simulations confirm that luminosity and SED shape must indeed be linked in a physical blazar sequence.

**Author(s):** Peiyuan Mao<sup>1</sup>, F. Massaro<sup>1</sup>, C. Megan Urry<sup>1</sup>  
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#### **243.42 – Using the H- $\beta$ Emission Line as a Means of Mass Determination for Spiral Galaxy AGNs**

This study focuses on the AGN of spiral galaxies in hopes to use the H- $\beta$  line to determine the mass of the central black hole. We are replicating the method of Vestergaard and Peterson by extinction correcting emission spectra from these black holes, both for cosmic redshift and for FeII emissions using IRAF. From there we can accurately measure the full width half max of the H-beta line in these spectrum as well as the luminosity and these paired with the OIII lines give us an estimate on the mass of the black hole. The purpose of this is to compare it to the values to pitch angle measurements and to explore the Mass-Pitch Angle relation as outlined by J. Kennefick from the University of Arkansas.

**Author(s):** Thomas Cameron<sup>1</sup>, Lucas Ratz<sup>1</sup>, Debra L. Burris<sup>1</sup>  
**Institution(s):** 1. University of Central Arkansas

#### **243.43 – The Potential for Cubesats to Determine Black Holes Masses in Nearby Active Galactic Nuclei and Contribute to Other Time Domain Science**

A 3U (30cmx10cmx10cm) CubeSat with a 9cm diameter aperture telescope can deliver unprecedented time domain coverage in the ultraviolet (UV) for the purposes of Active Galactic Nucleus (AGN) reverberation mapping to determine supermassive black hole (SMBH) masses. SMBH's reside at the centers of most, if not all, massive galaxies and accretion onto those black holes generates a great deal of emission peaking in the UV. These accretion disks are also surrounded by a nearby, fast moving gas region called the Broad Line Region (BLR). As light pulses generated near the black hole spread out, they first illuminate the accretion disk, and then the BLR. For a sample of bright AGN, a dedicated cubesat can follow these changes in brightness on a daily basis for up to 100 days from low Earth orbit. With such monitoring of changes in the accretion disk and then the BLR, an accurate distance between the two regions can be determined. Combining this UV coverage with optical emission-line spectroscopy from the ground allows for a direct measurement of the mass of the central black hole. This exchange of time resolution for spatial resolution can also be used to determine the structure of the central region of the AGN. Ground-based photometric and spectroscopic measurements will complement the UV by tracing the optically emitting and hence cooler regions of the AGN to provide one of the best measurements of supermassive black hole masses.

In addition to the primary science mission, the long observing campaigns and the large field of view required to get comparison stars for relative photometry allow for other competitive science. We have identified UV activity in M dwarfs as ancillary science that can be addressed with such a cubesat. This activity will have a strong impact on the habitability of any possible planet around the star.

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#### **243.44 – Probing the Relationship Between Black Hole Mass and Galaxy Mass for Reverberation-Mapped AGN**

We investigate the relationship between the black hole mass and galaxy mass for active galactic nuclei (AGN) with direct black hole mass measurements. Black hole masses were determined from reverberation mapping, which relies on the velocity of the broad line region (BLR) clouds and the light travel time as a measure of the size of the BLR. We constrain the rotation velocity, and therefore the mass, of each AGN host galaxy with HI spectroscopy obtained at the NRAO Green Bank Telescope. We also explore the relationship between black hole mass and dark matter mass by constraining the stellar mass component with ground-based and Hubble Space Telescope optical images combined with the integrated HI flux as a

constraint the mass of the gas component. Black hole scaling relations such as these can provide convenient alternatives for large numbers of black hole mass estimates when time and resource constraints preclude black hole mass measurements. Additionally, they can provide constraints for simulations of galaxy evolution and co-evolution with the central black hole.

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**Institution(s):** 1. CSIRO, 2. Georgia State University

#### **243.45 – Searching with the Large Binocular Telescope for Accreting Supermassive Black Holes in Bulgeless Galaxies**

There is increasing evidence that supermassive black holes are created and evolve in bulgeless galaxies, revealing pathways for merger free, secular growth. Constraints on the fraction of bulgeless galaxies that host an AGN remain, however, extremely limited. Following the recent discovery of a large population of bulgeless galaxies with red mid-infrared colors, that are highly suggestive of heated dust by powerful accreting massive black holes, we have employed the Large Binocular Telescope to investigate the near-IR spectra of six of these systems. We present here the data and measurements of near-infrared hydrogen molecular and recombination lines. We find no evidence for broad components of the Paschen Alpha emission lines, suggesting the AGNs are either too weak or too absorbed to be detected. Based on new estimates of extinction and comparisons with optical measurements we discuss the likelihood of these systems being heavily obscured AGN or galactic nuclei with vigorous, yet dust embedded star formation.

**Author(s):** Jason Ferguson<sup>2</sup>, Anca Constantin<sup>2</sup>, Shobita Satyapal<sup>1</sup>, Barry Rothberg<sup>1</sup>

**Institution(s):** 1. George Mason University, 2. James Madison University

#### **243.48 – Observations of WIBRaLS Blazars with K2**

We report on the recent results of our ongoing program to characterize the rapid variability of a sample of IR and optically bright blazars with K2. The K2 mission, through its superb photometric precision and its ability to continuously sample light curves on timescales of minutes to months is providing unrivaled information on blazar variability. In its previous incarnation as the Kepler mission, only a few blazars were present in its field of view. Nevertheless, Kepler's observations of blazars uncovered rich and complicated variability down to the most rapid timescales it could sample and indicated a need for more robust time-series analysis techniques. Our K2 sample of IR and optically bright blazars will be a unique set of blazars with light curves sampled on timescales not possible with ground based observatories. We present our recent blazar results from the K2 mission and discuss the analysis challenges they pose.

**Author(s):** Michael T. Carini<sup>1</sup>, Rebecca Brown<sup>1</sup>  
**Institution(s):** 1. Western Kentucky Univ.

#### **243.50 – Characteristics of the optical variability of AGNs as a possible identification tool**

We present connections between broad categories of active galaxies and how their optical brightness varies with time. This could open new avenues for identifying active galactic nuclei, and observations could lend themselves to a deeper understanding of AGN structure. For this purpose, we obtain the CRTS light curves of the active galaxies in the Palomar Sample. These curves are then modeled with a CARMA (Continuous-Time Auto-Regressive Moving Average) process and transferred to the frequency domain. The characteristics of the variability are extracted from the power density spectrum. Finally, we search for correlations between active galaxies type (LINER, Seyfert Galaxy, Quasar, etc) and variability characteristics to test the use of our method as an identification tool.

**Author(s):** Alexander Romelfanger<sup>1</sup>  
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### 243.51 – An optical and near-infrared color-magnitude diagram for type I Active Galactic Nuclei

This project is seeking another standard candle for measuring cosmic distances by trying to establish a color-magnitude diagram for active galactic nuclei (AGN). Type I AGN selected from the NASA/IPAC Extragalactic Database (NED) were used to establish a correlation between the color and the luminosity of AGN. This work builds on previous NASA/IPAC Teacher Archive Research Program team attempts to establish such a relationship. This is novel in that it uses both optical and 1-2 micron near-infrared (NIR) wavelengths as a better color discriminator of the transition between accretion-dominated and dust/torus-dominated emission.

Photometric data from the Sloan Digital Sky Survey (SDSS) and the Two Micron All Sky Survey (2MASS) was extracted and analyzed for type I AGN with redshifts  $z < 0.20$ . Our color-magnitude diagram for the area where the dust vaporizes is analogous to a stellar Hertzsprung-Russell (HR) diagram. Data from SDSS and 2MASS were specifically selected to focus on the sublimation boundary between the coolest part of the accretion disk and the hottest region of the inner edge of the dusty torus surrounding the accretion disk to find the greatest ratio for the color. The more luminous the AGN, the more extended the dust sublimation radius, causing a larger hot dust emitting surface area, which corresponds to a greater NIR luminosity.

Our findings suggest that the best correlations correspond to colors associated with the Sloan  $z$  band and any of the 2MASS bands with slight variations dependent on redshift. This may result in a tool for using AGN as a standard for cosmic distances. This research was made possible through the NASA/IPAC Teacher Archive Research Program (NITARP) and was funded by NASA Astrophysics Data Program.

**Author(s): Robert J Palmer<sup>5</sup>**, John Gibbs<sup>1</sup>, Varoujan Gorjian<sup>2</sup>, Lee Pruett<sup>3</sup>, Diedre Young<sup>4</sup>, Robert Boyd<sup>5</sup>, Joy Byrd<sup>4</sup>, Jaicie Cheshier<sup>4</sup>, Stephanie Chung<sup>3</sup>, Ruby Clark<sup>1</sup>, Joseph Fernandez<sup>5</sup>, Elyse Gonzales<sup>3</sup>, Anika Kumar<sup>3</sup>, Gillian McGinnis<sup>3</sup>, John Palmer<sup>5</sup>, Luke Perrine<sup>1</sup>, Brittny Phelps<sup>5</sup>, Margaret Reginio<sup>4</sup>, Kristi Richter<sup>3</sup>, Elias Sanchez<sup>1</sup>, Claire Washburn<sup>1</sup>

**Institution(s):** 1. Glencoe High School, 2. JPL/Caltech, 3. Notre Dame High School, 4. Ridgway Christian High School, 5. Willmar Senior High School

### 243.52 – Modeling the SED of LLAGNs

Since ADAFs (Advection Dominated Accretion Flow) are believed to be able to launch jets, we tested for the presence of these flows in LLAGNs (Low Luminosity Active Galactic Nucleus) by modeling their SEDs (Spectral Energy Distribution). We selected LLAGNs from a sample of LINERs (Low Ionization Nuclear Emission Region) confirmed to harbor a central point source at several wavelengths. The SED of these LINERs was built from archival data. We model the observed SED with a truncated disk, an ADAF, and a jet. We fit our model with and without the ADAF component in order to determine whether the inclusion of the ADAF is necessary to explain the observed spectral characteristics of LLAGNs.

**Author(s): Vaughn Petersen<sup>1</sup>**, Helene Flohic<sup>1</sup>

**Institution(s):** 1. University of the Pacific

### 243.53 – Filling The Gap of LINERs' SED

Low-ionization nuclear emission-line regions (LINERs) are found in nearly half of nearby galaxies. Some of the active galactic nuclei (AGNs) in these galaxies may harbor radiatively inefficient accretion flows (RIAFs), which may launch powerful outflows in the form of jets and wind. These outflows can influence the growth of the AGN by feedback.

The spectral energy distribution (SED) of the AGN can help us determine which LINERs have RIAFs. However, published SEDs of LINERs are sparse and lack the data needed to constrain the accretion flow models.

In order to build more complete SEDs of LINERs, we present the

results of observations of 4 LINERs with APEX in the sub-mm. We also analyzed archival observations of 4 LINERs with ALMA. Finally, we put upper limits on the gamma-ray flux of 12 LINERs with archival FERMI observations.

**Author(s): Gerold Curell<sup>1</sup>**, Vaughn Petersen<sup>1</sup>, Helene Flohic<sup>1</sup>

**Institution(s):** 1. University of The Pacific

### 243.54 – Mid-IR Observations of AGN

We present new observations of AGN, predominantly from the 10.4m GranTeCan. These observations are modeled and interpreted within the context of the clumpy torus models. In this poster we present our recent results and interpretation of the model outputs.

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**Contributing team(s):** Piratas AGN group

### 243.55 – Imaging AGN Feedback in NGC 3393 with CHEERS

The Chandra Extended Emission-line Region Survey (CHEERS) is the 'ultimate' resolution X-ray imaging survey of nearby far-IR selected AGN. By comparing deep Chandra observations with complementary HST and radio data, we investigate the morphology of the extended narrow-line region on scales of  $< 100$  pc. We present new results on the gas surrounding the Compton-thick AGN NGC 3393. The luminous extended narrow-line X-ray emission from this gas allows us to study the role and extent of AGN feedback as sub-kpc jets interact with the surrounding ISM.

**Author(s): W. Peter Maksym<sup>1</sup>**, Giuseppina Fabbiano<sup>1</sup>, Martin Elvis<sup>1</sup>, Margarita Karovska<sup>1</sup>, Alessandro Paggi<sup>1</sup>, Junfeng Wang<sup>3</sup>, Thaisa Storchi-Bergmann<sup>2</sup>

**Institution(s):** 1. Harvard-Smithsonian Center for Astrophysics, 2. Universidade Federal do Rio Grande do Sul, 3. Xiamen University

### 243.56 – NGC1266: Compton-thick AGN or Ultra-compact Starburst?

NGC1266 is a nearby lenticular galaxy hosting a massive molecular outflow driven by its active galactic nucleus (AGN). The turbulence injected into its ISM by the outflow may account for the suppression of its star formation by a factor of 50-150. ALMA and CARMA measurements of dense gas tracers had shown that its nuclear region lies behind a column of  $N(H_2) = 3 \times 10^{24} \text{ cm}^{-2}$ , and ALMA barely resolved a region of continuum FIR emission contained within 30pc of the nucleus emitting  $L(IR) > 10^{10}$  solar luminosities. With our recent NuSTAR observation of this galaxies, we determine whether the dust is heated by a Compton-thick AGN or an ultra-compact central starburst.

**Author(s): Lauranne Lanz<sup>3</sup>**, Katherine A. Alatalo<sup>2</sup>, Murray Brightman<sup>1</sup>, Patrick M. Ogle<sup>3</sup>, Philip N. Appleton<sup>3</sup>

**Institution(s):** 1. California Institute of Technology, 2. Carnegie Observatories, 3. IPAC/California Institute of Technology

### 243.57 – Swift monitoring of the "bare" AGN Ark120

We present the first results from our monitoring campaign of the prototypical bare AGN Ark 120 observed with the Swift UVOT and XRT. A simultaneous study of UV, optical, and X-ray variability in AGN is one of the most effective tools to shed light on their central engine. Ark 120 appears to be highly variable at all wavelengths and over all the timescales probed during the Swift campaign, with a higher degree of variability in the higher energy bands. The temporal variations are accompanied by spectral changes, which may provide crucial information on the origin of variability and the interplay between disk and corona in AGN.

**Author(s): Mario Gliozzi<sup>1</sup>**

**Institution(s):** 1. George Mason Univ.

### 243.58 – A WISE Test of Links Between Megamaser

## Activity and Nuclear Obscuration

Water megamaser disks detected in 22 GHz emission in galactic nuclear regions provide direct geometrical distances to galaxies and the most precise and accurate masses of supermassive black holes. Nevertheless, these systems are extremely rare. Improvements on their detection rates in future surveys rely on better understanding of their physical properties, in relation to those of their host galaxies. Using data from the Wide-Field Infrared Survey Explorer we systematically study the mid-IR properties of the galaxies with and without nuclear water maser emission to better constrain the connection between water masing activity and the circumnuclear dust absorption and radiation reprocessing in galaxy centers.

**Author(s):** Catherine Witherspoon<sup>1</sup>, Anca Constantin<sup>1</sup>  
**Institution(s):** 1. James Madison University

### 243.59 – GBT spectral monitoring observations of megamaser disk systems

We use single-dish radio spectra of known 22 GHz H<sub>2</sub>O megamasers, primarily gathered from the large data set observed by the Megamaser Cosmology Project, to investigate various aspects of the accretion disk physics. We characterize the several classes of variability present in the megamaser spectra, which have different timescales and presumed underlying physical causes. In doing so, we found rapid intra-day variability in the maser spectrum of ESO 558–G009 that is likely the result of interstellar scintillation, for which we favor a nearby (D~70 pc) scattering screen. We also set limits on the magnetic field strengths in seven sources, using strong flaring events to check for the presence of Zeeman splitting. These limits are typically 200–300 mG (1 $\sigma$ ), but our most stringent limit reaches 73 mG for the galaxy NGC 1194. These measurements begin to probe the regime where the magnetic pressure becomes comparable to the gas pressure in the disk, thereby placing constraints on the vertical support mechanism.

**Author(s):** Dominic Pesce<sup>5</sup>, James A. Braatz<sup>3</sup>, James J. Condon<sup>3</sup>, Feng Gao<sup>3</sup>, Christian Henkel<sup>2</sup>, Eugenia Litzinger<sup>4</sup>, Fred K.Y. Lo<sup>3</sup>, Mark J. Reid<sup>1</sup>  
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**Contributing team(s):** Megamaser Cosmology Project

### 243.60 – The 2013-2015 Optical Outburst and Historic Light Curve of the Blazar 3C 454.3

We present the twenty-seven year optical light curve for the blazar 3C 454.3 obtained at the Colgate University Foggy Bottom Observatory (FBO) as part of our intensive blazar variability monitoring program. In its current prolonged outburst (2013–2015), following its historic minimum in 2012, 3C 454.3 has exhibited a series of week- to month-long flares as well as shorter timescale activity. We investigate the characteristic timescales and intensities of outbursts and flares, V-R and R-I color index variations, and possible microvariability. We compare this well-sampled outburst with previous outbursts. We gratefully acknowledge support for student research through a National Science Foundation REU grant (AST-1005024) to the Keck Northeast Astronomy Consortium, the NASA / New York Space Grant, and Colgate University's Justus and Jayne Schlichting Student Research and NASC Division funds.

**Author(s):** Thomas J. Balonek<sup>1</sup>, Zachary Weaver<sup>1</sup>, Nicholas Didio<sup>1</sup>, Leah Jenks<sup>1</sup>, Carolyn Morris<sup>1</sup>, Jovana Zagorac<sup>1</sup>, Brian D'Auteuil<sup>1</sup>, Katherine L. Karnes<sup>1</sup>, Joshua S Reding<sup>1</sup>, Caitlin Rose<sup>3</sup>, Anneliese M Rilinger<sup>4</sup>, Michael T. Lam<sup>2</sup>  
**Institution(s):** 1. Colgate Univ., 2. Cornell Univ, 3. Vassar Coll, 4. Williams Coll

### 243.61 – The Significance of Star Formation in Active Galactic Nuclei

Active galactic nuclei (AGN) mid-infrared spectra display low- and high-ionization emission lines attributed to various species. AGN may be identified by their optical spectral properties, namely the existence of (Type 1) or lack thereof (Type 2), broad-line emission,

emanating from the nuclear region. Four subclasses of AGN were analytically examined and compared in this study: Type 1 Seyferts, Type 2 Seyferts, quasars, and starburst galaxies. A comparative investigation between the high-ionization AGN emission lines and the low-ionization star formation emission lines was conducted using archival mid-infrared spectroscopic data from the Spitzer Space Telescope. We will discuss the importance of star formation in each of the subclasses based on emission line measurements.

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**Institution(s):** 1. Wingate University

## 244 – Laboratory Astrophysics - Atoms and Plasmas Poster Session

### 244.01 – Ne<sup>+</sup>, Ne<sup>2+</sup>, Ar<sup>+</sup>, and Ar<sup>2+</sup> fine-structure electron-impact excitation data for applications in ultra low temperature plasmas

Fine-structure electron-impact excitation of ions plays an important role in cooling most interstellar environments and is important for far infrared (IR) and submillimeter (submm) observations. New atomic structure and collisional data are presented using both semi-relativistic and fully-relativistic R-matrix methods for Ne<sup>+</sup>, Ne<sup>2+</sup>, Ar<sup>+</sup>, and Ar<sup>2+</sup>. Some illustrative modeling results using the data are also given.

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**Institution(s):** 1. Auburn University, 2. Queen's University Belfast, 3. University of Georgia

### 244.02 – Intensity and Energy Level Analysis of the Vacuum Ultraviolet Spectrum of Four Times Ionize Nickel (Ni V)

Recent measurements of four times ionized iron and nickel (Fe V & Ni V) wavelengths in the vacuum ultraviolet (VUV) have been taken using the National Institute for Standards and Technology (NIST) Normal Incidence Vacuum Spectrograph (NIVS) with a sliding spark light source with invar electrodes. The wavelengths observed in those measurements make use of high resolution photographic plates with the majority of observed lines having uncertainties of approximately 3mÅ. In addition to observations made with photographic plates, the same wavelength region was observed with phosphor image plates, which have been demonstrated to be accurate as a method of intensity calibration when used with a deuterium light source. This work will evaluate the use of phosphor image plates and deuterium lamps as an intensity calibration method for the Ni V spectrum in the 1200–1600Å region of the VUV. Additionally, by pairing the observed wavelengths of Ni V with accurate line intensities, it is possible to create an energy level optimization for Ni V providing high accuracy Ritz wavelengths. This process has previously been applied to Fe V and produced Ritz wavelengths that agreed with the above experimental observations.

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**Institution(s):** 1. Arizona State University, 2. NIST

### 244.03 – New Rovibrationally-resolved Photodissociation Cross Sections of NH, SH<sup>+</sup>, and SiO for UV Irradiated Environments

Photodissociation cross sections for interstellar (IS) applications have typically only been obtained for transitions out of the rovibrational ground state, for transitions to low-lying electronic states, and to obtain dissociation rates in the standard IS radiation field with average IS grains. Here we present cross sections computed for three important diatomics for transitions from all rovibrational levels of the electronic ground state to numerous excited electronic states for wavelengths up to and beyond the H Lyman limit. The cross sections were obtained with potential energies and transition dipole moment functions computed at the MRCI-Q level of theory. State resolved cross sections are provided to allow for the calculation of local photodissociation rates. LTE cross

sections are also presented which assume a Boltzmann distribution of rovibrational levels. Applications of the results to interstellar clouds, photodissociation regions, protoplanetary disks, and stellar atmospheres are discussed.

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**Institution(s):** 1. Queens University Belfast, 2. University of Georgia

#### 244.04 – Rovibrational CO analysis in PDR models

CO is one of the most important molecules in the interstellar medium and in photodissociation regions (PDRs). Most of the extragalactic non-stellar IR to submm CO emission originates in PDRs. (Hollenbach & Tielens 1999). Pure rotational CO lines have been previously used in PDR models to provide density, temperature, and other diagnostics. However, for environments exposed to intense UV radiation, CO vibrational levels become significantly populated. Given new calculations of rovibrational collisional rate coefficients for CO-H (Walker et al. 2015, Song et al. 2015) and CO-H<sub>2</sub> (Yang et al. 2015), we explore their effects in standard Cloudy PDR (Ferland et al. 2013) and Radex (van der Tak et al. 2007) models. In particular, CO vibrational transitions due to H<sub>2</sub> collisions are studied for the first time using reliable full-dimensional CO-H<sub>2</sub> collisional data.

Ferland, G. J., et al. 2013, *Rev. Mex. Astron. y Astrof.*, 49, 137  
Hollenbach, D. J. & Tielens, A. G. G. M. 1999, *RMP*, 71, 173  
Song, L., et al. 2015, *ApJ*, in press  
van der Tak, F. F. S., et al. 2007, *A&A*, 468, 627  
Walker, K. M., et al. 2015, *ApJ*, 811, 27  
Yang, B., et al. 2015, *Nature Comm.*, 6, 6629

This work was supported in part by NASA grants NNX12AF42G and NNX15AI61G.

**Author(s):** Phillip C. Stancil<sup>1</sup>, Renata Cumbee<sup>1</sup>, Ziwei Zhang<sup>1</sup>, Kyle M. Walker<sup>1</sup>, Benhui Yang<sup>1</sup>, Gary J. Ferland<sup>2</sup>  
**Institution(s):** 1. Univ. of Georgia, 2. University of Kentucky

#### 244.05 – Rovibrationally inelastic scattering of CN-H<sub>2</sub>: Full-dimensional close-coupling study

Rotational and vibrational rate coefficients of CN in collisions with H<sub>2</sub> are essential for modeling CN infrared spectra in interstellar gas. We report here full-dimensional potential energy surface (PES) and rovibrational scattering calculations for the CN-H<sub>2</sub> collision system. A full-dimensional (6D) PES was calculated using the high-level ab initio CCSD(T)-F12B method. The invariant polynomial method was applied to fit the PES analytically in 6D. Quantum coupled-channel calculations of rotational excitation cross section of CN(j<sub>1</sub>=4) scattered by para-H<sub>2</sub>(j<sub>2</sub>=0, 2) and ortho-H<sub>2</sub>(j<sub>2</sub>=1) were performed for collision energies ranging from 1.0 to 1500 cm<sup>-1</sup>. State-to-state rate coefficients of CN(j<sub>1</sub>=4) are computed for H<sub>2</sub> rotational states j<sub>2</sub>=0-2. Comparison of the pure rotational cross sections and rate coefficients were made with previous available theoretical and experimental results. For the first time we present rovibrational quenching cross sections and rate coefficients of CN in collisions with H<sub>2</sub> on the new 6D PES.

Work at UGA and Emory are supported by NASA grant NNX12AF42G, at UNLV by NSF Grant PHY-1205838, and at Penn State by NSF Grant PHY-1203228.

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#### 244.06 – Ritz wavelengths of Fe I, Si II and Ni II for quasar absorption spectroscopy

The study of absorption lines in the spectra of galaxies along the line of sight to distant quasars can give important information about the abundances, ionization and kinematics of atoms within these

galaxies. They have also been used to study the variability of the fine structure constant at high redshifts. However, the laboratory wavelengths need to be known to better than 6 parts in 10<sup>8</sup> (20 ms<sup>-1</sup>). A paper by M. Murphy and J. C. Berengut (2014, *MNRAS* 438,388) includes a table of spectral lines for which the laboratory wavelength uncertainties are greater than this, including 13 resonance lines of Fe I, 11 lines of Ni II, and 4 lines of Si II.

Improved wavelengths for these lines were derived by re-analyzing archival spectra of iron hollow cathode lamps and a silicon carbide Penning discharge lamp. These spectra have previously been used in a comprehensive analysis of the spectrum of Fe I (Nave et al. 1994, *ApJS* 94, 221) and in a study of Si II, Si IV, and C IV for quasar spectroscopy (Griesmann & Kling, 2000, *ApJ* 536, L113). By re-optimizing the energy levels of Fe I, the absolute uncertainty of the resonance lines has been reduced by over a factor of 2 and the relative uncertainty by an order of magnitude. A similar analysis for Si II gives improved values for the resonance lines with wavelength uncertainties of around 4 parts in 10<sup>8</sup>. Analysis of new spectra of Ni II is in progress.

**Author(s):** Gillian Nave<sup>1</sup>  
**Institution(s):** 1. NIST

#### 244.07 – Hyperfine structure constants of singly ionized manganese obtained from analysis of Fourier Transform spectra

There is an on-going project in the Atomic Spectroscopy Group at NIST to obtain comprehensive spectral data for all of the singly ionized iron group elements and acquire more accurate energy levels, wavelengths and hyperfine structure (HFS) constants. The heavy abundance of the iron group elements and their contributions to a wide range of stellar spectra makes them of interest for astrophysical observations.

Existing spectroscopic data for Mn are insufficient to model spectra obtained from HgMn stars such as HD 175640. Since manganese has an odd number of nucleons, its spectral lines generally exhibit HFS, a relativistic effect due to interaction between the magnetic moment of the nucleus and the orbiting electrons. If proper treatment of line broadening effects such as HFS is not taken, there is a poor fit of the lines in stellar spectra, leading to an overestimate of the abundance of Mn. The abnormally high abundance of manganese in HgMn stars means both weak and strong transitions are important. Weak lines may not be observed in the laboratory, but HFS constants for them can be derived from stronger transitions that combine with the two levels involved in the weak transition.

Holt et al. (1999) measured HFS constants for 56 energy levels using laser spectroscopy. We have analyzed Fourier Transform spectra of a high current Mn/Ni hollow cathode lamp to obtain magnetic dipole A constants levels of Mn II. The A constants of Holt et al. (1999, *MNRAS* 306, 1007) for the z5P, z7P<sub>2</sub>, a5P and z5F levels were the starting point for our analysis, from which we derived A constants for 71 energy levels, including 51 previously unstudied levels. Our A constant for the a7S<sub>3</sub> ground level differs by 5x10<sup>-4</sup> cm<sup>-1</sup> from that of Blackwell-Whitehead et al. (2005, *ApJS* 157, 402) and has a factor of 6 lower uncertainty.

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**Institution(s):** 1. Lamar University, 2. National Institute of Standards and Technology  
**Contributing team(s):** Imperial College London

#### 244.08 – Non-LTE Analysis of Interstellar Line Spectra of SiO

SiO emission lines are important probes of chemical processes in diverse astrophysical environments. In circumstellar outflows of AGB stars, the production of silicate grains is preceded by SiO formation, making SiO a useful measure of Si depletion. SiO is also commonly observed in shocks associated with the outflows of young stellar objects, both low- and high-mass. To model SiO emission for non-LTE conditions requires collisional rate coefficients due to H<sub>2</sub> impact which are currently unavailable. Unknown collisional rate coefficients are often estimated from known systems. For the case of

SiO-H<sub>2</sub>, rate coefficients have previously been adapted from a different collider, He (Dayau & Balanca 2006), based on a reduced-mass scaling approach. Recently it has been suggested that scaling via the interaction potential well depth and the reduced masses of the collisional systems may be more reliable (Walker et al. 2014). Using the non-LTE spectral modeling package Radex (van der Tak et al. 2007), we construct diagnostic plots of SiO line ratios using SiO-H<sub>2</sub> collisional rate coefficients based on (i) reduced-mass scaling from the LAMDA database, (ii) potential well-depth scaling, and (iii) a more comprehensive input with multiple colliders (H<sub>2</sub>, He and H). Our goal is to give a more rigorous approach to SiO line emission simulations to better understand Si chemistry, dust formation/destruction, and other astrophysical processes. This work was supported by NASA ATP grant NNX15AI61G.

**Author(s):** Ziwei Zhang<sup>1</sup>, Phillip C. Stancil<sup>1</sup>  
**Institution(s):** 1. *The University of Georgia*

#### **244.09 – Improved Co I log(gf) & hfs data and Abundance Determinations in the Photospheres of the Sun & Metal-poor Star HD 84937**

New emission branching fraction measurements for 898 lines of the first spectrum of cobalt (Co I) from hollow cathode lamp spectra recorded with a 1m Fourier transform spectrometer (FTS) and a high resolution echelle spectrometer are reported. Radiative lifetimes from laser induced fluorescence measurements are combined with the branching fractions to determine accurate log(gf)s for the 898 lines. Selected published hyperfine structure (hfs) constants for levels of neutral Co are used to generate complete hfs component patterns for 195 transitions of Co I. These new laboratory data are applied to determine the Co abundance in the Sun and metal-poor star HD 84937, yielding log εps(Co) = 4.955 ± 0.007 (sigma = 0.059) based on 82 Co I lines and log εps(Co) = 2.785 ± 0.008 (sigma = 0.065) based on 66 Co I lines respectively. A Saha balance test on the photosphere of HD 84937 is performed using 16 UV lines of Co II, and good agreement is found with the Co I result in this metal-poor ([Fe I / H] = -2.32, [Fe II / H] = -2.32) dwarf star. The resulting value of [Co/Fe] = +0.14 supports a rise of Co/Fe at low metallicity that has been suggested in other studies. These new Co I data are part of a continuing effort to explore the limits of 1D/LTE photospheric models in metal-poor stars and to determine the relative abundance of Fe-group elements at low metallicity. This work is supported in part by NASA grant NNX10AN93G (J.E.L.), by NSF grant AST-1211055 (J.E.L.), and by NSF grant AST-1211585 (C.S.).

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#### **244.10 – New dielectronic recombination rates including below-threshold resonances for Li-like and Be-like systems**

The interaction between radiation and matter is a fundamental physical process in astrophysics. In plasmas with low electron temperatures, the dielectronic recombination (DR) rates for a range of ions can be very sensitive to near-threshold resonances and as a result there are large discrepancies in current DR databases. Recently the mechanism of below threshold recombination was proposed [1]. It was found that including below threshold resonances in the DR calculation can eliminate the hyper sensitivity of the rate coefficients to resonance positions. In this work, we first identify which ions have near threshold resonances in the Li-like and Be-like sequences. Three problematic ions (C3<sup>+</sup>, O4<sup>+</sup>, and Mg8<sup>+</sup>) were investigated and their DR rates recalculated to include below-threshold resonances. A search has also been performed for spectral evidence of this mechanism. The new DR rates can be used to calculate in modeling for low temperature plasmas.

[1] F. Robicheaux, S. D. Loch, M. S. Pindzola, and C. P. Ballance, PRL, 233201 (2010)

**Author(s):** Qianxia Wang<sup>1</sup>, Connor Ballance<sup>3</sup>, Michael Pindzola<sup>1</sup>, Randall K. Smith<sup>2</sup>, Adam Foster<sup>2</sup>, John C. Raymond<sup>2</sup>, Connor Favreau<sup>1</sup>, Jim Lauridson<sup>1</sup>, Stuart Loch<sup>1</sup>  
**Institution(s):** 1. *Auburn University*, 2. *Harvard Smithsonian Center for Astrophysics*, 3. *Queen's University Belfast*

#### **244.11 – The Role of Uncertainties in Atomic Data and Their Effect on Plasma Diagnostics**

Uncertainties in atomic rate coefficients have a direct impact on plasma diagnostic using spectral line intensities. However, without a systematic approach to the generation of such uncertainties, it is difficult to know the effect of those uncertainties on the diagnosis of the temperature and density of a plasma.

We present methods to assign baseline uncertainties on the electron-impact excitation, ionization, and recombination rate coefficients. These are propagated through a collisional-radiative model to produce uncertainties on the well know G and R-ratios for a He-like system. In this way, a range of values can be placed on the temperature and density of a plasma.

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### **245 – College-Level General Education Practices and Resources Poster Session**

#### **245.01 – Teaching Fair Use with Astronomy Imagery**

Plagiarism among students is most common because of a misunderstanding of copyright and fair use. Images and text are frequently used without proper credit to the original author, and works are frequently acknowledged improperly. For example, space imagery is often used in posters, presentations, on the web, on Facebook, and even in the classrooms, but often are not properly cited. A lesson plan on fair use is presented, outlining what constitutes fair use and how to properly acknowledge the work done by artists and authors everywhere, with examples drawn from the Astronomy Picture of the Day (APOD).

**Author(s):** Teresa Wilson<sup>1</sup>  
**Institution(s):** 1. *Michigan Technological University*

#### **245.02 – Do Interactive Globes and Games Help Students Learn Planetary Science?**

The popularity of animations and interactive visualizations in undergraduate science education might lead one to assume that these teaching aids enhance student learning. We tested this assumption for the case of the Google Earth virtual globe with a comparison of control and treatment student groups in a general education class of over 370 students at a large public university. Earth and Planetary Science course content was developed in two formats: using Keyhole Markup Language (KML) to create interactive tours in Google Earth (the treatment group) and Portable Document Format (PDF) for on-screen reading (the control group). The PDF documents contained identical text and images to the placemark balloons or "tour stops" in the Google Earth version. Some significant differences were noted between the two groups based on the immediate post-questionnaire with the KML students out-performing the PDF students, but not on the delayed measure. In a separate but related project, we undertake preliminary investigations into methods of teaching basic concepts in planetary mantle convection using numerical simulations. The goal of this project is to develop an interface with a two-dimensional finite element model that will allow students to vary parameters such as the temperatures assigned to the boundaries of the model domain, to help them actively explore important variables that control convection.

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#### **245.03 – Pedagogical Discipline Representations that Facilitate the Learning of Complex Modern**

## Astrophysics Topics

Pedagogical discipline representations (PDRs) are representations that are especially useful for teaching and learning about a topic, even though these representations would not typically be found in a textbook or used by two experts in the discipline who are engaged in discourse with one another on the topic. In some cases PDRs are significantly simplified versions of representations experts might use in a colloquium talk when discussing a topic; in others they can be highly contextualized representations with unique features that purposefully engage novice learners' pre-existing mental models and promote critical discourse. This poster shows several of the novel PDRs we have created and used in order to help Astro 101 students reason about complex astrophysical topics, such as interferometry and gravitational microlensing.

**Author(s):** Colin Scott Wallace<sup>4</sup>, Timothy G. Chambers<sup>3</sup>, Edward E. Prather<sup>1</sup>, Julia R. Kamenetzky<sup>1</sup>, Seth D. Hornstein<sup>2</sup>  
**Institution(s):** 1. University of Arizona, 2. University of Colorado Boulder, 3. University of Michigan, 4. University of North Carolina at Chapel Hill

### 245.04 – Enhancing ASTRO101 Student Engagement Using Student-Created ScienceSKETCHES

As astronomy teaching faculty are changing their teaching strategies from those less desirable approaches that allow students to passively listen to professor-centered, information-lectures to more desirable, active-student engagement classrooms characterized by active learning, ASTRO 101 professors are looking for more ways to help students learn to participate in authentic scientific practices. This is consistent with notion advocated by the NRC that students should practice scientific thinking, scientific discourse, and scientific practices while learning science. Noticing that much informal scientific discussion is mediated by sketches—such as those occasionally lively discussions held after hours during scientific conferences—scholars at the CAPER Center for Astronomy & Physics Education Research have been piloting a series of active learning tasks where students are challenged to create scientific drawings to illustrate their understanding of astronomical phenomena or structures. Known informally as *ScienceSKETCHES*, examples of these tasks challenge students to illustrate: the spectral curve differences between high and low mass stars; the differences among galaxy shapes; the distribution of stars for the Andromeda Galaxy in terms of luminosity versus temperature; old and young planetary surfaces; or the relationships between distances and speeds of orbiting objects. Although our initial testing has focused on predominately on paper and pencil tasks, with the occasional cell phone picture of a *ScienceSKETCH* being texted to the professor, the electronic-based teaching world is nearly ready to support these sorts of drawing tasks. Already, the ability to complete and submit scientific sketches is becoming commonplace across electronic learning platforms, including shared white-boarding in many desktop videoconferencing systems, and handheld device learning systems for interactive classrooms, like those from *Learning Catalytics*, among many others. Our initial results suggest that this strategy is worthwhile line of research and development for a wide range of astronomy education researchers and curriculum developers.

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**Institution(s):** 1. CAPER Center for Astronomy & Physics Education Research, 2. University of Wyoming

### 245.05 – A New Coherent Science Content Storyline Astronomy Course for Pre-Service Teachers at Penn State

The Earth and Space Science Partnership (ESSP) is a collaboration among Penn State scientists, science educators and seven school districts across Pennsylvania. One of the ESSP goals has been to provide pre-service teachers with new or improved science course offerings at Penn State in the Earth and Space Science domains. In particular, we aim to provide students with opportunities to learn astronomy content knowledge through teaching methods that engage them in investigations where they experience the practices used by astronomers. We have designed a new course that builds on our

research into students' ideas about Solar System astronomy (Plummer et al. 2015) and the curriculum our team created for a professional development workshop for in-service teachers (Palma et al. 2013) with this same theme. The course was offered for the first time in the spring 2015 semester.

We designed the course using a coherent science content storyline approach (see, e.g., Palma et al. 2014), which requires all of the student investigations to build towards a big idea in science; in this case, we chose the model for formation of our Solar System. The course led pre-service teachers through a series of investigations that model the type of instruction we hope they will adopt in their own classrooms. They were presented with a series of research questions that all tie in to the big idea of Solar System formation, and they were responsible for collecting and interpreting their own data to draw evidence-based conclusions about one aspect of this model. Students in the course were assessed on their astronomy content knowledge, but also on their ability to construct arguments using scientific reasoning to answer astronomy questions.

In this poster, we will present descriptions of the investigations, the assessments used, and our preliminary results about how the course led this group of pre-service teachers to improved understanding of astronomy content and the practices astronomers use in their investigations of the Solar System.

We gratefully acknowledge support from the NSF MSP program award DUE#0962792.

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**Institution(s):** 1. Penn State Univ.  
**Contributing team(s):** The Earth and Space Science Partnership

### 245.06 – Teaching ASTRO 101 Students the Art of Scientific Argumentation

Going beyond asking students to simply memorize facts about the universe, a longstanding challenge in teaching astronomy centers on successfully teaching students about the nature of science. As introductory astronomy survey courses, known widely as ASTRO 101, can sometimes be the last science course non-science majoring undergraduates take, many faculty hope to emphasize the scientific enterprise as a broad field in inquiry making valuable contributions to civilization as a whole, rather than as an isolated study of objects far from Earth. Scholars have long proposed that an understanding of the nature of science as a human endeavor requires explicit instruction. In other words, students successfully learning the facts of astronomy does not in any way ensure that students will learn anything about the nature of how astronomy is done. In a purposeful effort to improve students' understanding about the practices and discourse of astronomy, scholars working with the CAPER Center for Astronomy & Physics Education research are developing a suite of carefully designed instructional sequences—called *Scientific Argumentation*—focused on teaching students the differences between data and evidence, how to communicate and defend evidence-based conclusions, and how to be informed skeptics of scientific claims. Early results show students moving from naïve understandings of scientific practices to more informed understandings as well as demonstrating enhanced value for science in general as an worthwhile human endeavor with far reaching benefits.

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**Institution(s):** 1. CAPER Center for Astronomy & Physics Education Research, 2. East Carolina University, 3. University of Wyoming

### 245.07 – Development of an Online Exoplanet Course for In-Service Teachers

The Earth and Space Science Partnership (ESSP) is a collaboration among Penn State scientists, science educators and seven school districts across Pennsylvania. Penn State also offers through its fully online World Campus the opportunity for In-Service science teachers to earn an M.Ed. degree in Earth Science, and we currently offer a required online astronomy course for that program. We have

previously presented descriptions of how have incorporated research-based pedagogical practices into ESSP-sponsored workshops for in-service teachers (Palma et al. 2013) and into a pilot section of introductory astronomy for non-science majors (Palma et al. 2014). In this presentation, we detail the design and development of a new online astronomy course to be offered through the M.Ed. Earth Science degree program. This course also uses a coherent content storyline approach (Roth et al. 2011), and will engage the teachers in investigations using authentic data within the Claims Evidence Reasoning framework (McNeill & Krajcik 2012). The course theme will be exploring exoplanets in order to show how these objects have forced us to reconsider some ideas in our model for the formation of the Solar System, which is a disciplinary core idea identified in the Next Generation Science Standards (citation). Course materials will be made available through Penn State's open courseware initiative and will be promoted to teachers throughout PA through the Pennsylvania Earth Science Teachers' Association (PAESTA). We gratefully acknowledge support from the NSF MSP program award DUE#0962792.

**Author(s):** Daniel Barringer<sup>1</sup>, Christopher Palma<sup>1</sup>  
**Institution(s):** 1. Pennsylvania State University

### 245.08 – Big Data in AER

Penn State University teaches Introductory Astronomy to more undergraduates than any other institution in the U.S. Using a standardized assessment instrument, we have pre-/post- tested over 20,000 students in the last 8 years in both resident and online instruction. This gives us a rare opportunity to look for long term trends in the performance of our students during a period in which online instruction has burgeoned.

**Author(s):** Julia M. Kregenow<sup>1</sup>  
**Institution(s):** 1. Penn State University

### 245.09 – Discovery & Interaction in Astro 101 Laboratory Experiments

The availability of low-cost, high-performance computing hardware and software has transformed the manner by which astronomical concepts can be re-discovered and explored in a laboratory that accompanies an astronomy course for arts students. We report on a strategy, begun in 1992, for allowing each student to understand fundamental scientific principles by interactively confronting astronomical and physical phenomena, through direct observation and by computer simulation. These experiments have evolved as :

- a) the quality and speed of the hardware has greatly increased
- b) the corresponding hardware costs have decreased
- c) the students have become computer and Internet literate
- d) the importance of computationally and scientifically literate arts graduates in the workplace has increased.

We present the current suite of laboratory experiments, and describe the nature, procedures, and goals in this two-semester laboratory for liberal arts majors at the Astro 101 university level.

**Author(s):** Frank Patrick Maloney<sup>1</sup>, Philip Maurone<sup>1</sup>, Laurence E. DeWarf<sup>1</sup>  
**Institution(s):** 1. Villanova University

### 245.10 – Astronomy Fun with Mobile Devices

Those mobile devices your students bring to class can do more than tweet and text. Engage your students with these web-based astronomy learning tools that allow students to manipulate astronomical data to learn important concepts. The tools are HTML5, CSS3, Javascript-based applications that provide access to the content on iPad and Android tablets. With "Three Color" students can combine monochrome astronomical images taken through different color filters or in different wavelength regions into a single color image. "Star Clusters" allows students to compare images of clusters with a pre-defined template of colors and sizes to compare clusters of different ages. An adaptation of Travis Rector's "NovaSearch" allows students to examine images of the central regions of the Andromeda Galaxy to find novae and to measure the time over which the nova fades away. New additions to our suite of applications allow students to estimate the surface temperatures of

exoplanets and the probability of life elsewhere in the Universe.

Further information and access to these web-based tools are available at [www.astro.indiana.edu/ala/](http://www.astro.indiana.edu/ala/).

**Author(s):** Catherine A. Pilachowski<sup>1</sup>, Frank Morris<sup>2</sup>  
**Institution(s):** 1. Indiana University, 2. Software Contractor

### 245.11 – Automated Estimation of the Orbital Parameters of Jupiter's Moons

Every semester the Physics Department at the University of St. Thomas has the Physics 104 class complete a Jupiter lab. This involves taking around twenty images of Jupiter and its moons with the telescope at the University of St. Thomas Observatory over the course of a few nights. The students then take each image and find the distance from each moon to Jupiter and plot the distances versus the elapsed time for the corresponding image. Students use the plot to fit four sinusoidal curves of the moons of Jupiter. I created a script that automates this process for the professor. It takes the list of images and creates a region file used by the students to measure the distance from the moons to Jupiter, a png image that is the graph of all the data points and the fitted curves of the four moons, and a csv file that contains the list of images, the date and time each image was taken, the elapsed time since the first image, and the distances to Jupiter for Io, Europa, Ganymede, and Callisto. This is important because it lets the professor spend more time working with the students and answering questions as opposed to spending time fitting the curves of the moons on the graph, which can be time consuming.

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**Institution(s):** 1. University of St. Thomas

### 245.12 – Discovering Astronomy: An Astro 101 e-book

Discovering Astronomy, now available in its 6th edition as an eText, has many advantages and features for your students. We have partnered with etextink.com and WebAssign.net to produce an affordable set of cost-saving options for your students. Also available is the *Discovering Astronomy Activity Manual*, which provides students with an active-learning experience.

Our etext is device independent and thus accessible through any web browser. *Americans with Disabilities Act* compatibility provides access for all students. Hotlinks to outside sites provide further information for interested students. Lecture demonstration videos of important concepts, made specifically for this new edition, are embedded within the text as appropriate. Students can highlight text, take notes, and bookmark locations within the text. Important terms are linked to the glossary. Search capabilities allow students to easily find what they want.

Instructors can interact with their students directly through the etext once the class roster has been provided. For example, instructors can embed assignments into *their* students' etext and add their own notes and updates, which are immediately visible to *their* students.

Updates can be quickly made by us as new findings become available. For example, updates from New Horizons were added at the time of the closest approach to Pluto, and an update on the recent announcement of current water on Mars was added the day of the announcement.

We will present results of our own experience with college and high school students' use of *Discovering Astronomy* in online courses.

Details of the book, a sample chapter, and other information are available at [discoveringastronomy.weebly.com](http://discoveringastronomy.weebly.com).

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**Institution(s):** 1. Henry Ford College, 2. STSci, 3. University of Alabama, 4. University of Kansas

### 245.13 – A Concept-Oriented Custom Lab Manual for Astronomy 101

Astronomy 101 students are typically non-science majors fulfilling a general education requirement in the physical sciences. Many schools require that students complete a lab component with the course in order to meet the graduation requirement. The introductory astronomy course curriculum varies widely between instructors, and as such there is no agreed-upon standard set of topics or skills for lab activities. This is very challenging for the busy, heavily-loaded faculty member who needs a range of lab activities for their students. We have developed a collection of 40 concept-oriented activities for Astro 101 lab courses across a wide range of topics. The labs are designed to develop foundational skills and deep conceptual understanding in a hands-on, collaborative, learner-centered environment. They emphasize simple, inexpensive equipment to focus attention on key concepts rather than complicated apparatus, and to ease implementation for instructors working with limited resources. Instructors select only those labs that match their own course content, sequence the topics to align with their curriculum, and provide a fully custom lab manual to their students. Students, in turn, need only pay for labs they will use, keeping the materials affordable. On the web, see [mccradyricelabs.com](http://mccradyricelabs.com) for more information.

**Author(s):** Nate McCrady<sup>2</sup>, Emily L. Rice<sup>1</sup>

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#### **245.14 – Modifying your Physics and Astronomy Courses to Incorporate Heliophysics - Some Examples**

Although physics and astronomy courses include heliophysics topics, students still leave the courses without knowing what heliophysics is and how heliophysics relates to their daily lives. To meet goals of NASA's Living With a Star Program, UCF Physics has modified courses such as SCALE-UP: Electricity and Magnetism for Engineers and Scientists, Astronomy (for non-science majors), and Astrophysics to include heliophysics topics. In this poster, we present the previous labs, the student-modified labs to incorporate heliophysics, and we present student learning statistics.

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**Institution(s):** 1. University of Central Florida

#### **245.15 – Observing Projects in Introductory Astronomy**

Introductory astronomy classes without laboratory components face a unique challenge of how to expose students to the process of science in the framework of a lecture course. As a solution to this problem small group observing projects are incorporated into a 40 student introductory astronomy class composed primarily of non-science majors. Students may choose from 8 observing projects such as graphing the motion of the moon or a planet, measuring daily and seasonal motions of stars, and determining the rotation rate of the Sun from sunspots. Each group completes two projects, requiring the students to spend several hours outside of class making astronomical observations. Clear instructions and a check-list style observing log help students with minimal observing experience to take accurate data without direct instructor assistance. Students report their findings in a lab report-style paper, as well as in a formal oral or poster presentation. The projects serve a double purpose of allowing students to directly experience concepts covered in class as well as providing students with experience collecting, analyzing, and presenting astronomical data.

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#### **245.16 – Astronomy for Everyone: Harvard's Move Toward an All-Inclusive Astronomy Lab and Telescope**

Harvard University has a growing astronomy program that offers various courses to the undergraduate concentrators, secondaries and non-majors. Many of the courses involve labs that use the 16-inch DFM Clay Telescope for night-time observations and the heliostat for

observing the Sun. The goal is to proactively adapt the lab and telescope facilities to accommodate all students with disabilities. The current focus is converting the labs to accommodate visually impaired students. Using tactile images and sound, the intention is to create an experience equivalent to that of a student with full sight.

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## **246 – K-12 Education and Public Outreach Poster Session**

### **246.01 – Cosmic Concepts: A Video Series for Scaffolded Learning**

Scaffolding is widely considered to be an essential element of effective teaching and is used to help bridge knowledge gaps for learners. Scaffolding is especially important for distance-learning programs and computer-based learning environments. Preliminary studies are showing that when students learn about complex topics within computer-based learning environments without scaffolding, they fail to gain a conceptual understanding of the topic. As a result, researchers have begun to emphasize the importance of scaffolding for web-based as well as in-person instruction.

To support scaffolded teaching practices and techniques, while addressing the needs of life-long learners, we have created the Cosmic Concepts video series. The series consists of short, one-topic videos that address scientific concepts with a special emphasis on those that traditionally cause confusion or are layered with misconceptions. Each video focuses on one idea at a time and provides a clear explanation of phenomena that is succinct enough for on-demand reference usage by all types of learners. Likewise, the videos can be used by educators to scaffold the scientific concepts behind astronomical images, or can be sequenced together to create well-structured pathways for presenting deeper and more layered ideas. This approach is critical for communicating information about astronomical discoveries that are often dense with unfamiliar concepts, complex ideas, and highly technical details. Additionally, learning tools in video formats support multi-sensory presentation approaches that can make astronomy more accessible to a variety of learners.

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**Institution(s):** 1. STScI

### **246.02 – Distributing Sloan Digital Sky Survey Plates and Posters as Interactive Teaching Tools**

Thousands of aluminum spectroscopic plug plates from the Sloan Digital Sky Surveys await second lives as teaching tools in the Plates for Education program. Educators from formal and informal settings around the globe can take part in this program, which was launched in August of 2015. As part of this EPO effort, educators are provided with a plate, a corresponding poster, and educational materials (through the [voyages.sdss.org](http://voyages.sdss.org) website). Each plug plate represents the spectroscopic targets from a unique three-degree section of the sky. The poster displays the optical image associated with the target area. Together with the SkyServer Plate Browser and Navigate tools, students can locate individual objects, examine spectra, and pursue their own studies. As of September 2015, forty-five plates and posters had been distributed to teachers during professional development workshops. Follow-up research will be conducted to determine how effective the plates and posters are in teaching students about astronomy and the SDSS data. Materials and outlines for conducting professional development workshops are available to SDSS collaborators interested in hosting their own educational events.

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**Institution(s):** 1. University of Portsmouth, 2. University of Washington, 3. Yerkes Observatory

### **246.03 – Authentic Research in the Classroom:**

## **NITARP Teachers Connect Astronomy with NGSS.**

The NASA/IPAC Teacher Archive Research Program (NITARP) uses authentic astronomical research to bring the Next Generation Science Standards (NGSS) into the classroom. The creation of the NGSS was a collaborative effort between teams composed of teachers, scientists and other professionals from twenty-six states. These standards provide a framework for the change in how science is taught at all levels from kindergarten to twelfth grade in participating states. Scientific concepts are grouped into broad categories (physical, biological and earth sciences), and call for an interdisciplinary approach to content, along with the integration of engineering practices into the curriculum. This approach to the teaching of science has led educators to place more emphasis on authentic learning and problem-solving in their curricula. Project-based learning is a strategy that can effectively allow students to learn core scientific concepts within the context of a focused and complex scientific problem.

The NASA/IPAC Teacher Archive Research Program (NITARP) pairs teams of teachers and students with NASA astronomers. These teams are immersed in an astronomy research project over the course of the year, and are responsible for writing a project proposal, doing original research and presenting that research at a professional conference. The students who are involved in the NITARP research are provided with a rich hands-on experience that both exposes them to a deep understanding of an astronomical problem (and the core physics and math behind it), as well as the process of doing real science. The NITARP program offers a unique opportunity to bring project-based learning into K-12 science classrooms. We will highlight the ways in which this program has been implemented in classrooms across the country, as well as the connections to the NGSS.

This research was made possible through the NASA/IPAC Teacher Archive Research Program (NITARP) and was funded by NASA Astrophysics Data Program.

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### **246.04 – BiteScis: Connecting K-12 teachers with science graduate students to produce lesson plans on modern science research**

Many students graduate high school having never learned about the process and people behind modern science research. The BiteScis program addresses this gap by providing easily implemented lesson plans that incorporate the whos, whats, and hows of today's scientific discoveries. We bring together practicing scientists (motivated graduate students from the selective communicating science conference, ComSciCon) with K-12 science teachers to produce, review, and disseminate K-12 lesson plans based on modern science research. These lesson plans vary in topic from environmental science to neurobiology to astrophysics, and involve a range of activities from laboratory exercises to art projects, debates, or group discussion. An integral component of the program is a series of short, "bite-size" articles on modern science research written for K-12 students. The "bite-size" articles and lesson plans will be made freely available online in an easily searchable web interface that includes association with a variety of curriculum standards. This ongoing program is in its first year with about 15 lesson plans produced to date.

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### **246.05 – NITARP: Effects on Student Participants**

NITARP (NASA/IPAC Teacher Archive Research Program) is a teacher mentorship program designed to give educators experiences in authentic research in the area of astronomy. While the main focus of the program is aimed at giving educators experience working with and publishing scientific research, teachers are encouraged to involve

students with the experience. NITARP funds up to two students to travel along with the educator while allowing an additional two students to attend but with no additional financial assistance. Teachers are welcome to have more student participants but no more than 4 may travel with the teacher to Caltech and the AAS meeting. Given that the focus of the NITARP program is on the educators, little is known about the effects of the program on the student participants other than anecdotal evidence. In order to better understand the impact on the students, we have designed a survey to be administered to past student participants. The survey was constructed with a goal to determine if the NITARP experience had an impact on students' views of science and influenced their educational paths. While the NITARP project has assembled some evidence of the impact on students, this is the first formal attempt to capture that impact. This poster will present the results of that survey.

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### **246.06 – Examples from Astronomy for High School Physics**

A formal course in physics is increasingly becoming a standard requirement in the high school curriculum. With that dissemination comes the challenge of reaching and motivating a population that is more diverse in their academic abilities and intrinsic motivation. The abstract nature of pure physics is often made more accessible when motivated by examples from everyday life, and providing copious mathematical as well as conceptual examples has become standard practice in high school physics textbooks. Astronomy is a naturally captivating subject and astronomical examples are often successful in capturing the curiosity of high school students as well as the general population. This project seeks to diversify the range of pedagogical materials available to the high school physics instructor by compiling and publishing specific examples where an astronomical concept can be used to motivate the physics curriculum. This collection of examples will consist of both short problems suitable for daily homework assignments as well as longer project style activities.

Collaborations are encouraged and inquiries should be directed to sdieterich at carnegiescience dot edu.

This work is funded by the NSF Astronomy and Astrophysics Postdoctoral Fellowship Program through NSF grant AST-1400680.

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### **246.07 – Active Astronomy Roadshow Haiti**

College-age Haitian students working with advisors and volunteers from UMass Lowell in 2015 developed and tested an activity-based K-8 curriculum in astronomy, space, and earth science. Our partner school is located in Les Cayes, Haiti a city where only 65% of children attend school, and only half of those will complete 6th grade. Astronomy provides an accessible and non-intimidating entry into science, and activity-based learning contrasts with the predominant traditional teaching techniques in use in Haiti, to reach and inspire a different cohort of learners. Teachers are predominantly women in Haiti, so part of the effort involves connecting them with scientists, engineers and teacher peers in the US. As a developing nation, it is vital for Haitian (as for all) children to grow up viewing women as leaders in science. Meanwhile in the US, few are aware of the reality of getting an education in a 3rd world nation (i.e. most of the world), so we also joined with teachers in Massachusetts to give US school children a peek at what daily life is like for their peers living in our vibrant but impoverished neighbor. Our Haitian partners are committed to helping their sister-schools with curriculum and educator workshops, so that the overall quality of education can rise, and not be limited to the very few schools with access to resources. We will describe the activities, motivation, and the lessons learned from our first year of the project.

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**Contributing team(s):** UMass Lowell Haiti Development Studies Center

#### **246.08 – Enriching Cross Curriculum Projects with Astronomy for Gifted Students**

The aim of many GT (Gifted and Talented) teachers is to provide comprehensive and long term projects to enrich curriculum for their students rather than shorter "worksheet based" activities. Atkins Middle School has collaborated with faculty from the University of Central Arkansas over the past 9 years to create projects which span the academic year and enrich learning while emphasizing the goals of the science standards. An overview of those projects and Astronomy's role within them will be presented.

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#### **246.09 – Skynet Junior Scholars: Bringing Astronomy to Deaf and Hard of Hearing Youth**

Skynet Junior Scholars (SJS), funded by the National Science Foundation, aims to engage middle school youth from diverse audiences in investigating the universe with research quality robotic telescopes. SJS project development goals include: 1) Online access to optical and radio telescopes, data analysis tools, and professional astronomers, 2) An age-appropriate web-based interface for controlling remote telescopes, 3) Inquiry-based standards-aligned instructional modules. From an accessibility perspective, the goal of the Skynet Junior Scholars project is to facilitate independent access to the project by all youth including those with blindness or low vision and those who are Deaf or Hard of Hearing.

Deaf and Hard of Hearing (DHH) students have long been an underserved population within STEM fields, including astronomy. Two main barriers include: (1) insufficient corpus of American Sign Language (ASL) for astronomy terminology, and (2) DHH education professionals who lack astronomy background. A suite of vocabulary, accessible hands-on activities, and interaction with trained professionals, are critical for enhancing the background experiences of DHH youth, as they may come to an astronomy lesson lacking the basic "incidental learning" that is often taken for granted with hearing peers (for example, from astronomy in the media).

A collaboration between the Skynet Junior Scholars (SJS) project and the Wisconsin School for the Deaf is bringing astronomy to the DHH community in an accessible way for the first time. We follow a group of seven DHH youth over one semester as they interact with the SJS tools and curriculum to understand how they assimilate astronomy experiences and benefit from access to telescopes both directly (on school campus and at Yerkes Observatory) and through Skynet's robotic telescope network (optical and radio telescopes, inquiry-based modules, data analysis tools, and professional astronomers). We report on our first findings of resources and best practices for engaging DHH youth in astronomy in the future.

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#### **246.10 – Skynet Junior Scholars: From Idea to Enactment--Tales from the Trenches II Implementation with Blind and Low Vision Youth**

Skynet Junior Scholars is an ambitious program that aims to:  
--Develop online tools that enable middle school and high school aged youth to use robotic optical and radio telescopes to do astronomy;  
--Create an inquiry-based curriculum that promotes critical thinking and scientific habits of mind;  
--Proactively incorporate Principles of Universal Design in all SJS

development tasks to ensure access by blind/low vision and deaf/hard of hearing youth;  
--Prepare 180 adult youth leaders from diverse backgrounds including 4-H leaders, museum educators, amateur astronomers and teachers to facilitate SJS activities in a variety of settings.

In this paper we describe the work of staff and volunteers at the Wisconsin School for the Blind and Visually Impaired who have implemented SJS activities in school and camp environments, as well as ways in which they have empowered their students to take on leadership roles. Students from the Wisconsin School for the Blind and Visually Impaired planned and co-hosted a Magic of Astronomy (Harry Potter Themed) star party that incorporated topics learned as part of the SJS program; filters, exposure time, locating objects in the sky, as well as, how to make an image request from the Skynet network. Their experiences in successfully doing active astronomy will provide insight into how anyone can engage everyone in programs like Skynet Junior Scholars.

Skynet Junior Scholars is supported by the National Science Foundation under Grant Numbers 1223687, 1223235 and 1223345.

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**Contributing team(s):** Skynet Robotic Telescope Network, University of North Carolina

#### **246.11 – Sharing Gravity's Microscope: Star Formation and Galaxy Evolution for Underserved Arizonans**

Learning science in a community is important for children of all levels and especially for many underserved populations. This project combines HST research of galaxy evolution using gravitationally lensed galaxies with hands-on activities and the Starlab portable planetarium to link astronomy with families, teachers, and students. To explore galaxy evolution, new activities were developed and evaluated using novel evaluation techniques. A new set of galaxy classification cards enable inquiry-based learning about galaxy ages, evolution, and gravitational lensing. Activities using new cylinder overlays for the Starlab transparent cylinder will enable the detailed examination of star formation and galaxy evolution as seen from the viewpoint inside of different types of galaxies. These activities were presented in several Arizona venues that enable family and student participation including ASU Earth and Space Open House, Arizona Museum of Natural History Homeschooling Events, on the Salt River Pima-Maricopa Indian Community, and inner city Phoenix schools serving mainly Hispanic populations. Additional events targeted underserved families at the Phoenix Zoo, in Navajo County, and for the Pascua Yaqui Tribe. After evaluation, the activities and materials will also be shared with local teachers and nationally.

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#### **246.12 – Foundations in Science and Mathematics Program for Middle School and High School Students**

The Foundations in Science and Mathematics (FSM) is a graduate student led summer program designed to help middle school and high school students strengthen their knowledge and skills in mathematics and science. FSM provides two-week-long courses over a broad spectrum of disciplines including astronomy, biology, chemistry, computer programming, geology, mathematics, and physics. Students can choose two types of courses: (1) courses that help students learn the fundamental concepts in basic sciences and mathematics (e.g., "Precalculus"); and (2) knowledge courses that might be excluded from formal schooling (e.g., "Introduction to Universe"). FSM has served over 500 students in the Bloomington, IN, community over six years by acquiring funding from Indiana

University and the Indiana Space Grant Consortium. FSM offers graduate students the opportunity to obtain first hand experience through independent teaching and curriculum design as well as leadership experience.

We present the design of the program, review the achievements, and explore the challenges we face. We are open to collaboration with similar educational outreach programs. For more information, please visit <http://www.indiana.edu/~fsm/>.

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### **246.13 – The NASA/IPAC Teacher Archive Research Program (NITARP): Updates**

NITARP, the NASA/IPAC Teacher Archive Research Program, gets teachers involved in authentic astronomical research. We partner small groups of educators with a professional astronomer mentor for a year-long original research project. The teams echo the entire research process, from writing a proposal, to doing the research, to presenting the results at an American Astronomical Society (AAS) meeting. The program runs from January through January. Applications are available annually in May and are due in September. The educators' experiences color their teaching for years to come, influencing hundreds of students per teacher. This poster will give updates on the project, including numbers of teachers and students reached, and highlights of recent refereed publications.

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**Institution(s):** 1. IPAC/Caltech

**Contributing team(s):** NITARP team

## **247 – Majors and Graduate Student Education and Professional Development Poster Session**

### **247.01 – The Lowell Observatory Predoctoral Scholar Program**

Lowell Observatory is pleased to solicit applications for our Predoctoral Scholar Fellowship Program. Now beginning its eighth year, this program is designed to provide unique research opportunities to graduate students in good standing, currently enrolled at Ph.D. granting institutions. Lowell staff research spans a wide range of topics, from astronomical instrumentation, to icy bodies in our solar system, exoplanet science, stellar populations, star formation, and dwarf galaxies. The Observatory's new 4.3 meter Discovery Channel Telescope has successfully begun science operations and we anticipate the commissioning of new instruments in 2015, making this a particularly exciting time in our history. Student research is expected to lead to a thesis dissertation appropriate for graduation at the doctoral level at the student's home institution. The Observatory provides competitive compensation and full benefits to student scholars. For more information, see <http://www2.lowell.edu/rsch/predoc.php> and links therein. Applications for Fall 2016 are due by May 1, 2016.

**Author(s):** Gerard van Belle<sup>1</sup>, Lisa A. Prato<sup>1</sup>

**Institution(s):** 1. Lowell Observatory

### **247.02 – A Community of Scientists and Educators: The Compass Project at UC Berkeley**

The Berkeley Compass Project is a self-formed group of graduate and undergraduate students in the physical sciences at the University of California, Berkeley. Its goals are to improve undergraduate physics education, provide opportunities for professional development, and increase retention of students from populations underrepresented in the physical sciences. For undergraduate students, the core Compass

experience consists of a summer program and several seminar courses. These programs are designed to foster a diverse, collaborative student community in which students engage in authentic research practices and regular self-reflection. Graduate students, together with upper-level undergraduates, design and run all Compass programs. Compass strives to incorporate best practices from the science education literature. Experiences in Compass leave participants poised to be successful students researchers, teachers, and mentors.

**Author(s):** Nathaniel Roth<sup>1</sup>, Josiah Schwab<sup>1</sup>

**Institution(s):** 1. UC Berkeley

### **247.03 – The National Astronomy Consortium Summer Student Research Program at NRAO-Socorro: Year 2 structure**

I will present a summary of the program structure used for the second year of hosting a summer student research cohort of the National Astronomy Consortium (NAC) at the National Radio Astronomy Observatory in Socorro, NM. The NAC is a program partnering physics and astronomy departments in majority and minority-serving institutions across the country. The primary aim of this program is to support traditionally underrepresented students interested in pursuing a career in STEM through a 9-10 week summer astronomy research project and a year of additional mentoring after they return to their home institution. I will describe the research, professional development, and inclusivity goals of the program, and show how these were used to create a weekly syllabus for the summer. I will also highlight several unique aspects of this program, including the recruitment of remote mentors for students to better balance the gender and racial diversity of available role models for the students, as well as the hosting of a contemporaneous series of visiting diversity speakers. Finally, I will discuss structures for continuing to engage, interact with, and mentor students in the academic year following the summer program. A goal of this work going forward is to be able to make instructional and organizational materials from this program available to other sites interested in joining the NAC or hosting similar programs at their own institution.

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**Institution(s):** 1. NASA, 2. National Radio Astronomy Observatory, 3. National Radio Astronomy Observatory

### **247.04 – AstroCom NYC: A National Model for Urban Minority Engagement**

AstroCom NYC is an undergraduate mentoring program designed to improve urban minority student access to opportunities in astrophysical research by greatly enhancing partnerships between research astronomers in New York City (City University of New York – an MSI, American Museum of Natural History, and Columbia). AstroCom NYC provides centralized, personalized mentoring as well as financial and academic support, to CUNY undergraduates throughout their studies, plus the resources and opportunities to further CUNY faculty research with students. The goal is that students' residency at AMNH helps them build a sense of belonging in the field, and readies and inspires them for graduate study. AstroCom NYC provides a rigorous Methods of Scientific Research course developed specifically to this purpose, a laptop, research and career mentors, outreach activities, scholarships and stipends, Metrocards, and regular assessment for maximum effectiveness. The goal of this support is to remove barriers to access and success. AMNH serves as the central hub for our faculty and students, who are otherwise dispersed among all five boroughs of the City. We welcomed our third and largest cohort last year, along with 13 additional students through a NASA community college initiative. We review plans for Year 4, when we expect all of our interns to compete for external summer REUs, and our growing participation and leadership within partner activities.

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**Institution(s):** 1. AMNH, 2. Columbia U., 3. CUNY BMCC & AMNH, 4. CUNY Hunter College & AMNH, 5. CUNY York College & AMNH

## 247.05 – Indiana University's Innovative Recruitment Initiative: Getting You into IU

The University Graduate School at Indiana University (IU) is committed to fostering inclusiveness amongst graduate and professional students. The University Graduate School has developed a number of recruitment programs to provide opportunities to students with a diverse background to learn about and prepare for graduate school. One of these, "Getting You into IU" (GU2IU), is a three-day pre-application recruitment event that brings underrepresented prospective Ph.D. and M.F.A. (Master of Fine Arts) applicants to IU Bloomington to interact with the faculty, participate in workshops, and to experience the campus and community. Applicants are preselected by the respective academic programs in which they are interested and are provided a customized itinerary of faculty interviews. The program has been successful in targeted yields of applicants, admission and matriculation in a broad variety of academic units. Further information about these programs is available at <http://graduate.indiana.edu/about/diversity/visit-iu.shtml>.

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## 247.06 – Capacity Building in South African Astronomy and Astrophysics

South Africa (SA) has had great success in creating major astronomical facilities - SALT, KAT and MeerKAT. However, the existing SA astronomical community is almost entirely white. The lack of black scientists (80% of SA population is black) is obviously one of the many legacies of apartheid and a major initiative was required to rectify the situation. The National Astrophysics and Space Science Program (NASSP) is aimed at ensuring the development of high level physics skills within SA, and specifically takes graduates with bachelor's degrees in math or the physical sciences and prepares them to do PhDs in astrophysics and related disciplines. However, in 2003 when NASSP was established, there were no black SA astronomers, who could act as role models and mentors. This jeopardized the chances of success of NASSP and with it astronomy in SA. An American organization, the National Society of Black Physicists (NSBP) received a \$355,000 grant from the WK Kellogg Foundation to increase the number of black SA astronomers. It enabled African American scientists - both professionals and students - to participate in NASSP. The African American professionals taught NASSP courses and acted as role models and mentors. The project was an overwhelming success. From its beginning in 2003, the NASSP honors program graduates have gone on to a Master's or PhD program at a rate of 60% (USA rate: 35%). American participation started in 2008. In the very next year the number of black students jumped dramatically, reaching 80% in 2013 and this level continued in 2010-2014. We believe this increase and its maintenance is in large part due to bringing black SA students from SA historically black colleges for two weeks to expose them to astronomy, to a one year program to allow them to catch up academically and to the mentoring activities of the members of NSBP.

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## 247.07 – Astronomy education and the Astrophysics

## Source Code Library

The Astrophysics Source Code Library (ASCL) is an online registry of source codes used in refereed astrophysics research. It currently lists nearly 1,200 codes and covers all aspects of computational astrophysics. How can this resource be of use to educators and to the graduate students they mentor? The ASCL serves as a discovery tool for codes that can be used for one's own research. Graduate students can also investigate existing codes to see how common astronomical problems are approached numerically in practice, and use these codes as benchmarks for their own solutions to these problems. Further, they can deepen their knowledge of software practices and techniques through examination of others' codes.

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**Institution(s):** 1. *Astrophysics Source Code Library*, 2. *Michigan Technological University*

## 247.08 – Utilizing the AAVSO's Variable Star Index (VSX) In Undergraduate Research Projects

Among the many important services that the American Association of Variable Star Observers (AAVSO) provides to the astronomical community is the Variable Star Index (VSX - <https://www.aavso.org/vsx/>). This online catalog of variable stars is the repository of data on over 334,000 variable stars, including information on spectral type, range of magnitude, period, and type of variable, among other properties. A number of these stars were identified as being variable through automated telescope surveys, such as ASAS (All Sky Automated Survey). The computer code of this survey classified newly discovered variables as best it could, but a significant number of false classifications have been noted. The reclassification of ASAS variables in the VSX data, as well as a closer look at variables identified as miscellaneous type in VSX, are two of many projects that can be undertaken by interested undergraduates. In doing so, students learn about the physical properties of various types of variable stars as well as statistical analysis and computer software, especially the VStar variable star data visualization and analysis tool that is available to the astronomical community free of charge on the AAVSO website (<https://www.aavso.org/vstar-overview>). Two such projects are described in this presentation, the first to identify BY Draconis variables erroneously classified as Cepheids in ASAS data, and the second to identify SRD semiregular variables misidentified as "miscellaneous" in VSX.

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## 247.09 – CAMPARE and Cal-Bridge: Two Institutional Networks Increasing Diversity in Astronomy

We describe two programs, CAMPARE and Cal-Bridge, with the common mission of increasing participation of groups traditionally underrepresented in astronomy, through summer research opportunities, in the case of CAMPARE, scholarships in the case of Cal-Bridge, and significant mentoring in both programs, leading to an increase in their numbers successfully pursuing a PhD in the field.

In 6 years, the CAMPARE program has sent 62 students, >85% from underrepresented groups, to conduct summer research at one of twelve major research institutions in California, Arizona, and Wyoming. The graduation rate among CAMPARE scholars is 97%, and of the 37 CAMPARE scholars who have graduated with a Bachelor's degree, almost 60% (21) have completed or are pursuing graduate education in astronomy or a related field, at institutions including UCLA, USC, UC Riverside, Stanford, Univ. of Rochester, Georgia Tech, Kent State, Indiana Univ., Univ. of Oregon, Syracuse, and the Fisk-Vanderbilt Master's-to-PhD program.

The Cal-Bridge program is a CSU-UC Bridge program comprised of faculty from 5 University of California (UC), 8 California State University (CSU), and 8 California Community College (CCC) campuses in Southern California. Cal-Bridge provides much deeper mentoring and professional development experiences over the last two years of undergraduate and first year of graduate school to students from this diverse network of higher education institutions. Cal-Bridge Scholars benefit from financial support, intensive, joint

mentoring by CSU and UC faculty, professional development workshops, and exposure to research opportunities at the participating UC campuses.

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### 247.10 – Methods of Scientific Research: Teaching Scientific Creativity at Scale

We present a scaling-up plan for AstroComNYC's *Methods of Scientific Research* (MSR), a course designed to improve undergraduate students' understanding of science practices. The course format and goals, notably the open-ended, hands-on, investigative nature of the curriculum are reviewed. We discuss how the course's interactive pedagogical techniques empower students to learn creativity within the context of experimental design and control of variables thinking. To date the course has been offered to a limited numbers of students in specific programs. The goals of broadly implementing MSR is to reach more students and early in their education—with the specific purpose of supporting and improving retention of students pursuing STEM careers. However, we also discuss challenges in preserving the effectiveness of the teaching and learning experience at scale.

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**Institution(s):** 1. CUNY BMCC, 2. CUNY Hunter College

### 247.11 – Building Better Bridges: An Evaluation of The Bridge to the Ph.D. Program

Columbia University's Bridge to the Ph.D. in the Natural Sciences Program is increasing the number of underrepresented scholars entering graduate programs and equipping them to succeed in these programs. In a given year, three to five Bridge participants are hired as full-time Columbia University research assistants for up to two years. Now in its seventh year, the Program supports seven participants, and its alumni (including five astronomers) have gone on to Ph.D. programs across the country. Although to date fewer than 40 people have participated in the Program, a number too small for an exclusively statistical evaluation of its effectiveness, we are collecting invaluable longitudinal data on the career progressions of underrepresented aspiring scientists across the natural sciences. At least a dozen Bridge alumni will earn their Ph.D. in the next two-three years, and we will then learn much more about the impact that the Bridge Program has had on our participants' trajectories. Among other things, we hope to use these data to determine the Program's effectiveness in developing feelings of self-efficacy and participants' confidence in their ability to succeed in doctoral programs, to measure the rate at which Bridge alumni successfully complete doctoral programs relative to their peers, and to identify the aspects of the Program that participants find most helpful to their progress at different stages of their paths to and through doctoral programs. Here we describe the data we have already obtained as part of our on-going study, and preliminary results from our analysis.

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### 247.12 – The Undergraduate Research Resources at the Pisgah Astronomical Research Institute

Pisgah Astronomical Research Institute (PARI), a former NASA tracking station located in western North Carolina, has been offering programs, campus, and instrument use for undergraduate research and learning experiences since 2000. Over these years, PARI has collaborated with universities and colleges in the Southeastern U.S. Sharing its campus with institutions of higher learning is a priority for PARI as part of its mission to “to providing hands-on educational

and research opportunities for a broad cross-section of users in science, technology, engineering and math (STEM) disciplines.”

PARI is a 200 acre campus for environmental, earth, geological, physical, and astronomical sciences. For example, the PARI 26-m and 4.6-m radio telescopes are excellent for teaching electromagnetic theory, spectroscopy, atomic and molecular emission processes, and general physics and astronomy concepts. The PARI campus has lab and office space, data centers with high speed internet, distance learning capabilities, radio and optical telescopes, earth science sensors, housing and cafeteria.

Also, the campus is in an excellent spot for environmental and biological sciences lab and classroom experiences for students. The campus has the capability to put power and Internet access almost anywhere on its 200 acre campus so experiments can be set up in a protected area of a national forest. For example, Earthscope operates a Plate Boundary Observatory sensor on campus to measure plate tectonic motion. And, Clemson University has an instrument measuring winds and temperatures in the Thermosphere. The use of the

PARI campus is limited only by the creativity faculty to provide a rich educational environment for their students. An overview of PARI will be presented along with a summary of programs, and a summary of undergraduate research experiences over the past 15 years. Access to PARI and collaboration possibilities will be presented.

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**Institution(s):** 1. Pisgah Astronomical Research Institute

## 248 – Out-of-School Astronomy Education Practices and Resources for Kids to Grown-Ups Poster Session

### 248.01 – Exploring the Full Spectrum: the Power of Combining Art and Science

Science is publicly perceived as a challenging discipline open only to a small elite of extremely intelligent individuals. Its historic deficiency of women and racial minorities has helped to keep it on a outwardly unreachable pedestal far higher than the public's reach. One way we can pull science out its stiff academic walls is to incorporate it into an artistic performance. I have produced a multi-disciplinary performance event, called “The View From Nowhere”, which combined dance, physics and philosophy, all in one evening. The event is part of a long-term series which will attempt to translate scientific concepts into a diverse range of works by international choreographers. Because of the success of this series, both in the public feedback as well as in the amount of educational baggage acquired by the participants, I analyzed the structure of my own event and compared it to other existing ones to generate a model for multidisciplinary collaborations between the arts and the sciences. I will present a general structure for building collaborations between artists and scientists, more specifically in the context of visual, sound and performance art. From outlining the psychological aspects of human learning and their relationship with science communication, to discussing the potential of art as educational medium, I will discuss how science-inspired performances along with a pedagogy of the topic by a scientist allows a wider pool of people to have access to topics which are normally difficult to grasp in a traditional academic context. I will also be presenting the outline of a current APS-funded, long-term project which aims to build artistic collaborations between researchers in fluid dynamics from NYU, Georgia Tech, and University of Maryland and international artists which will result in an exhibit on the topic of quantum fluids at the New York City art venue Pioneer Works.

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**Institution(s):** 1. CUNY Hunter College, 2. New York University

### 248.02 – Expanding the Universe of "Astronomy on Tap" Public Outreach Events

Astronomy on Tap (AoT, astronomyontap.org) is free public outreach

event featuring engaging science presentations in bars, often combined with music, games, and prizes, to encourage a fun, interactive atmosphere. AoT events feature several short astronomy-related presentations primarily by local professional scientists, but also by visiting scientists, students, educators, amateur astronomers, writers, and artists. Events are held in social venues (bars, coffee shops, art galleries, etc.) in order to bring science directly to the public in a relaxed, informal atmosphere. With this we hope to engage a more diverse audience than typical lectures at academic and cultural institutions and to develop enthusiasm for science among voting, tax-paying adults. The flexible format and content of an AoT event is easy to adapt and expand based on the priorities, resources, and interests of local organizers. The social nature of AoT events provides important professional development and networking opportunities in science communication. Since the first New York City event in April 2013, Astronomy on Tap has expanded to more than ten cities globally, including monthly events in NYC, Austin, Seattle, and Tucson; semi-regular events in Columbus, New Haven, Santiago, Toronto, and Denver; occasional (so far) events in Rochester (NY), Baltimore, Lansing, and Washington, DC; and one-off events in Chicago and Taipei. Several venues regularly attract audiences of over 200 people. We have received media coverage online, in print, and occasionally even on radio and television. In this poster we describe the overarching goals and characteristics of AoT events, distinct adaptations of various locations, resources we have developed, and the methods we use to coordinate among the worldwide local organizers.

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**Institution(s):** 1. American Museum of Natural History, 2. CUNY College of Staten Island, 3. European Southern Observatory, 4. Institute of Astronomy & Astrophysics, Academia Sinica (ASIAA), 5. Lunar and Planetary Laboratory, University of Arizona, 6. Michigan State University, 7. NASA GSFC, 8. Ohio State University, 9. Regis University, 10. Rochester Institute of Technology, 11. University of Colorado, Boulder, 12. University of Washington, 13. UT Austin, 14. Yale University

#### 248.03 – STARtorialist: Astronomy Fashion & Culture Blog and Reader Survey Results

STARtorialist (startorialist.com) is a Tumblr-based blog that curates the proliferation of “Astro Fashion” – clothing accessories, decor, and more – with the goal of celebrating the beauty of the universe and highlighting the science behind the astronomical imagery. Since launching in January 2013, we have written over 1000 unique posts about everything from handmade and boutique products to mass-produced commercial items to haute couture seen on fashion runways. Each blog post features images and descriptions of the products with links to the original astronomical images or other relevant science content. We also feature profiles of astronomers, scientists, students, and communicators wearing, making, or decorating with “startorial” items. Our most popular posts accumulate hundreds or thousands of notes (faves or reblogs, in Tumblr parlance), and one post has nearly 150,000 notes. In our second year, we have grown from 1,000 to just shy of 20,000 followers on Tumblr, with an increased audience on Twitter, Instagram, and Facebook as well. We present preliminary results from a reader survey conducted September-October 2015 in collaboration with science communication researcher Dr. Paige Jarreau. The survey provides data on reader habits, motivations, attitudes, and demographics in order to assess how STARtorialist has influenced our readers’ views on science, scientists, and the scientific community as a whole.

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**Institution(s):** 1. Columbia University, 2. CUNY College of Staten Island, 3. Louisiana State University

#### 248.04 – Progressive Research and Outreach at the WestRock Observatory

The WestRock Observatory (WRO), located in Columbus State University's Coca-Cola Space Science Center (CCSSC), is dedicated to education and research in astronomy through hands-on engagement and public participation. The WRO has recently received funding to upgrade the PlaneWave CDK 24-inch Corrected Dall-Kirkham Astrogaph telescope. Recent additions to the telescope include an all-new Apogee Alta F16 CCD camera complete with a filter wheel (with narrowband and broadband filters) and a Minor Planet Center Observatory Code (W22). These new upgrades have allowed Astrophysics students to conduct unique research ranging from high precision minor planet astrometry, to broad- and narrow-band imaging of nebulae, to light curve analysis for variable star photometry. These new endeavours, in conjunction with an existing suite of Solar telescopes, gives the WRO the ability to live-stream solar and night-time observing. These streams are available both online and through interactive displays at the CCSSC making the WRO an educational outreach program for a worldwide public audience and a growing astronomical community. Current funding is allowing students to get even more research experience than previously attainable further enabling the expansion of our publicly available gallery of nebula and galaxy images. Support and funding for the acquirement, installation, and upgrading of the new PlaneWave CDK24 has been provided by the International Museum and Library Services via the Museums for America Award. Additionally, individual NASA Space Grant Scholarships have helped to secure a number of student interns partially responsible for recent improvements.

**Author(s):** Johnny Eugene Brown<sup>1</sup>, Austin Lantz Caughey<sup>1</sup>, Brendon O'Keeffe<sup>1</sup>, Michael Johnson<sup>1</sup>, Rosa Nina Murphy Williams<sup>1</sup>  
**Institution(s):** 1. Columbus State University

#### 248.05 – Skynet Junior Scholars: From Idea to Enactment--Tales from the Trenches I. Implementation in 4-H settings.

The creators of Skynet Junior Scholars were ambitious to say the least when they set out to:

- Develop online tools that enable middle school and high school aged youth to use robotic optical and radio telescopes to do astronomy;
- Create an inquiry-based curriculum that promotes critical thinking and scientific habits of mind;
- Proactively incorporate Principles of Universal Design in all SJS development tasks to ensure access by blind/low vision and deaf/hard of hearing youth;
- Prepare 180 adult youth leaders from diverse backgrounds including museum educators, amateur astronomers, teachers 4-H leaders to facilitate SJS activities in a variety of settings.

After 3 years of development SJS is in full implementation mode. As of August, 2015, 105 youth leaders and leader supervisors from 24 states have completed professional development and many have formed SJS youth groups. In this paper we describe what it takes for a successful implementation of Skynet Junior Scholars in a 4-H setting, from the viewpoint of adult leaders in the trenches who have created novel implementation models to make SJS work in diverse environments from monthly 4-H meetings to immersive residential camps.

4-H is the nation's largest positive youth development organization, with a membership of more than six million young people in the U.S. In 2003 the national organization formed a strong commitment to STEM education with the goal to “to engage one million new youth in a dynamic process of discovery and exploration in science, engineering and technology to prepare them to meet the challenges of the 21st century”. Skynet Junior Scholars has formed a strong and growing partnership with state 4-H agencies in West Virginia and Wisconsin, with a goal of establishing SJS as a national 4-H curriculum.

Skynet Junior Scholars is supported by the National Science Foundation under Grant Numbers 1223687, 1223235 and 1223345.

**Author(s):** Jason Burnside<sup>5</sup>, Lynn Feldman<sup>4</sup>, Suzanne Gurton<sup>1</sup>, Sue Ann Heatherly<sup>2</sup>, Vivian L. Hoette<sup>3</sup>, Jenny Murray<sup>5</sup>, Ginger Zastrow<sup>4</sup>

**Institution(s):** 1. *Astronomical Society of the Pacific*, 2. *National Radio Astronomy Observatory*, 3. *University of Chicago Yerkes Observatory*, 4. *University of Wisconsin Extension*, 5. *WVU Extension*

### **248.06 – Skynet Junior Scholars: From Idea to Enactment--Tales from the Trenches III. Implementing SJS in Out-of-School Time Settings**

The creators of Skynet Junior Scholars were ambitious to say the least when they set out to:

- Develop online tools that enable middle school and high school aged youth to use robotic optical and radio telescopes to do astronomy;
- Create an inquiry-based curriculum that promotes critical thinking and scientific habits of mind;
- Proactively incorporate Principles of Universal Design in all SJS development tasks to ensure access by blind/low vision and deaf/hard of hearing youth;
- Prepare 180 adult youth leaders from diverse backgrounds including 4-H leaders, museum educators, amateur astronomers and teachers to facilitate SJS activities in a variety of settings.

So, after three years of development, how is SJS actually working? In this paper we describe what it takes for a successful implementation of Skynet Junior Scholars, from the viewpoint of adult leaders in the trenches who work with youth at schools but in free-choice learning environments. What are the lessons learned in recruiting and engaging youth in observational astronomy projects when academic incentives like grades are no longer part of the equation? Stories and ideas will be presented from classroom teachers, informal educators and amateur astronomers who work with youth in this environment.

Skynet Junior Scholars is supported by the National Science Foundation under Grant Numbers 1223687, 1223235 and 1223345.

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**Contributing team(s):** Skynet Robotic Telescope Network, University of North Carolina

### **248.07 – Dark Skies, Bright Kids Year 7**

We present updates from our seventh year of operation including new club content, continued assessments, and our fifth annual Star Party. Dark Skies, Bright Kids (DSBK) is an entirely volunteer-run outreach organization based out of the Department of Astronomy at the University of Virginia. Our core mission is to enhance elementary science education and literacy in Central Virginia through fun, hands-on activities that introduce basic Astronomy concepts. Our primary focus is hosting an 8-10 week after-school astronomy club at underserved elementary and middle schools. Each week, DSBK volunteers take the role of coaches to introduce astronomy-related concepts ranging from the Solar System to galaxies to astrobiology, and to lead students in interactive learning activities. Another hallmark of DSBK is hosting our Annual Central Virginia Star Party, a free event open to the community featuring star-gazing and planetarium shows.

**Author(s):** Lauren E. Bittle<sup>1</sup>, Kelsey E. Johnson<sup>1</sup>, H. Jacob Borish<sup>1</sup>, Andrew Burkhardt<sup>1</sup>, Ariel Firebaugh<sup>1</sup>, Danielle Hancock<sup>1</sup>, Christian Rochford Hayes<sup>1</sup>, Sean Linden<sup>1</sup>, Sandra Liss<sup>1</sup>, Allison Matthews<sup>1</sup>, Brian Prager<sup>1</sup>, Matthew Pryal<sup>1</sup>, Kimberly R. Sokal<sup>1</sup>, Nicholas William Troup<sup>1</sup>, Trey Wenger<sup>1</sup>

**Institution(s):** 1. *University of Virginia*

### **248.08 – Kilohoku Ho`okele Wa`a : Astronomy of the**

### **Hawaiian Navigators**

This poster provides an introduction to the astronomy of the Hawaiian wayfinders, Kilohoku Ho`okele Wa`a. Rooted in a legacy of navigation across the Polynesian triangle, wayfinding astronomy has been part of a suite of skills that allows navigators to deliberately hop between the small islands of the Pacific, for thousands of years. Forty years ago, in one manifestation of the Hawaiian Renaissance, our teachers demonstrated that ancient Hawaiians were capable of traversing the wide Pacific to settle and trade on islands separated by thousands of miles. Today those same mentors train a new generation of navigators, making Hawaiian voyaging a living, evolving, sustainable endeavor. This poster presents two components of astronomical knowledge that all crewmen, but particularly those in training to become navigators, learn early in their training. Na Ohana Hoku, the Hawaiian Star Families constitute the basic units of the Hawaiian sky. In contrast to the Western system of 88 constellations, Na Ohana Hoku divides the sky into four sections that each run from the northern to the southern poles. This configuration reduces cognitive load, allowing the navigator to preserve working memory for other complex tasks. In addition, these configurations of stars support the navigator in finding and generatively using hundreds of individual, and navigationally important pairs of stars. The Hawaiian Star Compass divides the celestial sphere into a directional system that uses 32 rather than 8 cardinal points. Within the tropics, the rising and setting of celestial objects are consistent within the Hawaiian Star Compass, providing for extremely reliable direction finding. Together, Na Ohana Hoku and the Hawaiian Star Compass provide the tropical navigator with astronomical assistance that is not available to, and would have been unknown to Western navigators trained at higher latitudes.

**Author(s):** Stephanie Slater<sup>1</sup>, Timothy F. Slater<sup>3</sup>, Kalepa C. Baybayan<sup>2</sup>

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### **249 – Research Opportunities for Students Poster Session**

#### **249.01 – A Survey of Light Pollution in the Rogue Valley, Southwest Oregon, by St. Mary's School, Medford, Oregon**

The Rogue Valley in Southwest Oregon was known for its beautiful dark skies, but due to population growth the dark skies are vanishing. A light pollution chart using Defense Meteorological Satellite Program (DMSP) data was published in 2006, but did not show the spatial variation in detail. In the spring of 2014, the 9<sup>th</sup> grade physics students, astronomy students, and members of the Astronomy Club from St. Mary's School conducted the first detailed night sky survey. The purpose of the survey is to create a baseline of the variations in light pollution in the Rogue Valley.

The project continued into 2015, incorporating suggestions made at the 2014 AAS Conference to improve the study by including more light meter data and community outreach. Students used light meters, Loss of the Night app, and the Dark Sky meter app. Students researched light pollution and its effects on the environment, measured night sky brightness in the Rogue Valley, and completed a light audit in an area of their choice. They created a presentation for a final physics grade. The basis for this project, along with procedures can be found on the GaN, Globe at Night, ([www.globeatnight.org](http://www.globeatnight.org)) website. The light audit and research portion were developed from the Dark Sky Rangers section of the website ([www.globeatnight.org/dsr/](http://www.globeatnight.org/dsr/)).

The 2014 survey and public outreach increased awareness of light pollution in the Rogue Valley and around the state of Oregon. Examples include a local senior project to change lighting at a baseball stadium and a 4-H club in Northeast Oregon starting a GaN survey in their area. GaN shows growth in the amount of data collected in Oregon from 8 data points in 2006 to 193 in 2014. The Rogue Valley magnitude data from the spring of 2015 indicates a drop from an average magnitude of 4 to an average magnitude of 2.

This is due to hazy skies from smoke drifting into the valley from a Siberian wildfire. Data collection during the summer and fall was hampered due to smoke from local wildfires.

**Author(s):** Holly Bense<sup>1</sup>, Genna Dorrell<sup>1</sup>, James Feng<sup>1</sup>, Sean Hicks<sup>1</sup>, Jason Mars Liu<sup>1</sup>, Steven Liu<sup>1</sup>, Mitchell Moczygemba<sup>1</sup>, Jason Sheng<sup>1</sup>, Leah Sternenburg<sup>1</sup>, Emi Than<sup>1</sup>, Emry Timmons<sup>1</sup>, Jerry Wen<sup>1</sup>, Bella Yaeger<sup>1</sup>, Ruiyang You<sup>1</sup>  
**Institution(s):** 1. St. Mary's School

### 249.02 – Google Classroom and Open Clusters: An Authentic Science Research Project for High School Students

STEM education is about offering unique opportunities to our students. For the past three years, students from two high schools (Breck School in Minneapolis, MN, and Carmel Catholic High School in Mundelein, IL) have collaborated on authentic astronomy research projects. This past year they surveyed archival data of open clusters to determine if a clear turnoff point could be unequivocally determined. Age and distance to each open cluster were calculated. Additionally, students requested time on several telescopes to obtain original data to compare to the archival data. Students from each school worked in collaborative teams, sharing and verifying results through regular online hangouts and chats. Work papers were stored in a shared drive and on a student-designed Google site to facilitate dissemination of documents between the two schools.

**Author(s):** Chelen H. Johnson<sup>1</sup>, Marcella Linahan<sup>2</sup>, Allison Frances Cuba<sup>2</sup>, Samantha Rose Dickmann<sup>2</sup>, Eleanor B Hogan<sup>1</sup>, Demetra N Karos<sup>1</sup>, Kendall G Kozikowski<sup>1</sup>, Lauren Paige Kozikowski<sup>1</sup>, Samantha Brooks Nelson<sup>1</sup>, Kevin Thomas O'Hara<sup>2</sup>, Brandi Lucia Ropinski<sup>2</sup>, Gabriella Scarpa<sup>1</sup>, Catharine D. Garmany<sup>3</sup>  
**Institution(s):** 1. Breck School, 2. Carmel Catholic High School, 3. NOAO

### 249.03 – Suggestions to Gain Deeper Understanding of Magnetic Fields in Astrophysics Classrooms

I present two tools that could be used in an undergraduate or graduate classroom to aid in developing intuition of magnetic fields, how they are measured, and how they affect large scale phenomena like the solar wind. The first tool is a Mathematica widget I developed that simulates observations of magnetic field in the Interstellar Medium (ISM) using the weak Zeeman effect. Woolsey (2015, JAESE) discusses the relevant background information about what structures in the ISM produce a strong enough effect and which molecules are used to make the measurement and why. This widget could be used in an entry level astronomy course as a way to show how astronomers actually make certain types of measurements and allow students to practice inquiry-based learning to understand how different aspects of the ISM environment strengthen or weaken the observed signal. The second tool is a Python model of the solar wind, The Efficient Modified Parker Equation Solving Tool (TEMPEST), that is publicly available on GitHub (<https://github.com/lnwoolsey/tempest>). I discuss possible short-term projects or investigations that could be done using the programs in the TEMPEST library that are suitable for upper-level undergraduates or in graduate level coursework (Woolsey, 2015, JRAEO).

**Author(s):** Lauren N. Woolsey<sup>1</sup>  
**Institution(s):** 1. Harvard University

### 249.04 – The NSF PAARE Projects at SC State

We review our progress over the past 7.5 years and the path forward under the NSF program “Partnerships in Astronomy and Astrophysics Research and Education (PAARE)”. Our first project, “A Partnership in Observational and Computational Astronomy (POCA)” was a part of the 2008 PAARE cohort which we finished on September 30, 2015. We will summarize the results of those years and look at our way forward under a second PAARE award made in August 2014 (POCA II).

Our partnership under the second PAARE award includes South Carolina State University (a Historically Black College/University), Clemson University (a Ph.D. granting institution) as well as

individual investigators at NASA Ames and Carnegie Mellon University. Our recent work on variable and peculiar stars, work with the Kepler Observatory and our educational products in cosmology for non-STEM majors will be presented as well as our success with undergraduate and graduate students. We will also discuss how we are sharing resources with Clemson through distance learning and undergraduate research projects.

Our support includes NSF awards AST-0750814 and AST-1358913 to South Carolina State University as well as resources and support provided by Clemson University and the National Optical Astronomy Observatory. Support for the Kepler observations is provided by NASA to South Carolina State University under awards NNX11AB82G and NNX13AC24G. Additional details can be found at: <http://physics.scsu.edu/paare/>

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**Institution(s):** 1. Carnegie Mellon University, 2. Clemson University, 3. NASA ARC, 4. NOAO, 5. South Carolina State Univ.

### 249.05 – National Radio Astronomy International Exchange Program (NINE)

NINE aims to create synergistic partnerships between NRAO and its US-Based NINE partner institutions and universities, with astronomy-related institutions in other countries. We seek to create a vibrant exchange of students that are interested in learning about activities associated with the radio astronomy field, and to create enduring partnerships that will help train a global, collaborative Science, Technology, Engineering, and Mathematics (STEM) knowledgeable workforce.

**Author(s):** Lory Mitchell Wingate<sup>1</sup>  
**Institution(s):** 1. National Radio Astronomy Observatory

### 249.06 – The APSU 0.5m Telescope: Helping to Transform Undergraduate Education

We present details of the newly rebuilt APSU 0.5m telescope and discuss its role in the Physics & Astronomy curriculum at Austin Peay State University. This telescope enables advanced astronomical course work, student projects, a small research capability, and a large public outreach effort for the APSU Physics & Astronomy Department.

We discuss the basic capabilities of the telescope, the current instrument suite including potential growth options for the 0.5m, our plans for student led and faculty research efforts, and early EPO work. Initial results from the commissioning data are presented to illustrate the research and imaging capabilities of the system.

**Author(s):** Spencer L. Buckner<sup>1</sup>, J. Allyn Smith<sup>1</sup>, Elizabeth Juelfs<sup>1</sup>, Bryan Gaither<sup>1</sup>, Tyler Wilson<sup>1</sup>, Fred Roberts<sup>2</sup>  
**Institution(s):** 1. Austin Peay State Univ., 2. Military System Group

### 249.07 – Applying the Principles of Systems Engineering and Project Management to Optimize Scientific Research

Systems Engineering is an interdisciplinary practice that analyzes different facets of a suggested area to properly develop and design an efficient system guided by the principles and restrictions of the science community. When entering an institution with quantitative and analytical scientific theory it is important to make sure that all parts of a system correlates in a structured and systematic manner so that all areas of intricacy will be prevented or quickly deduced. My research focused on interpreting and implementing Systems Engineering techniques in the construction, integration and operation of a NASA Radio Jove Kit to Observe Jupiter radio emissions. Jupiter emissions read at very low frequencies so when building the telescope it had to be able to read less than 39.5 MHz. The projected outcome was to receive long L-bursts and short S-bursts signals; however, during the time of observation Jupiter was in conjunction with the Sun. We then decided to use the receiver

built from the NASA Radio Jove Kit to hook it up to the Karl Jansky telescope to make an effort to listen to solar flares as well, nonetheless, we were unable to identify these signals and further realized they were noise. The overall project was a success in that we were able to apply and comprehend, the principles of Systems Engineering to facilitate the build.

**Author(s):** Adria J Peterkin<sup>1</sup>

**Institution(s):** 1. National Radio and Astronomy Observatory

### **249.08 – The Value of Methodical Management: Optimizing Science Results**

As science progresses, making new discoveries in radio astronomy becomes increasingly complex. Instrumentation must be incredibly fine-tuned and well-understood, scientists must consider the skills and schedules of large research teams, and inter-organizational projects sometimes require coordination between observatories around the globe. Structured and methodical management allows scientists to work more effectively in this environment and leads to optimal science output. This report outlines the principles of methodical project management in general, and describes how those principles are applied at the National Radio Astronomy Observatory (NRAO) in Charlottesville, Virginia.

**Author(s):** Linnea Saby<sup>1</sup>

**Institution(s):** 1. National Radio Astronomy Observatory

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## **250 – Teaching Professional Development for K-12, College, and Other Astronomy Educators Poster Session**

### **250.02 – Teacher-Scientist-Communicator-Learner Partnerships: Reimagining Scientists in the Classroom.**

We present results of our work to reimagine Teacher-Scientist partnerships to improve relationships and outcomes. We describe our work in implementing Teacher-Scientist partnerships that are expanded to include a communicator, and the learners themselves, as genuine members of the partnership. Often times in Teacher-Scientist partnerships, the scientist can often become more easily described as a special guest into the classroom, rather than a genuine partner in the learning experience. We design programs that take the expertise of the teacher and the scientist fully into account to develop practical and meaningful partnerships, that are further enhanced by using an expert in communications to develop rich experiences for and with the learners. The communications expert may be from a broad base of backgrounds depending on the needs and desires of the partners -- the communicators include, for example: public speaking gurus; journalists; web and graphic designers; and American Sign Language interpreters. Our partnership programs provide online support and professional development for all parties. Outcomes of the program are evaluated in terms of not only learning outcomes for the students, but also attitude, behavior, and relationship outcomes for the teachers, scientists, communicators and learners alike.

**Author(s):** Jacob Noel-Storr<sup>1</sup>, Michael Terwilliger<sup>1</sup>

**Institution(s):** 1. InsightSTEM, Inc.

**Contributing team(s):** InsightSTEM Teacher-Scientist-Communicator-Learner Partnerships Team

### **250.03 – Best Practices for Effective Poster Design**

This meta-poster illustrates how good poster design can effectively communicate scientific ideas to a broad professional audience. Inclusion of illustrative figures supplemented by concise explanations of scientific information will provide a clear overview of your science to aid your oral pitch.

**Author(s):** Kimberly Michelle Star Cartier<sup>1</sup>, Ming Zhao<sup>1</sup>, Thomas G. Beatty<sup>1</sup>, Robert C. Morehead<sup>1</sup>, Daniel Jontof-Hutter<sup>1</sup>

**Institution(s):** 1. Pennsylvania State University

## **250.04 – Fostering Student Awareness in Observatory STEM Careers**

It takes more than scientists to run an observatory. Like most observatories, only about 20% of Gemini Observatory's staff is PhD. Scientists, but 100% of those scientists would not be able to do their jobs without the help of engineers, administrators, and other support staff that make things run smoothly. Gemini's Career Brochure was first published in 2014 to show that there are many different career paths available (especially in local host communities) at an astronomical observatory. Along with the printed career brochure, there are supplementary videos available on Gemini's website and Youtube pages that provide a more detailed and personal glimpse into the day-in-the-life of a wide assortment of Gemini employees. A weakness in most observatory's outreach programming point to the notion that students (and teachers) feel there is a disconnect between academics and where students would like to end up in their career future. This project is one of the ways Gemini addresses these concerns. During my 6-month internship at Gemini, I have updated the Career Brochure website conducted more in-depth interviews with Gemini staff to include as inserts with the brochure, and expanded the array of featured careers. The goal of my work is to provide readers with detailed and individualized employee career paths to show; 1) that there are many ways to establish a career in the STEM fields, and 2), that the STEM fields are vastly diverse.

**Author(s):** Alexis Ann Keonaonaokalauae Acohid<sup>1</sup>, Peter D. Michaud<sup>1</sup>

**Institution(s):** 1. Gemini Observatory

**Contributing team(s):** Gemini Public Information and Outreach Staff

### **250.05 – Promoting undergraduate involvement through the University of Arizona Astronomy Club**

The University of Arizona Astronomy Club is devoted to undergraduate success in astronomy, physics, planetary sciences and many other related fields. The club promotes many undergraduate opportunities; research projects, participating in telescope observational runs, sponsoring conference attendance as well as several public outreach opportunities. Research projects involving exoplanet transit observations and radio observations of cold molecular clouds allow undergraduates to experience data collection, telescope operations, data reduction and research presentation. The club hosts many star parties and various other public outreach events for the Tucson, Arizona location. The club often constructs their own outreach materials and structures. The club is currently working on creating a portable planetarium to teach about the night sky on the go even on the cloudiest of nights. The club is also working on creating a binocular telescope with two 10" mirrors as a recreation of the local Large Binocular Telescope for outreach purposes as well. This is a club that strives for undergraduate activity and involvement in a range of academic and extracurricular activities, and is welcoming to all majors of all levels in hopes to spark astronomical interest.

**Author(s):** Allison M. McGraw<sup>1</sup>, Carmen Austin<sup>1</sup>, Matthew Noyes<sup>1</sup>, Jenny Calahan<sup>1</sup>, Jennifer Lautenbach<sup>1</sup>, Andrew Henrici<sup>1</sup>, M. Ryleigh Fitzpatrick<sup>1</sup>, Yancy L. Shirley<sup>1</sup>

**Institution(s):** 1. Steward Observatory

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## **301 – Probing Early-type Galaxies**

### **301.01 – Probing Early-Type Galaxy Halos Using Planetary Nebulae**

Planetary nebulae offer an invaluable probe of the stellar kinematics at very large radii in early-type galaxies, reaching regimes where we can learn about both the dark matter halo of the system and the formation history of the stellar component. We present results from the largest kinematic survey to-date of extragalactic planetary nebulae in the outer halos early-type galaxies, obtained using the custom Planetary Nebula Spectrograph instrument. The survey currently comprises validated homogeneous catalogs for 33 early-type galaxies, with data typically extending to beyond 5 effective radii.

This survey confirms that planetary nebulae trace the bulk stellar population very closely, allowing these data to be combined with more conventional absorption-line spectral studies at smaller radii. Analysis shows that: (1) there is a kinematic dichotomy amongst the galaxies between those that display rapidly-falling velocity dispersion profiles and those where the dispersion remains roughly constant with radius – a distinction that reflects both orbital and mass profile differences; (2) rotation in outer regions correlates strongly with rotation in inner regions – they are fairly monolithic systems; (3) the velocity field usually contains symmetries that indicate triaxiality; (4) some systems have outer velocity fields that imply these regions are not in any sort of equilibrium.

**Author(s):** Michael Merrifield<sup>4</sup>, Magda Arnaboldi<sup>1</sup>, Lodovico Coccato<sup>1</sup>, Ortwin Gerhard<sup>3</sup>, Nicola Napolitano<sup>2</sup>, Claudia Pulsoni<sup>3</sup>  
**Institution(s):** 1. ESO, 2. INAF, 3. MPE, 4. Nottingham University  
**Contributing team(s):** The Planetary Nebula Spectrograph Collaboration

### 301.02D – Where stellar halos coexist with intracluster light: a case study of the giant Virgo-central galaxy M87

What is the role that accretion events play in the evolution of galaxies in dense environments, such as galaxy clusters? Cosmological simulations allow us to study in detail the evolution of galaxies' halos in cluster environments and have shown that the formation of extended halos around central cluster galaxies and intracluster light (ICL) is closely correlated to the morphological transformation of galaxies in clusters. However, the extremely low surface brightness of these components makes it difficult to gather observational constraints. Planetary nebulas (PNs) offer a unique tool to investigate these environments owing to their strong [OIII] emission line. I will present a study of the light and stellar motion in the halo of the giant elliptical galaxy M87 and its surrounding IC component at the centre of the Virgo cluster, prime targets to shed light on the hierarchical assembly of structure in the Universe. We make use of a deep and extended PN sample (~ 300 objects) to study out to ~150 kpc in radius M87. We show that at all distance the galaxy halo overlap with the Virgo ICL. However, they are dynamically distinct components with different density profiles, and parent stellar populations, consistent with the halo of M87 being redder and more metal rich than the ICL. Moreover, the synergy between PN kinematical information and deep V/B-band photometry made it possible to unveil an ongoing accretion process in the outskirts of M87, that has caused a non-negligible modification of the halo properties. The ongoing assembly of this galaxy at distances  $R > 60$  kpc is also shown by the overall PN halo kinematics, reflecting the dynamical complexity of a still growing system.

**Author(s):** Alessia Longobardi<sup>1</sup>  
**Institution(s):** 1. Max-Planck-Institut für extraterrestrische Physik

### 301.03 – Central stellar mass deficits of early-type galaxies

The centers of giant galaxies display stellar mass deficits ( $M_{\text{def}}$ ) which are thought to be a signature left by inspiraling supermassive black holes (SMBHs) from pre-merged galaxies. We quantify these deficits using the core-Sérsic model for the largest ever sample of early-type galaxies and find  $M_{\text{def}} \sim 0.5$  to  $4 M_{\text{BH}}$  (SMBH mass). We find that lenticular disc galaxies with bulge magnitudes  $M_V \leq -21.0$  mag also have central stellar deficits, suggesting that their bulges may have formed from major merger events while their surrounding disc was subsequently built up, perhaps via cold gas accretion scenarios. Interestingly, these bulges have sizes and mass densities comparable to the compact galaxies found at  $z \sim 1.5$  to  $2$ .

**Author(s):** Bililign Tsige Dullo<sup>1</sup>, Alister Graham<sup>2</sup>  
**Institution(s):** 1. Instituto de Astrofísica de Canarias - IAC, 2. Swinburne University

### 301.04 – The X-ray halos of the most MASSIVE

### galaxies in the Universe

Despite decades of research, the assembly history and evolution of the most massive elliptical galaxies in the Universe remains mysterious. The physical properties (gas temperatures, halo masses, stellar kinematics etc.) of local elliptical galaxies are now being probed in depth by studies such as Atlas3D. However, due to their limited volume, these studies still do not include the most massive galaxies. Here I will present our investigation of the X-ray and optical properties of a complete sample of  $M > 10^{11} M_{\odot}$  sources within the MASSIVE Galaxy Survey (Ma et al. 2014), extending the previous Atlas3D analyses by an order of magnitude in K-band luminosity. We harness the exquisite spatial resolution and sensitivity of the Chandra X-ray observatory, combined with integral field optical spectroscopy, to provide the most complete and unbiased picture, to date, for the effect of large and small scale environment on the evolution of elliptical galaxies.

**Author(s):** Andy D. Goulding<sup>5</sup>, Jenny E. Greene<sup>5</sup>, Chung-Pei Ma<sup>6</sup>, Nicholas J. McConnell<sup>2</sup>, John Blakeslee<sup>4</sup>, Akos Bogdan<sup>1</sup>, Jens Thomas<sup>3</sup>  
**Institution(s):** 1. Harvard Smithsonian, CfA, 2. IfA Hawaii, 3. MPE, 4. NRC Herzberg, 5. Princeton University, 6. UC Berkeley

### 301.05 – Outflows in Sodium Excess Objects

van Dokkum and Conroy reported that some giant elliptical galaxies show extraordinarily strong Na I absorption lines and suggested that this is the evidence of unusually bottom-heavy initial mass function. Jeong et al. later studied galaxies with unexpectedly strong Na D absorption lines (Na D excess objects: NEOs) and showed that the origins of NEOs are different for different types of galaxies. According to their study, the origin of Na D excess seems to be related to interstellar medium (ISM) in late-type galaxies, but there seems to be no contributions from ISM in smooth-looking early-type galaxies. In order to test this finding, we measured the Doppler components in Na D lines of NEOs. We hypothesized that if Na D absorption line is related to ISM, the absorption line is more likely to be blueshifted in the spectrum by the motion of ISM caused by outflow. Many of late-type NEOs show blueshifted Na D absorption lines, so their origin seems related to ISM. On the other hand, smooth-looking early-type NEOs do not show Doppler departure and Na D excess in early-type NEOs is likely not related to ISM, which is consistent with the finding of Jeong et al.

**Author(s):** Jongwon Park<sup>2</sup>, Hyunjin Jeong<sup>1</sup>, Sukyoung Yi<sup>2</sup>  
**Institution(s):** 1. Korea Astronomy and Space Science Institute, 2. Yonsei University

## 302 – Planetary Nebulae and Supernova Remnants

### 302.01 – Analysis of Co-spatial UV-Optical STIS Spectra of Seven Planetary Nebulae From HST Cycle 19 GO 12600

We present an analysis of seven spatially resolved planetary nebulae (PNe), NGC 2440, NGC 3242, NGC 5315, NGC 5882, NGC 7662, IC 2165, and IC 3568, from observations in the Cycle 19 program GO 12600 using HST STIS. These seven observations cover the wavelength range 1150-10,270 Å with 0.2 and 0.5 arcsec wide slits, and are co-spatial to within 0.1 arcsec along a 25 arcsec length across each nebula. The wavelength and spatial coverage enabled a detailed study of physical conditions and abundances from UV and optical line emissions (compared to only optical lines) for these seven PNe. The first UV lines of interest are those of carbon. The resolved lines of C III] 1906.68 and 1908.73 yielded a direct measurement of the density within the volume occupied by doubly-ionized carbon and other similar co-spatial ions as well as contributed to an accurate measurement of the carbon abundance. Each PN spectrum was divided into smaller spatial regions or segments in order to assess inferred density variations among the regions along the entire slit. There is a clear difference in the inferred density for several regions of each PNe. Variations in electron temperature and chemical abundances were also probed and shown to be completely homogeneous within the errors. Lastly, these nebulae were modeled

in detail with the photoionization code CLOUDY. This modeling constrained the central star parameters of temperature and luminosity and tested the effects different density profiles have on these parameters. We gratefully acknowledge generous support from NASA through grants related to the Cycle 19 program GO 12600, as well as from the University of Oklahoma.

**Author(s):** Timothy R. Miller<sup>4</sup>, Richard B. C. Henry<sup>4</sup>, Reginald J. Dufour<sup>3</sup>, Karen B. Kwitter<sup>6</sup>, Richard A. Shaw<sup>2</sup>, Bruce Balick<sup>5</sup>, Romano Corradi<sup>1</sup>

**Institution(s):** 1. IAC, 2. NOAO, 3. Rice University, 4. University of Oklahoma, 5. University of Washington, 6. Williams College

### 302.02 – SN 1987A: Chandra Witnesses the End of an Era

Due to its age and close proximity, the remnant of SN 1987A is the only supernova remnant in which we can study the early developmental stages in detail, providing insight into stellar evolution, the mechanisms of the supernova explosion, and the transition from supernova to supernova remnant as the debris begins to interact with the surrounding circumstellar medium (CSM). We present 16 years of Chandra ACIS observations of SN 1987A, covering 4600 -10500 days after the supernova. The X-ray emission traces the progress of the blast wave and functions as a probe of the CSM. About 4000 days after the explosion, the blast wave began interacting with a dense equatorial ring created by winds of the progenitor. With Chandra, we are able to resolve this ring and monitor how it changes over time. Changes in the size and morphology of the ring and changes in the X-ray light curve reveal several turning points in the evolution of this newborn supernova remnant which indicate it may now be entering a new era in its evolution. A sudden drop in the radial expansion velocity of the ring from 7200 km/s to 1900 km/s and corresponding upturn in the soft X-ray light curve indicated the onset of interaction with the full equatorial ring at day 6000. At approximately day 7500, the east-west asymmetry of the ring began to reverse, while the spectra and soft X-ray light curve revealed that the increase in soft X-ray emission slowed dramatically. This suggests the average CSM density encountered by the blast wave decreased at this time, likely due to either a density gradient in the outer parts of the ring or the blast wave exiting the ring in the east. Since day 9700 the soft X-ray light curve has flattened and remained approximately constant, evidence that the blast wave has now left the dense material of the known equatorial ring and is beginning to probe the unknown territory beyond.

**Author(s):** Kari A. Frank<sup>1</sup>, David N. Burrows<sup>1</sup>

**Institution(s):** 1. Pennsylvania State University

### 302.03 – Dynamics of a Type Ia Supernova Remnant: X-ray and Radio Proper Motions in Tycho's SNR

We present results from new Chandra X-ray and JVLA radio observations of Tycho's supernova remnant, the remains of the supernova of 1572 A.D. The high spatial resolution of these instruments allows for accurate measurements of the proper motion of the forward shock in Tycho, with baselines now at 15 years for the X-ray data and 30 years for the radio. Type Ia SNe are of fundamental importance in astrophysics, yet the nature of their environments and progenitor systems is poorly understood. In a recent work, we have shown that the ISM surrounding Tycho varies systematically in density by a factor of 5, with larger excursions in some locations. A substantial density variation is consistent with limited previous proper motion studies that have been done in radio and X-rays. Our expanded baseline measurements allow us to further explore the variations in the dynamics of the shock wave, which can also be used to localize the explosion site. Previous proper motion measurements, made over much shorter time baselines, have shown some discrepancies in the shock velocity as measured in radio and X-rays. With our new, much improved data, we can compare proper motions in these two energy bands with much greater accuracy.

**Author(s):** Brian J. Williams<sup>2</sup>, John M. Blondin<sup>3</sup>, Kazimierz J. Borkowski<sup>3</sup>, Laura Chomiuk<sup>1</sup>, Parviz Ghavamian<sup>4</sup>, John W. Hewitt<sup>5</sup>, Robert Petre<sup>2</sup>, Stephen P. Reynolds<sup>3</sup>

**Institution(s):** 1. Michigan State University, 2. NASA Goddard, 3. North Carolina State University, 4. Towson University, 5. University of North Florida

### 302.04D – A Survey For Broadened CO Lines Toward Galactic Supernova Remnants

We performed molecular spectroscopy in 12CO J=2-1 with the Heinrich Hertz Submillimeter Telescope toward 50 Galactic supernova remnants as part of a systematic survey for broad molecular line regions indicative of interactions with molecular clouds. These observations revealed broad molecular lines toward nineteen remnants, including nine newly identified associations between molecular clouds and remnants. Morphology of the molecular emission suggests molecular shocks can arise at large separations from the remnants, consistent with a scenario where high-velocity ejecta from bipolar outflows or fast-moving knots shocks nearby molecular clouds. Also, broadened 12CO J=2-1 line emission should be detectable toward virtually all supernova remnant/molecular cloud interactions and, therefore, the total number of observed interactions is low. This result favors predictions that SN feedback plays little or no role in star formation over short timescales. In addition, we find no significant association between TeV gamma-ray sources and molecular cloud interactions, contrary to predictions that supernova remnant/molecular cloud interfaces are the primary venues for cosmic ray acceleration.

**Author(s):** Charles Kilpatrick<sup>1</sup>, John H. Bieging<sup>1</sup>, George Rieke<sup>1</sup>

**Institution(s):** 1. University of Arizona

### 302.05 – Shocked Gas from the supernova remnant G357.7+0.3

We present detection of hydrogen molecular hydrogen (H<sub>2</sub>) in mid-infrared using the Spitzer IRS. The supernova remnant (SNR) G357.7+0.3 is one of relatively unknown and under-studied SNRs. We performed an IRS spectral mapping centered on the northwestern shell of G357.7+0.3. The observations covered an area of 75arcsec x 60arcsec with short-low (SL) and 170arcsec x 55arcsec with long-low (LL). All rotational H<sub>2</sub> lines within the IRS wavelength range are detected except S(6) line. Interestingly, G357.7+0.3 shows lack of ionic lines compared with those in other SNRs observed. Only ionic line detected is [Si II] at 34.8micron. The detection of H<sub>2</sub> line is an evidence that G357.7+0.3 is interacting with dense molecular clouds. This is the first evidence showing that G357.7+0.3 is an interacting SNR with clouds. We generated a H<sub>2</sub> excitation diagram. A two-temperature fit yields a low temperature of 197 K with a column density 2.3E21/cm<sup>2</sup> and a high temperature of 663 K with a column density of 2.7E19/cm<sup>2</sup>. We performed high-J CO and OH observations with The German REceiver for Astronomy at Terahertz Frequencies (GREAT) on board of Stratospheric Observatory for Infrared Astronomy (SOFIA), but no lines are detected. We provide the upper limits of the lines. We also present millimeter observations of the SNR. The observations were made with the Arizona-MPIfR Heinrich Hertz Submillimeter Telescope (HHT), Arizona 12 Meter Telescope, and Atacama Pathfinder Experiment (APEX) Telescope. We discuss physical conditions of shocked gas in G357.7+0.3.

**Author(s):** Jeonghee Rho<sup>4</sup>, John Hewitt<sup>3</sup>, William T. Reach<sup>6</sup>, John H. Bieging<sup>5</sup>, Morten Andersen<sup>1</sup>, Rolf Güsten<sup>2</sup>

**Institution(s):** 1. Gemini Observatory, 2. Max Planck Institut für Radioastronomie, 3. NASA Goddard Space Flight Center, 4. SETI Institute and NASA Ames Research Center, 5. Univ. of Arizona, 6. USRA/SOFIA

### 302.06D – Characterizing Supernova Remnant and Molecular Cloud Interaction Sites Using Methanol (CH<sub>3</sub>OH) Masers

Astronomical masers are useful probes of the physical conditions of the gas in which they are formed. Masers form under specific physical conditions and therefore, can be used to trace distinct environments. In particular, collisionally excited 36 and 44 GHz

methanol ( $\text{CH}_3\text{OH}$ ) and 1720 MHz hydroxyl ( $\text{OH}$ ) masers are found associated with shocked gas produced by the interaction between supernova remnants (SNRs) and molecular clouds (MCs). The overall goal of my thesis research is to combine modeling and observations to characterize the properties and formation of  $\text{CH}_3\text{OH}$  masers in these SNR/MC interaction regions. More accurate information of the density (and density gradients) could, for example, be used as inputs or constraints for models of SNR cosmic ray acceleration. In this talk, I will present results from calculations of the physical conditions necessary for the occurrence of 36.169, 44.070, 84.521, and 95.169 GHz  $\text{CH}_3\text{OH}$  maser lines near SNRs, using a coupled radiative transfer and level population code. The modeling shows that given a sufficient  $\text{CH}_3\text{OH}$  abundance,  $\text{CH}_3\text{OH}$  maser emission arises over a wide range of densities and temperatures, with optimal conditions at  $n \sim 10^4$  to  $10^6 \text{ cm}^{-3}$  and  $T > 60 \text{ K}$ , overlapping with masing conditions for  $\text{OH}$  masers. Furthermore, the 36 and 44 GHz transitions display more significant maser optical depths compared to the 84 and 95 GHz transitions over the majority of the physical conditions. The line intensity ratios between multiple transitions significantly change with altering physical conditions and can be used to constrain the physical parameters of the gas where  $\text{CH}_3\text{OH}$  masers are detected. I use the modeling results as a diagnostic tool to interpret the observational results of a sample of SNRs with previous and recent  $\text{CH}_3\text{OH}$  maser detections (G1.4-0.1, W28, Sgr A East, G5.7-0.0, W44 and W51C). I will also discuss the close spatial and kinematic correlation of  $\text{CH}_3\text{OH}$  masers and ammonia ( $\text{NH}_3$  (3,3)) emission peaks, which is a reliable method for locating  $\text{CH}_3\text{OH}$  masers and may help determine the density structure in SNRs. By combining modeling and observations of different molecular species, I aim to develop a comprehensive picture of the gas structure in an SNR/MC interaction region.

**Author(s):** Bridget McEwen<sup>2</sup>, Ylva Pihlstrom<sup>2</sup>, Loran Sjouwerman<sup>1</sup>

**Institution(s):** 1. National Radio Astronomy Observatory, 2. The University of New Mexico

### 302.07 – What We Can Learn From Supernova Remnant Size Distributions

Previous literature regarding size distributions of supernova remnants generally discuss a uniform distribution for the radius, occasionally considering a Gaussian alternative. We indeed show that these distributions are consistent with log-normal, which can be considered a natural consequence of the Central Limit Theorem and Sedov expansion. Modeling explosion energy, remnant age, and ambient density as independent, random distributions, we show, using simple Monte Carlo simulations, that the size distribution is indistinguishable from log-normal when the SNR sample size is of order three hundred. This implies that these SNR distributions provide only information on the mean and variance, yielding additional information only when the sample size grows large. We then proceed to Bayesian statistical inference to characterize the information provided by the size distributions. In particular, we use the mean and variance of sizes and explosion energies to subsequently estimate the mean and variance of the ambient medium surrounding SNR progenitors. This in turn allows us to characterize potential bias in studies involving samples of supernova remnants.

**Author(s):** Benjamin Elwood<sup>1</sup>, Jeremiah Murphy<sup>1</sup>, Mariangelly Diaz<sup>1</sup>

**Institution(s):** 1. Florida State University

## 303 – AGN, QSO, Blazars: Dust, Obscuration, and Star Formation

### 303.01 – The star formation-AGN interplay in merging galaxies: insights from hydrodynamical simulations and observations.

Thermal emission from an Active Galactic Nucleus (AGN) can provide a significant contribution to the bolometric luminosity of galaxies, and its effect at infrared wavelengths can mimic the process

of star-formation, jeopardizing star formation rate (SFR) diagnostics. It is therefore important to model the AGN emission and to quantify its effect on the estimated SFRs when SED fitting tools are applied. We tackle this problem by studying the dust radiative transfer calculations of hydrodynamically simulated binary galaxy mergers covering a broad range of parameters, including stellar mass ratios, gas contents, AGN luminosity and viewing angles. We apply the energy balance SED fitting codes CHIBURST and CIGALE to the mock SEDs of our simulated merger, and then compare with the results of applying the same codes to the SEDs of observed merging galaxies in the Local Universe. At different stages of the interaction, we compare their derived SFRs and AGN fractions with those predicted by the hydrodynamical simulations, for a broad range of the interaction parameters, but focus on the stages near coalescence, when the AGN contribution exceed 10% of the total luminosity. We show that the contribution to IR luminosity is greatest during and immediately after coalescence, when the two supermassive black holes of the interacting pair merge and undergo an enhanced period of accretion. Under certain conditions, CIGALE succeeds at recovering the SFRs and AGN fractions with higher accuracy than other available codes, such as MAGPHYS, even during these extreme stages. Our results show that using the IR luminosity as a simple surrogate for star formation can significantly overestimate the true SFR by underestimating the contribution from the AGN. Finally, we study the effect of using different parametric star formation histories (SFHs) when fitting the SEDs of galaxies, and show that a delayed SFH is usually a reasonable choice for merging galaxies.

**Author(s):** Juan R. Martinez Galarza<sup>4</sup>, Howard Alan Smith<sup>4</sup>, Aaron Weiner<sup>3</sup>, Christopher C. Hayward<sup>1</sup>, Lorraine Lanz<sup>1</sup>, Andreas Zezas<sup>4</sup>, Lee Rosenthal<sup>2</sup>, Matthew Ashby<sup>4</sup>

**Institution(s):** 1. California Institute of Technology, 2. Heidelberg Institute for Theoretical Studies, 3. Rensselaer Polytechnic Institute, 4. Smithsonian Astrophysical Observatory

### 303.02D – The Star-Forming Properties of an Ultra-Hard X-ray Selected Sample of AGN

We present new results on the relationship of star formation to active galactic nuclei (AGN) activity in an ultra-hard X-ray selected sample which show a significant difference in the star-forming properties of AGN hosts both in the star formation rate (SFR) and the location of the star formation. While the observed scaling relations between galaxies and the supermassive black holes (SMBH) they host as well as numerical simulations suggest a star formation AGN connection, popular methods for measuring the SFR of galaxies are routinely contaminated by emission related to the AGN. Further selection methods for constructing samples of AGN are often biased due to obscuration and host galaxy contributions. We selected over 300 AGN in the 14-195 keV energy range to be observed with the Herschel Space Observatory and study their star forming properties in the FIR (70-500  $\mu\text{m}$ ) and allowing us to construct the most complete IR spectral energy distributions (SED) for a large, relatively unbiased sample of AGN. We used SED decomposition techniques to measure the dust temperatures, dust masses, SFR, and IR AGN fractions and compared them to non-AGN star-forming galaxies. The AGN host galaxies lie systematically below the main sequence of star formation primarily due to reduced levels of star formation. This is possibly the first direct indication of large scale AGN feedback affecting galaxies. The FIR morphology of AGN host galaxies are also more compact than normal star-forming galaxies which suggests either suggests a large portion of the FIR originates from the AGN or star-formation primarily occurs near the nucleus. In our analysis a significant fraction of the emission at 70  $\mu\text{m}$  can be associated with the AGN and any estimates of the SFR based on it are overestimated. Finally, I will discuss our measured SFR-AGN correlation and put it in context with the current understanding of galaxy and SMBH growth.

**Author(s):** Thomas Shimizu<sup>1</sup>, Richard Mushotzky<sup>1</sup>

**Institution(s):** 1. University of Maryland, College Park

### 303.03 – The relationship between AGN accretion luminosity and host star formation in dusty AGNs

We study the relationship between X-ray luminosity and the star formation rate (SFR) for a sample of dusty active galactic nuclei

(AGNs) at  $0.04 < z < 3.3$ . Our sample consists of dusty AGNs detected in both X-ray and far-Infrared by XMM and Herschel in the XMM-LSS field. All of the selected targets have spectroscopic redshifts and broad band photometry that allows black hole mass and spectral energy distribution (SED) analysis. We compare their X-ray and AGN-removed infrared luminosities, and find a positive correlation between  $L_X$  and SFR up to  $z=3$ . This is consistent with the secular evolution scenario, in which the nucleus and galaxy are fueled by the same gas supply at a relatively constant ratio. We study the dependence of the observed relation on luminosity, obscuration, supermassive black hole mass, Eddington ratio, and the fraction of AGN contribution to infrared luminosity. We also investigate the effect of binning choices on the observed trend. Comparing our results to those in the literature, we propose a unified physical scenario that explains the observed  $L_X$ -SFR connection once sample selection bias is accounted for.

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### 303.04D – Dust Obscured AGN are Masquerading as Star Formation in the Early Universe

The buildup of stellar and black hole mass peaked during  $z=1-3$ , making this a key epoch for understanding how the interplay of star formation and an active galactic nucleus (AGN) drive galaxy evolution. IR luminous galaxies, which are massive and heavily dust obscured ( $L_{IR} > 10^{11} L_{sun}$ ), dominate the stellar growth during this era, and many are harboring a hidden AGN. I have quantified the contribution of AGN heating to the infrared emission of 343 IR luminous galaxies from  $z=0.5-2.8$  using Spitzer mid-IR spectroscopy, available for every source, making this an unprecedented sample. I classify sources as star forming galaxies, AGN, or composites based on the presence of mid-IR continuum emission due to a dusty torus. My findings are: 1) Surprisingly, 60% of IR luminous galaxies show signs of some dust heating emanating from an AGN. I quantify the far-IR emission using deep Herschel imaging and find that the strength of mid-IR AGN emission is tightly correlated with the total contribution of an AGN to LIR, which has important consequences for calculating star formation rates in dusty high redshift galaxies. I demonstrate techniques to remove the contribution of AGN to LIR when mid-IR spectroscopy is available and when only limited photometry is available. 2) The composites are a separate class of galaxy which show a true mix of star formation and AGN activity in their mid- and far-IR emission. Because of dust obscuration, this activity is largely undetected at other wavelengths. This composite population is important for understanding galaxy evolution and makes up at least 30% of the deepest IR selected samples. I underscore the importance of considering composite galaxies separately in studies of star formation and black hole growth at high redshift.

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### 303.05 – Dust Obscuration and Observable Emission of Active Galactic Nuclei

The presence of toroidal distributions of obscuring material around active galactic nuclei (AGN) coherently accounts for many of their diverse observed properties. However, high spatial resolution observations that show dust emission extended along the polar axis in some cases would seem to contradict this basic geometric picture. We present simulations of clumpy dust distributions to demonstrate the variety of emission patterns that may emerge, which are dependent on wavelength and spatial scale. Data from ALMA currently and JWST in the future may distinguish some of the physical properties of the different AGN environments in detail. Fundamentally, the distribution of the emission does not necessarily match the distribution of material.

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### 303.06D – The Environments of Obscured Quasars

Supermassive Black Hole (SMBH) feedback is prescribed for driving the high-end shape of the galaxy luminosity function, clearing the circumnuclear environment during the end stages of mergers, and eventually turning off its own accretion. Yet the dominant processes and characteristics of active galactic nuclei are indistinct. Chief among this confusion is how significant the role of dust is in each galaxy. Orientation of the dusty torus is attributed to causing the differences between Sy1 and Sy2, but whether obscured quasars are found in particularly dusty host galaxies, if they exist at a different stage in the merger process (early on, before the dust is blown out), or if they are merely oriented differently than optical quasars is not yet so well distinguished. With obscured quasars now observed to make up 50% or greater of the population of quasars, the question of what causes obscuration becomes vital to address. With this in mind, I study matched samples of obscured and unobscured quasars to characterize their environments, with the intent of addressing what contribution environment has to obscuration levels. I investigate the megaparsec-scale environments of SIRTf Wide-field Infra-Red Extragalactic Survey (SWIRE) quasars at  $z \sim 1-3$  by cross-correlating the sample with 3.8 million galaxies from the Spitzer Extragalactic Representative Volume Survey (SERVS). Optically obscured quasars are compared to a control sample of optically-bright quasars via selection in the mid-infrared. Environments were observed at 3.6 and 4.5  $\mu m$  to a depth of  $\approx 2 \mu Jy$  ( $AB = 23.1$ ). Recent work has found diverse results in such studies, with dependence of environmental richness on both redshift and level of obscuration. I find that, within reasonable error, on average there is no distinct difference between the level of clustering for obscured and normal quasars, and that there is no dependence on redshift of this result within the range of  $1.3 < z < 2.5$ . I compare our results with recent studies and investigate the role of selection criteria in the assessment of clustering. I also explore the large scale SED structure of obscured and unobscured quasar host galaxies.

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## 304 – Star Formation and Massive Clusters

### 304.01 – Star Formation Studies in the Magellanic Clouds with JWST

The photometric and spectroscopic *Spitzer* Surveys of the Large and Small Magellanic Clouds (LMC, SMC): Surveying the Agents of Galaxy Evolution (SAGE) resulted in the discovery of thousands of massive young stellar objects. The JWST instruments will have an angular resolution at least 10 times better than *Spitzer* with hundreds or more times better sensitivity. This new capability in the 0.6 to 28 micron range will allow detailed studies of star formation regions at sub-solar metallicity in the LMC ( $\sim 0.5 Z_{sun}$ ) and SMC ( $\sim 0.2 Z_{sun}$ ) at the 0.05 pc scale size which is comparable to Galactic studies. In this presentation, we summarize highlights and open issues from the SAGE surveys and discuss some potential JWST observing programs that focus on the study of star formation at low metallicity in the Magellanic Clouds. Does the interstellar medium gas density threshold for star formation change at low metallicity? Is the dust content and ice composition of young stellar objects modified by the lower metallicity and high radiation fields found in the Magellanic Clouds? Do low metallicity solar mass pre-main sequence stars have sufficient circumstellar dust to form planets? The best regions for JWST followup will have been investigated with ALMA, HST and ground based high angular resolution telescopes. Examples of such regions include 30 Doradus, NGC 602, N159, and NGC 346.

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### 304.02D – The Effect of Metallicity on the Molecular Gas and Star Formation in the Magellanic Clouds

The Magellanic Clouds afford a unique view of the low metallicity star-forming interstellar medium, providing the nearest laboratories to study processes relevant to star formation at high redshifts. We use dust-based molecular gas maps based on the HERITAGE *Herschel* data (Meixner et al. 2013) to evaluate molecular gas depletion times as a function of spatial scale. We compare galaxy-scale analytic star formation models to our observations and find that successfully predicting the trends in the low metallicity data requires the inclusion of a diffuse neutral medium. However, the analytic models do not capture the scatter observed, which computer simulations suggest is driven primarily by the time-averaging effect of star formation rate tracers. The averaging of the scatter in the molecular gas depletion time as a function of scale size suggests that the drivers of the star formation process in these galaxies operate on large scales. Analyzing mid-IR spectroscopy from *Spitzer* in the Small Magellanic Cloud (SMC), we find that the modeling of the mid-infrared H<sub>2</sub> line emission gives temperatures, column densities, and fractions of warm H<sub>2</sub> that are similar to nearby galaxies. On small (~ few pc) scales in the SMC, we study the effect of metallicity on the structure of photodissociation regions using [CII] and [OI] spectroscopy combined with new ALMA ACA maps of <sup>12</sup>CO and <sup>13</sup>CO. We find that the effect of metallicity is more prominent in the lower column density gas, a likely consequence of enhanced photodissociation.

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**Contributing team(s):** HERITAGE Collaboration

### 304.03 – Investigating the Gao & Solomon Relationship with MALT90

In an survey of 53 galaxies, Gao & Solomon (2004) found a tight linear relationship between the infrared luminosity (a proxy for the star formation rate) and the HCN(1–0) luminosity, which is known as the Gao & Solomon relationship. Wu et al. (2005, 2010) found that this relationship extends from these extragalactic sources to the much less luminous Galactic clumps (~1 pc scales), and posited that there exists a fundamental unit for the ratio between infrared luminosity and dense gas mass for high-mass star-forming clumps. The luminosities of the Gao & Solomon (2004) galaxies could then be explained as a summation of this fundamental unit in the form of high-mass star-forming clumps. We test this explanation and other possible origins of the Gao-Solomon relationship using high-density tracers (including HCN(1–0), N<sub>2</sub>H+(1–0), HCO+(1–0), HNC(1–0), HC<sub>3</sub>N(10–9), and C<sub>2</sub>H(1–0)) for ~400 Galactic clumps from the Millimetre Astronomy Legacy Team 90 GHz (MALT90) survey. Along with ancillary data, we find that this fundamental unit is not likely to exist at the clump-scale. Specifically, there are not enough high-mass clumps in the Milky Way to achieve the total expected luminosity of the Galaxy. Extended infrared emission, which often lacks high-mass clumps, adds significant (and probably dominant) emission to the total infrared luminosity of a galaxy. Low-mass clumps appear to add a significant, if not dominant, component to a galaxy's total HCN(1–0) luminosity. We suggest that Gao & Solomon relationship could be a result of a universal large-scale star formation efficiency, initial mass function, clump mass function, and core mass function. The power-law slope of the Gao & Solomon relationship probably depends on the critical density of the tracer and the median density of the galaxy, as suggested in theoretical simulations.

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### 304.04 – The UV + IR Hybrid Star Formation Rate Across NGC6946

Knowledge of the star formation rate (SFR) of galaxies is essential to understand galaxy evolution and thus determining reliable, simple tracers of star-forming activity is of paramount importance to astrophysics. For instance, intrinsic ultraviolet (UV) emission from young stars is an excellent tracer of the SFR. Observed UV luminosities, however, have been strongly attenuated by intervening interstellar dust. Since emission from hot dust is readily available from IRAS, *Spitzer*, and WISE, it is common practice to combine mid-IR emission (around 25  $\mu$ m) with observed UV in order to obtain an SFR diagnostic of the form  $L_{\text{obs}}(\text{FUV}) + a_{\text{corr}} \times L_{\text{obs}}(25 \mu\text{m})$ . Conventionally, a single correction  $a_{\text{corr}}$ , previously determined for a sample of galaxies, is used. Here we test the reliability of this hybrid SFR diagnostic, allowing for a variable correction factor  $a_{\text{corr}}$ . For this, we have performed broadband UV-to-IR SED fittings in order to model the star formation histories across the spiral galaxy NGC6946. We have obtained SFRs and stellar masses across the galaxy, from physical scales of 5 kpc down to 500 pc. We find that  $a_{\text{corr}}$  varies significantly across the galaxy and increases with increasing specific star formation rate (sSFR), the ratio of SFR and stellar mass (or the ratio of young and old stars). The correction  $a_{\text{corr}}$  does not seem to be correlated to the amount of attenuation  $A_V$ . Variation of  $a_{\text{corr}}$  is most likely caused by different mixes of young and old stellar populations across the galaxy. This finding agrees well with our previous results for the interacting spiral galaxy NGC 6872, for which we have demonstrated the variation of  $a_{\text{corr}}$  and its correlation with sSFR. Our results show the need of caution when using only two broadband filters in order to determine SFR of individual galaxies or sub-galactic regions. The dust emission most likely overestimates SFR for highly star-forming, high sSFR regions, and underestimates it for more quiescent, low sSFR regions.

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### 304.05D – Sizes of Young Massive Clusters in Nearby Galaxies

Out to distances of a few tens of Mpc, the surface brightness profiles of star clusters can be resolved with HST imaging. At these distances, a typical spiral galaxy will span a few HST imaging fields, so hundreds of star clusters can be readily observed in one pointing. The apparent uniformity in star cluster size across a huge range of mass, age, environment, and metallicity has been noted by many studies and remains unexplained. We measure the half-light radii of YMC populations in nearby galaxies using the galfit software package in an attempt to address this issue. Our analysis reliably shows most YMCs are similar in size with half-light radii of 2-5 pc. In this talk, I will present our results on the shape of the cluster size distribution and its dependence on cluster age, mass, and galaxy environment for YMCs in M83 and NGC 628.

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**Contributing team(s):** LEGUS Team

### 304.06D – An Evolutionary Transition of Massive Star Clusters: Emerging Wolf-Rayet Clusters

It is not yet well understood how massive star clusters emerge from their natal material, despite huge implications for the fate of the cluster itself and potentially to the entire host galaxy. While this evolutionary transition from embedded natal clusters to cleared-out optical star clusters is clearly the result of the star formation, it is important to understand what physical processes are contributing to this feedback. We highlight an overlooked yet potentially significant source of feedback -- Wolf-Rayet (WR) stars. While a massive star cluster is expected to have cleared out before the WR phase, we have identified an emerging cluster, S26 in NGC 4449, that hosts a substantial population of evolved WRs and shows signs of ongoing feedback. We follow up this significant discovery with an observational survey to search for more sources undergoing this evolutionary phase. We obtain optical spectra of a sample of radio-

selected targets (characteristics chosen to identify those early in their evolution) to look for WR signatures; we term successful detections as 'emerging WR clusters'. We evaluate the importance of WR ionization and feedback on massive star cluster evolution and find that while many massive star clusters may emerge quickly, it seems that some might require additional feedback from the WRs.

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## 305 – Future Prospects in Extrasolar Planet Detection

### 305.01 – Exoplanet Yield Estimation for Decadal Study Concepts using EXOSIMS

The anticipated upcoming large mission study concepts for the direct imaging of exo-earths present an exciting opportunity for exoplanet discovery and characterization. While these telescope concepts would also be capable of conducting a broad range of astrophysical investigations, the most difficult technology challenges are driven by the requirements for imaging exo-earths. The exoplanet science yield for these mission concepts will drive design trades and mission concept comparisons.

To assist in these trade studies, the Exoplanet Exploration Program Office (ExEP) is developing a yield estimation tool that emphasizes transparency and consistent comparison of various design concepts. The tool will provide a parametric estimate of science yield of various mission concepts using contrast curves from physics-based model codes and Monte Carlo simulations of design reference missions using realistic constraints, such as solar avoidance angles, the observatory orbit, propulsion limitations of star shades, the accessibility of candidate targets, local and background zodiacal light levels, and background confusion by stars and galaxies. The python tool utilizes Dmitry Savransky's EXOSIMS (Exoplanet Open-Source Imaging Mission Simulator) design reference mission simulator that is being developed for the WFIRST Preliminary Science program. ExEP is extending and validating the tool for future mission concepts under consideration for the upcoming 2020 decadal review. We present a validation plan and preliminary yield results for a point design.

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### 305.03 – The WFIRST Microlensing Survey: Expectations and Unexpectedness

The WFIRST microlensing survey will provide the definitive determination of the demographics of cool planets with semimajor axes  $> 1$  AU and masses greater than that of the Earth, including free-floating planets. Together with the results from Kepler, TESS, and PLATO, WFIRST will complete the statistical census of planets in the Galaxy. These expectations are based on the most basic and conservative assumptions about the data quality, and assumes that the analysis methodologies will be similar to that used for current ground-based microlensing. Yet, in fact, the data quality will be dramatically better, and information content substantially richer, for the WFIRST microlensing survey as compared to current ground-based surveys. Thus WFIRST should allow for orders of magnitude improvement in both sensitivity and science yield. We will review some of these expected improvements and opportunities (the "known unknowns"), and provide a "to do list" of what tasks will need to be completed in order to take advantage of these opportunities. We will then speculate on the opportunities that we may not be aware of yet (the "unknown unknowns"), how we might go about determining what those opportunities are, and how we might figure out what we will need to do to take advantage of them.

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### 305.04 – Transiting Planets with LSST: Unique Opportunities and Challenges

The Large Synoptic Survey Telescope (LSST) will survey over 18,000 square degrees of the sky for ten years. LSST will collect several hundred multi-band photometric observations of approximately one billion stars, while a small portion of the sky (around 100 square degrees) will be observed around ten thousand times. LSST was not designed to detect exoplanets; however, we have demonstrated that several kinds of transiting exoplanets can be recovered in simulated LSST observations. This includes exoplanets around host stars that have not been frequently targeted by transiting planet searches, such as the galactic bulge, star clusters, nearby red dwarfs, and even the Large Magellanic Cloud. For high-cadence fields, the expected detection rates are a significant improvement over the regular-cadence fields and provide a strong incentive to consider exoplanet detections in choosing LSST's high-cadence fields. We continue to investigate questions that still remain for quantifying planet yields using current detection methods, comparing detection methods to find those that will be most efficient, and examining how to incorporate false positives.

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### 305.05 – Period Recoverability of Exoplanets Using LSST: A Yearly Yield Analysis

The Large Synoptic Survey Telescope (LSST) will generate light curves for approximately 1 billion stars over the course of its ten year initial mission. The majority of LSST light curves will contain about 1000 data points (so-called regular cadence) while select fields will have 10000 data points (deep-drilling cadence). Lund et al. (2015) demonstrated that several configurations of exoplanetary systems could be recovered using LSST in areas currently underrepresented in planet searches; i.e. the galactic bulge, the Magellanic clouds, and nearby red dwarfs. A fundamental question in working with LSST data is how time-sensitive detection of transient phenomena will affect the rate and type of expected scientific discoveries. Specifically, we aim to examine how quickly significant science results be achievable over the course of LSST's ten-year mission. We apply a methodology established in Jacklin et al. (2015) designed to examine hot Jupiter detectability over a range of planetary periods and radii in LSST's ten-year light curves. Here, we conduct a similar analysis on a yearly basis in order to examine the rate of detection over the course of the LSST mission. We specifically report on how the LSST yield of exoplanet detections evolves on a year-by-year basis for a variety of systems.

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### 305.06 – Direct Exoplanet Imaging with JWST NIRCам: Low-Mass Stars, Low-Mass Planets, and Critical Constraints on Planet Formation

As next generation exoplanet imagers are making their first discoveries, the largest population of stars in the Galaxy, the M dwarfs, are largely unaccounted for in their surveys. However, RV trends and micro lensing have revealed that M dwarfs host a substantial population of Neptune to Jupiter mass planets between  $\sim 1$ -10 AU. The unprecedented sensitivity of NIRCам on the JWST provides direct access to this population of gas-giants. A NIRCам 3 - 5  $\mu$ m survey for such planets will place critical constraints on planet formation by: 1) measuring the luminosities of young, sub-Jupiter mass planets, 2) providing constraints on the peak in the companion surface density vs. separation distribution, and 3) measuring the frequency of  $\leq$  Jupiter mass giants in the outskirts of these systems ( $> 10$  AU). We have carefully constructed a sample of nearby, young, late-type stars, performed NIRCам survey simulations, and will

report on the expected yield and advantages of JWST compared to current ground based capabilities.

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**Institution(s):** 1. ETH Zurich, 2. JPL, 3. NASA Ames Research Center, 4. Princeton University, 5. University of Liege

### 305.07 – Post-GAIA astrometry with JWST AMI for planet masses around nearby M dwarfs

Obtaining the mass for young planets is an important test of giant planet evolution theories. The combination of direct imaging and radial velocity or astrometric monitoring can provide a direct measurement of both planet mass and photometry. The Near-IR Imager and Slitless Spectrograph (NIRISS) on the the James Webb Space Telescope (JWST) will contain a 7-hole non-redundant mask in its pupil that will provide interferometric resolution with good dynamic range. NIRISS aperture masking interferometry (AMI) will provide an order of magnitude better contrast than ground-based aperture masking and be able to observe stars a few orders of magnitude fainter than from the ground. This will enable the detection of young jovian planets at the highest resolution available to JWST at the near-IR wavelengths to follow up GAIA planet detections around nearby M dwarfs within 30pc. Using an analytic model of the AMI PSF we measure the astrometric precision with NIRISS. I will present recent NIRISS cryo-vacuum tests and provide an estimate for astrometric precision with AMI.

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### 305.08 – Progress in the Development of Edge Scatter Control for Starshades

In the field of ExoPlanet detection and characterization, the use of a Starshade, an external occulter in front of a telescope at large separations, has been identified as one of the highly promising methods to achieve the goals. In the last major review (Lawson, JPL D-72279, 2013), the control of scattered sunlight from the edges of the starshade into the telescope was identified as one of the key technology development areas in order to make the starshade feasible. Modeling of the scattered light has resulted in very different results (Casement et al., SPIE Vol. 8442, 4H, 2012, Martin et al., SPIE Vol. 8864, 88641A, 2013) so a campaign of experimentation with edge samples was undertaken to attempt to resolve the discrepancies.

Here, we present our latest results from both modeling efforts and measurement of samples of materials which would be suitable for manufacturing the starshade edge. We have focused on coating metallic samples for ease of fabrication, including measuring the sharpness of an edge that can be fabricated using standard machine shop methods of a variety of materials that are suitable for space application. We then had these samples coated by two suppliers to evaluate how well these coating types would conform to the edge and provide scatter suppression. The results of scatter measurements of these coated edge samples are presented. In addition, we have subjected these samples to a limited set of environments to evaluate their durability and followed up by remeasuring a portion of these exposed samples to compare the scatter suppression before and after environmental exposure.

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**Institution(s):** 1. Northrop Grumman

### 305.09 – Globular Clusters as Cradles of Life and Advanced Civilizations

Globular clusters are bound groups of about a million stars and stellar remnants. They are old, largely isolated, and very dense. We consider what each of these special features can mean for the development of life, the evolution of intelligent life, and the

long-term survival of technological civilizations. We find that, if they house planets, globular clusters provide ideal environments for advanced civilizations that can survive over long times. We therefore propose methods to search for planets in globular clusters. If planets are found and if our arguments are correct, searches for intelligent life are most likely to succeed when directed toward globular clusters. Globular clusters may be the first places in which distant life is identified in our own or in external galaxies.

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## 306 – Extrasolar Planets: Observations I

### 306.01D – Planet Candidate Validation and Spin-Orbit Misalignments from Doppler Tomography

Short-period planets around intermediate-mass ( $\sim 1.5\text{--}2.5 M_{\odot}$ ; A-mid F type) stars are a largely unexplored region of parameter space. These stars' typically rapid rotation and rotationally broadened spectral lines preclude the use of the precise radial velocity measurements that are typically used to discover planets and confirm transiting planet candidates. Nonetheless, exploring this population is important for constraining models of planet formation and migration. I have been using Doppler tomography to investigate this population. As a planet transits a rotating star, it successively obscures regions of the stellar disk with different radial velocities, resulting in a perturbation to the rotationally broadened line profile; this is the Rossiter-McLaughlin effect. In Doppler tomography, I spectroscopically resolve this perturbation and its movement during the transit. This allows me to not only validate transiting planet candidates, as I can show that the transiting object orbits the target star and is not a blended background eclipsing binary, but also to measure the spin-orbit misalignments of these planets. This is the (sky-projected) angle between the stellar spin and planetary orbital angular momentum vectors, and is a statistical probe of planetary migration; different migration mechanisms predict different distributions of spin-orbit misalignments. In this dissertation talk I will discuss my work to validate Kepler planet candidates around rapidly rotating stars using Doppler tomography, and to measure the spin-orbit misalignments of hot Jupiters discovered by ground-based surveys. I will also discuss the use of Doppler tomography to provide additional characterization of planets and their host stars, such as the detection of planetary orbital precession and stellar differential rotation. Finally, I will highlight the potential of current and future missions such as K2 and TESS to expand our knowledge of planets around intermediate-mass stars.

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### 306.02 – Orbital Architectures of Planet-Hosting Binary Systems

We present the first results from our Keck AO astrometric monitoring of Kepler Prime Mission planet-hosting binary systems. Observational biases in exoplanet discovery have long left the frequency, properties, and provenance of planets in most binary systems largely unconstrained. Recent results from our ongoing survey of a volume-limited sample of Kepler planet hosts indicate that binary companions at solar-system scales of 20–100 AU suppress the occurrence of planetary systems at a rate of 30–100%. However, some planetary systems do survive in binaries, and determining these systems' orbital architectures is key to understanding why. As a demonstration of this new approach to testing ideas of planet formation, we present a detailed analysis of the triple star system Kepler-444 (HIP 94931) that hosts five Ganymede- to Mars-sized planets. By combining our high-precision astrometry with radial velocities from HIRES we discover a highly eccentric stellar orbit that would have made this a seemingly hostile site for planet formation. This either points to an extremely robust and efficient planet formation mechanism or a rare case of favorable initial conditions. Such broader implications will be addressed by determining orbital architectures for our larger statistical sample of Kepler planet-hosting systems that have stellar companions on solar

system scales.

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### 306.03 – HST hot-Jupiter transmission spectral survey: from clear to cloudy exoplanets

The large number of transiting exoplanets has prompted a new era of atmospheric studies, with comparative exoplanetology now possible. Here we present the comprehensive results from a Large program with the Hubble Space Telescope, which has recently obtained optical and near-IR transmission spectra for eight hot-Jupiter exoplanets in conjunction with warm Spitzer transit photometry. The spectra show a wide range of spectral behavior, which indicates diverse cloud and haze properties in their atmospheres. We will discuss the overall findings from the survey, comment on common trends observed in the exoplanet spectra, and remark on their theoretical implications.

**Author(s):** David K Sing<sup>10</sup>, Jonathan J. Fortney<sup>8</sup>, Nikolay Nikolov<sup>10</sup>, Hannah Wakeford<sup>4</sup>, Tiffany Kataria<sup>10</sup>, Tom M. Evans<sup>10</sup>, Suzanne Aigrain<sup>12</sup>, Gilda E. Ballester<sup>7</sup>, Adam Seth Burrows<sup>5</sup>, Drake Deming<sup>11</sup>, Jean-Michel Desert<sup>9</sup>, Neale Gibson<sup>2</sup>, Gregory W. Henry<sup>6</sup>, Catherine Huitson<sup>9</sup>, Heather Knutson<sup>1</sup>, Alain Lecavelier des Etangs<sup>3</sup>, Frederic Pont<sup>10</sup>, Adam P. Showman<sup>7</sup>, Alfred Vidal-Madjar<sup>3</sup>, Michael W. Williamson<sup>6</sup>, Paul A. Wilson<sup>3</sup>

**Institution(s):** 1. California Institute of Technology, 2. ESO, 3. IAP, 4. NASA Goddard Space Flight Center, 5. Princeton University, 6. Tennessee State University, 7. University of Arizona, 8. University of California, 9. University of Colorado, 10. University of Exeter, 11. University of Maryland, 12. University of Oxford

### 306.05 – Ground-Based Evidence of Spectroscopic Features in the Atmosphere of HAT-P-26b

HAT-P-26b is a low-density, Neptune-mass exoplanet that transits its K1 host star every 4.2 days. With an equilibrium temperature of ~990 K, its atmosphere is expected to contain appreciable amounts of water and methane. However, due to obscuring clouds, the detection of spectroscopic features in other planetary atmospheres of comparable temperature has been elusive. Using Magellan's recently-upgraded LDSS-3C detector, we performed transmission spectroscopy observations of HAT-P-26b in the red optical (0.7 - 1.0  $\mu\text{m}$ ) and acquired broadband Spitzer measurements at 3.6 and 4.5  $\mu\text{m}$ . We will present the first constraints on the transmission spectrum of HAT-P-26b, which favor the detection of spectroscopic features and argue against the presence of thick, high-level clouds. We will also compare our findings to those of other characterized exoplanets and examine potential trends in the data.

**Author(s):** Kevin B. Stevenson<sup>2</sup>, Jacob Bean<sup>2</sup>, Greg Gilbert<sup>2</sup>, Michael R. Line<sup>1</sup>, Jonathan J. Fortney<sup>1</sup>, Jean-Michel Desert<sup>3</sup>  
**Institution(s):** 1. UC Santa Cruz, 2. University of Chicago, 3. University of Colorado

### 306.06 – Near-IR Spectroscopy of WASP-103b at Secondary Eclipse

We measure the near-IR emission spectrum of the benchmark hot Jupiter WASP-103b at secondary eclipse using HST/WFC3. WASP-103b receives relatively little far UV flux from its early-type host star as compared to other hot Jupiters, implying potentially different atmospheric chemistry. We probe the water bands between 1.1-1.7 microns with WFC3 to evaluate the presence of a thermal inversion layer, constrain the efficiency of heat recirculation to the night side, and compare the C/O ratio of WASP-103b to its host star. Because understanding the complex physics and chemistry of planetary atmospheres requires high significance, high fidelity measurements, these observations of WASP-103b provides an essential benchmark for testing planetary atmosphere models.

**Author(s):** Kimberly Michelle Star Cartier<sup>1</sup>, Ming Zhao<sup>1</sup>, Jason Wright<sup>1</sup>, Thomas G. Beatty<sup>1</sup>  
**Institution(s):** 1. Pennsylvania State University

### 306.07D – Frontiers of Exoplanet Atmosphere

## Characterization

Exoplanet atmosphere characterization has the potential to reveal the origins, nature, and even habitability of distant worlds. In this dissertation talk, I will present work that is a step toward realizing that potential for a diverse group of four extrasolar planets. I will discuss the results of intensive observational campaigns with the Hubble and Spitzer Space Telescopes to study the atmospheres of the super-Earth GJ 1214b and the hot Jupiters WASP-43b, WASP-12b, and WASP-103b. For GJ 1214b, I measured an unprecedentedly precise near-infrared transmission spectrum that definitively reveals the presence of clouds in the planet's atmosphere. For WASP-43b and WASP-12b, I also obtained very precise spectra. These exhibit water features at high confidence ( $>7$  sigma). The retrieved water abundance for WASP-43b extends the well-known Solar System trend of decreasing atmospheric metallicity with increasing planet mass. The detection of water for WASP-12b marks the first spectroscopic identification of a molecule in the planet's atmosphere and implies that it has solar composition, ruling out carbon-to-oxygen ratios greater than unity. For WASP-103b, I will present preliminary results from the new technique of phase-resolved spectroscopy that constrain the planet's temperature structure, dynamics, and energy budget. Taken together, these results provide a foundation for comparative planetology beyond the Solar System and the investigation of Earth-like, potentially habitable planets with future observing facilities.

**Author(s):** Laura Kreidberg<sup>1</sup>  
**Institution(s):** 1. University of Chicago

## 307 – Cosmology, CMB, and Dark Matter II

### 307.01 – PAPER-128 Status Update: Towards a 21cm Power Spectrum Detection

The Epoch of Reionization (EoR) represents an unexplored phase in cosmic history when UV photons from the first galaxies ionized the majority of the hydrogen in the intergalactic medium. The Donald C. Backer Precision Array for Probing the Epoch of Reionization (PAPER) is a dedicated experiment that aims to measure EoR fluctuations by mapping the red-shifted 21cm hyperfine transition of neutral hydrogen. While PAPER-64 put the most constraining upper limits on the 21cm power spectrum to date, PAPER-128 is forecast to offer a factor of 4 increase in sensitivity, putting it in the range of plausible predicted signal levels. We present a status update of our ongoing PAPER-128 data analysis efforts, including new insights into data quality assessment, calibration, and foreground removal. As we continue our pursuit of the cosmological signal, the lessons we have learned with PAPER are an integral component for next generation 21cm experiments like the Hydrogen Epoch of Reionization Array (HERA).

**Author(s):** Carina Cheng<sup>2</sup>, Danny Jacobs<sup>1</sup>, Saul Aryeh Kohn<sup>3</sup>, Aaron Parsons<sup>2</sup>  
**Institution(s):** 1. Arizona State University, 2. University of California, Berkeley, 3. University of Pennsylvania  
**Contributing team(s):** PAPER Collaboration

### 307.02D – Helium Reionization Simulations: Seeing the Forest for the Trees

Helium reionization is an important epoch in the Universe's history and the most recent large-scale transition of the intergalactic medium (IGM). Reionization is driven largely by quasars, and has important implications on the thermal history of the IGM. Numerical simulations are ideally suited to investigate this problem due to the highly biased nature of observed quasars and the large degree of photoheating expected from quasar spectral energy distribution measurements. Recently, we have run a new suite of large-scale cosmological simulations that solve N-body, hydrodynamics, and radiative transfer simultaneously in order to study the impact of helium reionization on the IGM. Running fully coupled simulations allows us to capture the crucial impact that reionization has on thermal properties of the gas, which in previous studies has been typically included only in post-processing. We have developed a model to include a quasar population in our simulations that

accurately reflects observations from the most recent BOSS and SDSS measurements. Our model reproduces the quasar luminosity function and the two point correlation function, the two main observational constraints on the high-redshift quasar population. Using this model, we vary the timing of helium reionization in order to isolate key observable features that can provide insight to properties of helium reionization, such as its duration and timing. We make predictions for the temperature density relation of the IGM and synthetic measurements related to the Lyman-alpha forest, both for HI and HeII. We process our synthetic spectra to measure the effective optical depth, the flux PDF, and the one-dimensional flux power spectrum. We show that features of reionization are readily visible in the HeII Lyman-alpha forest spectra and in the temperature evolution of the mean-density IGM, and might be detectable in the HI forest as well.

**Author(s):** Paul La Plante<sup>1</sup>

**Institution(s):** 1. Carnegie Mellon University

### 307.03 – Eliminating Polarized Leakage as a Systematic for 21 cm Epoch of Reionization Experiments

Because of the extreme brightness of foreground emission relative to the desired signal, experiments seeking the 21 cm HI signal from the epoch of reionization must employ foreground removal or avoidance strategies with high dynamic range. Almost all of these techniques rely on the spectral smoothness of the foreground emission, which is dominated by synchrotron emission. The polarized component of such emission can suffer Faraday rotation through the interstellar medium of the Milky Way, thereby inducing frequency structure which can be mistaken for real reionization signal. Therefore, it is of great importance for such experiments to eliminate leakage of Faraday-rotated, polarized emission into the unpolarized (Stokes I) component where the reionization signal lives. We discuss a number of approaches under investigation for mitigating this leakage in the PAPER and HERA experiments, including calibration and careful instrument design. Importantly, however, we show that the ionosphere may provide a very strong suppression of the polarized signal, when averaged over the integration times required for EoR experiments, by scrambling the phase of polarized sources. Moreover, this attenuation comes with very little suppression of the desired unpolarized signal. We consider the implications of this strategy for PAPER and HERA.

**Author(s):** James E. Aguirre<sup>1</sup>

**Institution(s):** 1. University of Pennsylvania

**Contributing team(s):** HERA Collaboration, PAPER Collaboration

### 307.04 – Extracting Physical Parameters for the First Galaxies from the Cosmic Dawn Global 21-cm Spectrum

The all-sky or global redshifted 21-cm HI signal is a potentially powerful probe of the first luminous objects and their environs during the transition from the Dark Ages to Cosmic Dawn ( $35 > z > 6$ ). The first stars, black holes, and galaxies heat and ionize the surrounding intergalactic medium, composed mainly of neutral hydrogen, so the hyperfine 21-cm transition can be used to indirectly study these early radiation sources. The properties of these objects can be examined via the broad absorption and emission features that are expected in the spectrum. The Dark Ages Radio Explorer (DARE) is proposed to conduct these observations at low radio astronomy frequencies, 40-120 MHz, in a 125 km orbit about the Moon. The Moon occults both the Earth and the Sun as DARE makes observations above the lunar farside, thus eliminating the corrupting effects from Earth's ionosphere, radio frequency interference, and solar nanoflares. The signal is extracted from the galactic/extragalactic foreground employing Bayesian methods, including Markov Chain Monte Carlo (MCMC) techniques. Theory indicates that the 21-cm signal is well described by a model in which the evolution of various physical quantities follows a hyperbolic tangent (tanh) function of redshift. We show that this approach accurately captures degeneracies and covariances between parameters, including those related to the signal, foreground, and the

instrument. Furthermore, we also demonstrate that MCMC fits will set meaningful constraints on the Ly- $\alpha$ , ionizing, and X-ray backgrounds along with the minimum virial temperature of the first star-forming halos.

**Author(s):** Jack O. Burns<sup>1</sup>, Jordan Mirocha<sup>1</sup>, geraint harker<sup>2</sup>, Keith Tauscher<sup>1</sup>, Abhirup Datta<sup>1</sup>

**Institution(s):** 1. Univ. of Colorado at Boulder, 2. University College London

### 307.05 – On detecting halo assembly bias with galaxy populations

The fact that the clustering and concentration of dark matter halos depend not only on their mass, but also the formation epoch, is a prominent, albeit subtle, feature of the cold dark matter structure formation theory, and is known as assembly bias. At low mass scales ( $\sim 10^{12} M_{\text{sun}}$ ), early-forming halos are predicted to be more strongly clustered than the late-forming ones. In this study we aim to robustly detect the signature of assembly bias observationally, making use of formation time indicators of central galaxies in low mass halos as a proxy for the halo formation history. Weak gravitational lensing is employed to ensure our early- and late-forming halo samples have similar masses, and are free of contamination of satellites from more massive halos. For the two formation time indicators used (resolved star formation history and current specific star formation rate), we do not find convincing evidence of assembly bias. We attribute the lack of detection to the possibility that these indicators do not correlate well with the halo formation history, and suggest alternatives that should perform better for future studies. In addition, we have developed a method to constrain the probability distribution function of halo mass of a given galaxy sample, and also demonstrate that the abundance matching-based halo mass assignments to galaxy groups and clusters may be biased, likely due to interlopers from more massive galactic systems.

**Author(s):** Yen-Ting Lin<sup>1</sup>, Rachel Mandelbaum<sup>2</sup>, Yun-Hsin Huang<sup>5</sup>, Hung-Jin Huang<sup>2</sup>, Neal Dalal<sup>6</sup>, Benedikt Diemer<sup>3</sup>, Andrey Kravtsov<sup>4</sup>

**Institution(s):** 1. Academia Sinica, 2. Carnegie Mellon University, 3. CfA, 4. The University of Chicago, 5. University of Arizona, 6. University of Illinois

### 307.06 – Constraints on Cosmological Parameters from the PS1 Spectroscopic SNIa Sample

We present an analysis of the 258 confirmed Type Ia Supernovae ( $0.03 < z < 0.65$ ) discovered over the full course of the Pan-STARRS1 (PS1) Medium Deep Survey. This sample is a subset of the 348 SNIa discovered by PS1 that can be used for the cosmology analysis. We present improvements to the PS1 photometry, astrometry and calibration that further reduce the systematic uncertainties in the PS1 SN Ia distances. We then discuss the combination of our PS1 sample with the full set of light curves from external samples to form the largest combined sample of SNIa. This analysis is the first to use the PS1 Supercal process that determines a global calibration solution to allow the combination of many different supernova samples. We will preview constraints on cosmological parameters with this combined sample. We will also discuss analysis of the larger PS1 photometric sample, as well as the low- $z$  SNIa survey, called Foundation, that is currently being conducted with the Pan-STARRS telescope.

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**Institution(s):** 1. University of Chicago

**Contributing team(s):** PS1 Collaboration

### 307.07 – Cosmic Shear Tomography from the Deep Lens Survey

The Deep Lens Survey (DLS) is designed as a pre-cursor Large Synoptic Survey Telescope (LSST) survey with an emphasis on depth. Using five tomographic redshift bins, we study their auto- and cross-correlations to constrain cosmological parameters. Both instrumental and astrophysical systematics are carefully addressed with the state-of-the-art techniques. We find that the cosmological leverage of the DLS is among the highest among existing  $>10$  sq. deg

cosmic shear surveys. Combining the DLS tomography with the 9-year results of the Wilkinson Microwave Anisotropy Probe (WMAP9) reduces the uncertainties of the WMAP9-only constraints by ~50%. Our constraints are fully consistent with the final Planck results and also the predictions of a  $\Lambda$ CDM universe.

**Author(s):** Myungkook J. Jee<sup>4</sup>, J. Anthony Tyson<sup>3</sup>, Stefan Hilbert<sup>2</sup>, Michael Schneider<sup>1</sup>, Samuel Schmidt<sup>3</sup>, David M. Wittman<sup>3</sup>  
**Institution(s):** 1. LLNL, 2. MPA, 3. UC Davis, 4. Yonsei University

## 308 – Starburst Galaxies I

### 308.01D – Starburst Driven Superbubbles Radiating to 10 K

Starburst driven superbubbles can produce large scale galactic outflows. Whether any given starburst can create an outflow depends on several variables including the rate at which energy and mass are injected into the interstellar medium (ISM), the radiative cooling prescription used, and the overall density distribution of the ISM. We investigate the effect that two different temperature floors in our radiative cooling prescription have on wind kinematics and content. We find that cooling to 10 K instead of to 104 K increases the mass fraction of cold neutral and hot X-ray gas in the galactic wind while halving that in warm H $\alpha$ . For sufficiently powerful starbursts our cooling prescription does not affect the terminal velocity of gas within the superbubble. Filaments embedded in the hot galactic wind contain warm and cold gas which moves slower than the surrounding wind, with the coldest gas hardly moving with respect to the galaxy. Optically bright filaments form at the edge of merging superbubbles and if anchored to a star forming complex will persist and grow to > 400 pc in length. These filaments are the main source of warm and cold gas being transported into the galactic halo. Using synthetic absorption profiles we measure the velocity of the warm and hot gas phases and find  $v_{\text{warm}} \propto v_{\text{hot}}^{0.5}$ . We also find that  $v_{\text{hot}} \propto \text{SFR}^{0.5}$ , which implies  $v_{\text{warm}} \propto \text{SFR}^{0.25}$ . Warm and cold gas embedded in the galactic wind show asymmetric absorption profiles consistent with observations and theoretical predictions. These asymmetries can be used to infer the kinematics of the filaments and associated dense cores.

**Author(s):** Ryan Tanner<sup>1</sup>, Gerald Cecil<sup>1</sup>, Fabian Heitsch<sup>1</sup>  
**Institution(s):** 1. University of North Carolina at Chapel Hill

### 308.02 – Investigating Starburst Galaxy Emission Line Equivalent Widths

Modeling star forming galaxies with spectral synthesis codes allows us to study the gas conditions and excitation mechanisms that are necessary to reproduce high ionization emission lines in both local and high- $z$  galaxies. Our study uses the locally optimally-emitting clouds model to develop an atlas of starburst galaxy emission line equivalent widths. Specifically, we address the following question: *What physical conditions are necessary to produce strong high ionization emission lines assuming photoionization via starlight?* Here we present the results of our photoionization simulations: an atlas spanning 15 orders of magnitude in ionizing flux and 10 orders of magnitude in hydrogen density that tracks over 150 emission lines ranging from the UV to the near IR. Each simulation grid contains  $\sim 1.5 \times 10^4$  photoionization models calculated by supplying a spectral energy distribution, grain content, and chemical abundances. Specifically, we will be discussing the effects on the emission line equivalent widths of varying the metallicity of the cloud,  $Z = 0.2 Z_{\odot}$  to  $Z = 5.0 Z_{\odot}$ , and varying the star-formation history, using the instantaneous and continuous evolution tracks and the newly released Starburst99 Geneva rotation tracks.

**Author(s):** Helen Meskhidze<sup>1</sup>, Chris T. Richardson<sup>1</sup>  
**Institution(s):** 1. Elon University

### 308.03 – Evidence against star-forming galaxies as the dominant source of IceCube neutrinos

The cumulative emission resulting from hadronic cosmic-ray interactions in star-forming galaxies (SFGs) has been proposed as the dominant contribution to the astrophysical neutrino flux at TeV

to PeV energies reported by IceCube. The same particle interactions also inevitably create gamma-ray emission that could be detectable as a component of the extragalactic  $\gamma$ -ray background (EGB), now measured with the Fermi-LAT in the energy range from 0.1 to 820 GeV. New studies of the blazar flux distribution at  $\gamma$ -ray energies above 50 GeV place an upper bound on the residual non-blazar component of the EGB. We show that these results are in strong tension with models that consider SFGs as the dominant source of the diffuse neutrino backgrounds.

**Author(s):** Keith Bechtol<sup>1</sup>  
**Institution(s):** 1. University of Wisconsin - Madison

### 308.04 – NuSTAR Observations of Starburst Galaxies

NuSTAR, the first satellite with hard X-ray focusing optics, opens up the possibility to not only detect starburst galaxies above 10 keV for the first time but also characterize their hard X-ray properties. Here we present an overview of a NuSTAR program to survey seven normal/starburst galaxies: NGC 253, M82, M83, NGC 3256, NGC 3310, Arp 299, and M31. We also discuss data analysis strategies. All galaxies have been observed coordinated with either *Chandra* or *XMM-Newton* or both. The main results of these observations were: we characterized the typical starburst spectrum above 10 keV and showed that the spectrum is soft (photon index  $\sim 3$ ) above 7 keV and determined that individually detected sources are generally black holes in a “transition” accretion state or neutron star systems accreting near the Eddington rate, and variability on time scales of weeks to months is typically detected. In the case of NGC 253 we decomposed the unresolved hard X-ray emission between background, unresolved binaries and truly diffuse flux and found that the diffuse flux upper limit is marginally above model predictions for inverse-Compton scattering of IR photons by cosmic rays.

**Author(s):** Andrew Ptak<sup>3</sup>, Ann E. Hornschemeier<sup>3</sup>, Daniel R. Wik<sup>2</sup>, Mihoko Yukita<sup>2</sup>, Bret Lehmer<sup>7</sup>, Andreas Zezas<sup>5</sup>, Tom Maccarone<sup>6</sup>, Tonia M. Venters<sup>3</sup>, Vallia Antoniou<sup>5</sup>, Fiona Harrison<sup>1</sup>, Daniel Stern<sup>4</sup>  
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**Contributing team(s):** NuSTAR Starburst team

### 308.05D – The Breakdown of Equipartition in the Central Molecular Zones of Starburst Galaxies

Magnetic fields in starburst galaxies are difficult to measure because of the density of the environments and the high degree of turbulence found in the fields. Because direct measurement of the magnetic field strength is not possible, it is often assumed that the energy densities in magnetic fields and cosmic rays are equal. Thus, the non-thermal radio synchrotron spectrum for a galaxy allows indirect estimates to be made of the magnetic field strength. However, the relationship between cosmic rays and the observed non-thermal emission from galaxies is complex. Both primary and secondary cosmic rays contribute to the total emitted synchrotron spectrum, and to accurately model the cosmic-ray electron populations, a variety of energy losses, including bremsstrahlung and inverse Compton emission, must be accounted for in the calculations. While classical equipartition formulae largely ignored these intricacies, there have been several recent revisions to the formulae to account for the intense conditions in starbursts. Yet, the application of the equipartition formula to starburst environments also presupposes that the timescales are long enough for the starburst regions to have reached equilibrium. Here, we test this assumption of equilibrium in nearby starburst galaxies by modeling both the observed gamma-ray spectrum, which provides a direct probe of the cosmic ray energy density, and the radio spectrum, which provides a probe of the magnetic field strength. We find that for each galaxy tested, the magnetic field energy density is significantly larger than the cosmic ray energy density, demonstrating that the equipartition argument is frequently invalid for central molecular zones.

**Author(s):** Tova Yoast-Hull<sup>1</sup>, John S. Gallagher<sup>1</sup>, Ellen Gould Zweibel<sup>1</sup>  
**Institution(s):** 1. University of Wisconsin-Madison

## 309 – Circumstellar Debris Disks

### 309.01 – Protoplanetary and Debris Disk Morphologies

The types of planets that form around other stars are highly dependent on their natal disk conditions. Therefore, the composition, morphology, and distribution of material in protoplanetary and debris disks are important for planet formation. Here we present the results of studies of two disk systems: AB Aur and AU Mic.

The circumstellar disk around the Herbig Ae star AB Aur has many interesting features, including spirals, asymmetries, and non-uniformities. However, comparatively little is known about the envelope surrounding the system. Recent work by Tang et al (2012) has suggested that the observed spiral arms may not in fact be in the disk, but instead are due to areas of increased density in the envelope and projection effects. Using Monte Carlo modeling, we find that it is unlikely that the envelope holds enough material to be responsible for such features and that it is more plausible that they form from disk material. Given the likelihood that gravitational perturbations from planets cause the observed spiral morphology, we use archival H band observations of AB Aur with a baseline of 5.5 years to determine the locations of possible planets.

The AU Mic debris disk also has many interesting morphological features. Because its disk is edge on, the system is an ideal candidate for color studies using coronagraphic spectroscopy. Spectra of the system were taken by placing a HST/STIS long slit parallel to and overlapping the disk while blocking out the central star with an occulting fiducial bar. Color gradients may reveal the chemical processing that is occurring within the disk. In addition, it may trace the potential composition and architecture of any planetary bodies in the system because collisional break up of planetesimals produces the observed dust in the system. We present the resulting optical reflected spectra (5200 to 10,200 angstroms) from this procedure at several disk locations. We find that the disk is bluest at the innermost locations of the disk, and that it becomes increasingly gray in regions farther from the central star.

**Author(s):** Jamie R Lomax<sup>6</sup>, John P. Wisniewski<sup>6</sup>, Carol A Grady<sup>3</sup>, Michael W. McElwain<sup>4</sup>, Jun Hashimoto<sup>6</sup>, Jessica Donaldson<sup>2</sup>, John H. Debes<sup>5</sup>, Eliot Malumuth<sup>1</sup>, Aki Roberge<sup>4</sup>, Alycia J. Weinberger<sup>2</sup>

**Institution(s):** 1. ADNET Systems, Inc, 2. Carnegie Institute of Washington, 3. Eureka Scientific, 4. NASA/GSFC, 5. Space Telescope Science Institute, 6. University of Oklahoma

**Contributing team(s):** SEEDS team

### 309.02D – Comprehensive Census and Analysis of Nearby Debris Disk Stars

Debris disks are intimately linked to planetary system evolution since the rocky material surrounding the star is believed to originate in collisions between planetesimals, asteroids and comets. With the conclusion of all major space infrared missions and lack of future large-scale infrared excess survey missions, it is time to make a complete list of all debris disk systems and search for trends in the population. A thorough search of the literature for infrared excess stars has been combined with a large-scale survey for excess stars in the Tycho-2 catalog that makes use of all available infrared photometry. The result is a list of ~580 unique high fidelity debris disk stars. This project seeks a comprehensive analysis of debris disk stars not yet completed on this large scale. A summary of the creation of the high fidelity debris disk census and the multi-facility endeavor to obtain various stellar and disk parameters for each debris disk will be presented. I will offer an exploration into the relationships between host stars and their debris disks through properties such as metallicity, age, and rotation.

**Author(s):** Tara H Cotten<sup>1</sup>

**Institution(s):** 1. University of Georgia

### 309.03 – HST STIS & NICMOS Coronagraphy of Four Debris Disks around Young Solar Analogs

We present new deep Hubble Space Telescope STIS coronagraphy of four debris disks around nearby young solar type stars (<40 Myr, G2-F3), corresponding to the age at which terrestrial planet formation was being completed in our own solar system. The four disks were first seen by our team in a reprocessing of the NICMOS archive using modern principal component analysis PSF subtraction algorithms. Our new STIS observations surpass the earlier NICMOS imagery in angular resolution, contrast, and sensitivity to extended diffuse scattered light, enabling a much clearer view of the diverse disk structures and asymmetries. Careful forward modeling of the PSF-subtraction process allows us to accurately assess the surface brightnesses in scattered light. Visible to near-infrared colors from HST STIS and NICMOS can constrain the dust particle properties. Analysis and modeling of these young planetary systems are ongoing.

**Author(s):** Marshall D. Perrin<sup>2</sup>, Elodie Choquet<sup>2</sup>, Alexandra Greenbaum<sup>1</sup>, Bin Ren<sup>1</sup>, John H. Debes<sup>2</sup>, Johan Mazoyer<sup>2</sup>, Marie Ygouf<sup>2</sup>, Laurent Pueyo<sup>2</sup>, Jonathan Aguilar<sup>1</sup>, Christine Chen<sup>2</sup>, David A. Golimowski<sup>2</sup>, Dean C. Hines<sup>2</sup>, Mamadou N'Diaye<sup>2</sup>, Glenn Schneider<sup>3</sup>, Remi Soummer<sup>2</sup>, Chris Stark<sup>2</sup>, Schuyler Wolff<sup>1</sup>

**Institution(s):** 1. Johns Hopkins University, 2. STScI, 3. University of Arizona

### 309.04D – Using Protoplanetary Disks to Weigh the Youngest Stars and Constrain The Earliest Stages of Stellar Evolution

Mass is the fundamental property that determines the evolutionary path of a star. In particular, the masses of young stars are of great relevance to many astrophysical problems, including star and planet formation. We have developed a novel approach that combines spatially resolved sub-millimeter spectral line imaging and optical/near-infrared high resolution spectroscopy to derive the fundamental properties of a young star: mass, temperature, and radius. By applying our technique to a sample of pre-main sequence stars, we are mapping out a dynamically-calibrated Hertzsprung-Russell diagram for the express purpose of evaluating pre-main sequence evolutionary models. Looking forward, ALMA is poised to deliver precise stellar masses in statistically large quantities, enabling a meaningful survey of the fundamental properties of young stars.

**Author(s):** Ian Czekala<sup>1</sup>

**Institution(s):** 1. Harvard-Smithsonian Center for Astrophysics

### 309.05 – An MCMC Circumstellar Disks Modeling Tool

We present an enhanced software framework for the Monte Carlo Markov Chain modeling of circumstellar disk observations, including spectral energy distributions and multi wavelength images from a variety of instruments (e.g. GPI, NICI, HST, WFIRST). The goal is to self-consistently and simultaneously fit a wide variety of observables in order to place constraints on the physical properties of a given disk, while also rigorously assessing the uncertainties in the derived properties. This modular code is designed to work with a collection of existing modeling tools, ranging from simple scripts to define the geometry for optically thin debris disks, to full radiative transfer modeling of complex grain structures in protoplanetary disks (using the MCFOST radiative transfer modeling code). The MCMC chain relies on direct chi squared comparison of model images/spectra to observations. We will include a discussion of how best to weight different observations in the modeling of a single disk and how to incorporate forward modeling from PCA PSF subtraction techniques. The code is open source, python, and available from github. Results for several disks at various evolutionary stages will be discussed.

**Author(s):** Schuyler Wolff<sup>2</sup>, Marshall D. Perrin<sup>3</sup>, Johan Mazoyer<sup>3</sup>, Elodie Choquet<sup>3</sup>, Remi Soummer<sup>3</sup>, Bin Ren<sup>2</sup>, Laurent Pueyo<sup>3</sup>, John H. Debes<sup>3</sup>, Gaspard Duchene<sup>4</sup>, Christophe Pinte<sup>1</sup>, Francois Menard<sup>1</sup>

**Institution(s):** 1. Institut de Planetologie et d'Astrophysique de Grenoble (IPAG), 2. Johns Hopkins University, 3. Space Telescope Science Institute, 4. University of California Berkeley

### 309.06 – Warm Circumstellar Debris Disks:

## **Dynamical Excitation by Massive External Perturbers?**

Observations of circumstellar debris disks have revealed that a subset of this population are warm disks (~300 K). A dynamically excited disk may indicate the presence of an exoplanet orbiting within and stirring the disk. However, observations suggest another possible mechanism for heating a debris disk: an external stellar-mass perturber exciting the eccentricities and inclinations of the particles in a disk.

We explore the consequences of an external perturber on the evolution of a debris disk using secular analysis and collisional N-body simulations. The perturber excites the eccentricities of the particles in the disk via the Kozai-Lidov mechanism, triggering a collisional cascade among the planetesimals. These collisions produce smaller dust grains and damp the particles' larger eccentricities.

We present the results of our study and discuss the connections to observations of warm disks and the implications for planet formation.

**Author(s):** Erika Nesvold<sup>1</sup>, Smadar Naoz<sup>2</sup>, Laura Vican<sup>2</sup>, Laura Vican<sup>2</sup>, Ben M. Zuckerman<sup>2</sup>, Erika Holmbeck<sup>3</sup>

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## **313 – Research and Professional Development Opportunities for Undergraduate Majors**

### **313.01 – The National Astronomy Consortium: Lessons learned from a program to support underrepresented students in pursuing STEM careers**

The National Astronomy Consortium (NAC) is a program partnering physics and astronomy departments in majority and minority-serving institutions across the country. The primary aim of this program is to support traditionally underrepresented students interested in pursuing a career in STEM through a 9-10 week summer astronomy research project and a year of additional mentoring after they return to their home institution. Students are also given an opportunity to apply for a second year in this program, often at a different site. In addition to providing research and professional experience, the NAC also seeks to strengthen ties between the majority and minority-serving institutions in order to better serve these students throughout their careers. I will report on lessons learned from the second year of hosting a cohort at the National Radio Astronomy Observatory in Socorro, NM. I will discuss the program structure during and after the summer, mentoring challenges, and ways that these challenges were addressed, including organizing a series of guest speakers and connecting students with a broader community of remote mentors.

**Author(s):** Elisabeth A. Mills<sup>4</sup>, Kartik Sheth<sup>1</sup>, Faye Giles<sup>3</sup>, Louis-Gregory Strolger<sup>5</sup>, Drew Brisbin<sup>3</sup>, Patricia T. Boyd<sup>2</sup>, Robert A. Benjamin<sup>6</sup>

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**Contributing team(s):** NAC Consortium

### **313.02 – Creating Future Stem Leaders: The National Astronomy Consortium:**

The National Astronomy Consortium (NAC) is a program led by the National Radio Astronomy Observatory (NRAO) and Associated Universities Inc., (AUI) in partnership with the National Society of Black Physicists (NSBP), and a number of minority and majority universities to increase the numbers of students from underrepresented groups and those otherwise overlooked by the traditional academic pipeline into STEM or STEM-related careers.

The seed for the NAC was a partnership between NRAO and Howard University which began with an exchange of a few summer students five years ago. Since then the NAC has grown tremendously. Today the NAC aims to host between 4 to 5 cohorts nationally in an innovative model in which the students are mentored throughout the year with multiple mentors and peer mentoring, continued engagement in research and professional development / career training throughout the academic year and throughout their careers. We will summarize the results from this innovative and highly successful program and provide lessons learned.

**Author(s):** Kartik Sheth<sup>2</sup>, Elisabeth A.C. Mills<sup>3</sup>, Patricia T. Boyd<sup>1</sup>, Louis-Gregory Strolger<sup>4</sup>, Robert A. Benjamin<sup>6</sup>, Drew Brisbin<sup>5</sup>, Faye Giles<sup>3</sup>

**Institution(s):** 1. *Goddard Space Flight Center / NASA*, 2. *National Aeronautics & Space Administration (NASA)*, 3. *NRAO*, 4. *Space Telescope Science Institute*, 5. *Universidad Diego Portales*, 6. *University of Wisconsin- Whitewater*

**Contributing team(s):** The National Astronomy Consortium

### **313.03 – The Pre-Major in Astronomy Program (Pre-MAP): What Makes a Great First Research Project?**

The Pre-Major in Astronomy Program (Pre-MAP) at the University of Washington has been providing incoming students with the opportunity to work on research projects in astronomy and astrophysics almost as soon as they step on campus. These projects, which are developed by graduate students, post-docs, and faculty members, must be accessible to students with limited formal education in astronomy and physics and only ~5 weeks of instruction in computer programming. Projects must be simple enough to be completed within ~6 weeks, but challenging enough to yield interesting outcomes that will encourage students to continue working on research even after the first quarter seminar is over. In this talk, I will identify the challenges and goals associated with designing a 6-week, introductory research project for new undergraduates. I will then discuss some of the most successful outcomes of recent Pre-MAP projects, which have included publications, presentations by Pre-MAP students at conferences, press releases, and observing proposals.

**Author(s):** Breanna A. Binder<sup>1</sup>, Edward Schwieterman<sup>1</sup>

**Institution(s):** 1. *University of Washington*

**Contributing team(s):** Pre-Major in Astronomy Program

### **313.04 – Promoting Inclusivity in STEM through Active Recruiting and Mentoring: The Pre-Major in Astronomy Program (Pre-MAP) at the University of Washington**

The Pre-Major in Astronomy Program (Pre-MAP) is a research and mentoring program for entering undergraduate students offered by the University of Washington Astronomy Department since 2005. The primary goal of Pre-MAP is to recruit and retain students from groups traditionally underrepresented in science, technology, engineering, and mathematics (STEM) through early exposure to guided research projects. The Pre-MAP seminar is the core component of the program and offers instruction in computing skills, data manipulation, science writing, statistical analysis, and scientific speaking and presentation skills. Students choose research projects proposed by faculty, post-docs and graduate students in areas related to astrophysics, planetary science, and astrophysics. Pre-MAP has been successful in retaining underrepresented students in STEM fields relative to the broader UW population, and we've found these students are more likely to graduate and excel academically than their peers. As of fall 2015, more than one hundred students have taken the Pre-MAP seminar, and both internal and external evaluations have shown that all groups of participating students report an increased interest in astronomy and science careers at the end of the seminar. This talk will provide an overview of the program and the structure of the core seminar. In particular, the talk will focus on additions and revisions to the seminar course over the last few years, such as the introduction of a public speaking coach, career and internship modules, and the formalization of external lab tours.

**Author(s):** Edward Schwieterman<sup>1</sup>, Breanna A. Binder<sup>1</sup>  
**Institution(s):** 1. University of Washington  
**Contributing team(s):** The Pre-Major in Astronomy Program

### 313.06 – The Undergraduate ALFALFA Team: A Collaboration for Undergraduate Research Opportunities and Faculty Development

Legacy astronomy surveys involve large collaborations over long time periods, making it challenging to involve undergraduates in meaningful projects. Collaborating with faculty at 19 undergraduate-focused institutions across the US and Puerto Rico and with US-NSF funding, the ALFALFA (Arecibo Legacy Fast ALFA) Team has developed the Undergraduate ALFALFA Team, an effective model to promote undergraduate research and faculty development within the ALFALFA HI blind survey project and follow-up programs. This talk will summarize the main components of the program, which include an annual undergraduate workshop at Arecibo Observatory, observing runs at Arecibo, computer infrastructure, summer and academic year research projects, and dissemination at national meetings (e.g., Cannon et al., Collins, Elliott et al, Craig et al., Hansen et al., Johnson et al., Morrison et al., O'Donoghue et al., Smith et al., Sylvia et al., Troischt et al., this meeting). This work has been supported by NSF grants AST-0724918/0902211, AST-075267/0903394, AST-0725380, and AST-1211005.

**Author(s):** Rebecca A. Koopmann<sup>14</sup>, Thomas J. Balonek<sup>2</sup>, John M. Cannon<sup>9</sup>, Kimberly A. Coble<sup>1</sup>, David W Craig<sup>19</sup>, Adriana Durbala<sup>18</sup>, Rose Finn<sup>10</sup>, Gregory L Hallenbeck<sup>14</sup>, Martha P. Haynes<sup>3</sup>, Sarah Higdon<sup>5</sup>, G. Lyle Hoffman<sup>8</sup>, David A. Kornreich<sup>7</sup>, Mayra E. Lebron<sup>15</sup>, Mary Crone-Odekon<sup>11</sup>, Aileen A. O'Donoghue<sup>12</sup>, Ronald Paul Olowin<sup>13</sup>, Carmen Pantoja<sup>15</sup>, Jessica L. Rosenberg<sup>4</sup>, Parker Troischt<sup>6</sup>, Aparna Venkatesan<sup>16</sup>, Eric M. Wilcots<sup>17</sup>  
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**Contributing team(s):** ALFALFA Team

### 313.07 – The Undergraduate ALFALFA Team: Outcomes for Over 250 Undergraduate Participants

The NSF-sponsored Undergraduate ALFALFA (Arecibo Legacy Fast ALFA) Team (UAT) is a consortium of 19 institutions founded to promote undergraduate research and faculty development within the extragalactic ALFALFA HI blind survey project and follow-up programs. In this talk we present outcomes for the more than 250 undergraduate students who have who have participated in the program during the 8 years of funding. 40% of these students have been women and members of underrepresented groups. To date 148 undergraduate students have attended annual workshops at Arecibo Observatory, interacting with faculty, graduate students, their peers, and Arecibo staff in lectures, group activities, tours, and observing runs. Team faculty have supervised 159 summer research projects and 120 academic year (e.g., senior thesis) projects. 68 students have traveled to Arecibo Observatory for observing runs and 55 have presented their results at national meetings such as the AAS. Through participation in the UAT, students are made aware of career paths they may not have previously considered. More than 90% of alumni are attending graduate school and/or pursuing a career in STEM. 42% of those pursuing graduate degrees in Physics or Astronomy are women. This work has been supported by NSF grants AST-0724918/0902211, AST-075267/0903394, AST-0725380, and AST-1211005

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**Contributing team(s):** ALFALFA Team

### 313.08 – The Undergraduate ALFALFA Team:

### Collaborative Research Projects

The NSF-sponsored Undergraduate ALFALFA (Arecibo Legacy Fast ALFA) Team (UAT) has allowed faculty and students from a wide range of public and private colleges and especially those with small astronomy programs to learn how science is accomplished in a large collaboration while contributing to the scientific goals of a legacy radio astronomy survey. The UAT has achieved this through close collaboration with ALFALFA PIs to identify research areas accessible to undergraduates. In this talk we will summarize the main research efforts of the UAT, including multiwavelength followup observations of ALFALFA sources, the UAT Collaborative Groups Project, the Survey of HI in Extremely Low-mass Dwarfs (SHIELD), and the Arecibo Pisces-Perseus Supercluster Survey. This work has been supported by NSF grants AST-0724918/0902211, AST-075267/0903394, AST-0725380, and AST-1211005.

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**Contributing team(s):** Undergraduate ALFALFA Team, ALFALFA Team

### 313.09 – The Undergraduate ALFALFA Team: A Model for Involving Undergraduates in Large Astronomy Collaborations

The NSF-sponsored Undergraduate ALFALFA (Arecibo Legacy Fast ALFA) Team (UAT) has allowed faculty and students from a wide range of public and private colleges and especially those with small astronomy programs to learn how science is accomplished in a large collaboration while contributing to the scientific goals of a legacy radio astronomy survey. This effort has been made possible through the collaboration of the ALFALFA PIs and graduate students, Arecibo Observatory staff, and the faculty at 19 undergraduate-focussed institutions. In this talk, we will discuss how the UAT model works for the ALFALFA project and lessons learned from our efforts over the 8 years of grant funding. We will provide suggestions on how the model could be applied to other legacy projects, particularly in such areas as online collaboration and software usage by undergraduates. This work has been supported by NSF grants AST-0724918/0902211, AST-075267/0903394, AST-0725380, and AST-1211005.

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**Contributing team(s):** Undergraduate ALFALFA Team, ALFALFA Team

## 316 – Cosmological Simulations of Galaxies

### 316.01 – Stochastic evolution of rotations of early type galaxies

Recent Integral-Field Spectrograph surveys (SAURON, ATLAS 3D, and SAMI project, for example) have revealed that early type galaxies have wide range of rotational properties even though they share similar photometric properties. High resolution numerical studies have shown that galaxy-galaxy interactions have significant effect on the rotation of early type galaxies, however, with limited number of sample galaxies.

We present kinematic analysis of thousands of galaxies in 20 clusters from a set of cosmological hydrodynamic zoom-in simulations. Although galaxy mergers play an important role, the direction of change in the amount of rotation depends on many merger parameters such as mass ratio, orbital parameters, and relative direction of galaxy rotations. Furthermore, all their merger parameters themselves are results of non-linear galaxy formation and evolution processes. By compiling numerous galaxy merger events, we discuss statistical properties of the evolution of early type galaxy rotation. We present the impacts of various interactions: major and minor mergers, multiple mergers, and flybys.

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**Institution(s):** 1. Yonsei university

### 316.02D – The Importance of Radial Migration to the Evolution of Spiral Galaxies

Spiral galaxy evolution is frequently considered in the context of environment, but internal processes may also play an important role. Radial migration is one such internal process, wherein a transient spiral arm rearranges the angular momentum distribution of the disk around corotation without causing kinematic heating. The efficiency of radial migration depends on both the duty cycle for transient patterns and the RMS change in orbital angular momentum induced by each pattern. Should radial migration be efficient, it could cause a substantial fraction of disk stars to move large radial distances over the lifetime of the disk, thus having significant impact on its kinematic, structural and chemical evolution.

In this talk, I will summarize a subset of work focusing on the physics that determines the magnitude of the RMS change in orbital angular momentum from each spiral pattern. I have derived an analytic “capture criterion” that predicts whether or not a disk star with finite random orbital energy is in a “trapped orbit” (i.e. the orbital family induced by the spiral pattern that can lead to radial migration). I will present this criterion and show that it is primarily a star's orbital angular momentum that determines whether or not it is in a trapped orbit. The capture criterion could be used to better understand the role of radial migration in N-body simulations as well as applied to models of galaxy evolution. I will describe an example study wherein I applied the capture criterion, in a series of disk galaxy models, to find the fraction of an ensemble of stars that is in trapped orbits. I found that this fraction decreases linearly with increasing radial velocity dispersion and conclude that radial migration may play a role in the evolution of disk galaxies, but it is insignificant to the evolution of high velocity dispersion populations.

**Author(s):** Kathryn J Daniel<sup>1</sup>, Rosemary F. G. Wyse<sup>1</sup>  
**Institution(s):** 1. Johns Hopkins University

### 316.03 – Galaxy Interactions with FIRE: Mapping Star Formation

We utilize a suite of 75 simulations of galaxies in idealised major mergers (stellar mass ratio  $\sim 2.5:1$ ), with a wide range of orbital parameters, to investigate the spatial extent of interaction-induced star formation. Two versions are used, one based on a Kennicutt-like subgrid model (Gadget, Springel & Hernquist 2003); the other based on the new Feedback In Realistic Environments model (FIRE, Hopkins et al. 2014). Although the total star formation in galaxy encounters is generally elevated relative to isolated galaxies, we find that this elevation is a combination of intense enhancements within the central kpc and moderately suppressed activity at large galactocentric radii. This effect appears to be stronger in the older Gadget model. Suppression in the disk is also found in the FIRE runs, but at larger scales. This is because tidal torques are weaker in the newer FIRE model, leading to a more extended nuclear starburst. Our predictions of the radial dependence of triggered star formation, and specifically the suppression of star formation beyond kpc-scales, will be testable with the next generation of integral-field spectroscopic surveys.

**Author(s):** Jorge Moreno<sup>1</sup>  
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### 316.04D – Emission from the Circumgalactic Medium: Providing New Insights on Galaxy Evolution

The circumgalactic medium (CGM) remains one of the least constrained and poorly understood components of galaxies. Theoretically, this is because predicted properties of such gas vary with key fundamental physical processes being debated in galaxy formation and evolution --- how do galaxies accrete gas and how does feedback work to remove it? Observationally, we have been limited to quasar absorption studies that probe individual galaxies with only one or a few lines of sight, providing an incomplete view of the CGM's distribution. Deep imaging studies of the gas in emission, can map the underlying spatial distribution of the CGM and allow the

gas density and temperature to be estimated. I present observationally constrained emission predictions from a high-resolution cosmological simulation of a Milky Way-like galaxy and demonstrate how this emission reflects the evolution of the CGM at late times and discuss the detection likelihoods for such emission. The simulation is matched to current observational constraints by showing that varying the extragalactic UV background can help bring the predictions into better agreement with recent data. The emission is less sensitive to such variations but its structure is strongly shaped by the underlying gas density and temperature. From  $z=1$  to  $z=0$ , the average density of the gas decreases while the average temperature increases, trends governed by the supernova feedback and the decrease of filamentary accretion. Observationally, we conclude that with moderate resolution and reasonable detection limits, future instrumentation should place constraints of the physical properties of the CGM.

**Author(s):** Lauren Corlies<sup>1</sup>, David Schiminovich<sup>1</sup>  
**Institution(s):** 1. Columbia University

### 316.05 – The Non-parametric Concentration of Dark Matter Halos in Cosmological N-body Simulations

A wealth of information on the evolution of structure in the universe can be gained by measuring how the properties of dark matter halos in numerical simulations evolve over time. However, the techniques commonly used to measure halo properties often make assumptions about a halo's structure that are not strictly true, resulting in systematically biased results. TesseRACt, a non-parametric tessellation-based technique for measuring halo concentration in N-body simulations, does not make any assumptions about a halo's structure, allowing halos to be axisymmetric, triaxial, contain substructure, and have ill-defined centers. Preliminary results are presented using TesseRACt to measure the concentration of dark matter halos in cosmological N-body simulations.

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**Institution(s):** 1. UIUC, 2. Vanderbilt University

### 316.06 – The Scylla Multi-Code Comparison Project

Cosmological hydrodynamical simulations are one of the main techniques used to understand galaxy formation and evolution. However, it is far from clear to what extent different numerical techniques and different implementations of feedback yield different results. The Scylla Multi-Code Comparison Project seeks to address this issue by running identical initial condition simulations with different popular hydrodynamic galaxy formation codes. Here we compare simulations of a Milky Way mass halo using the codes *enzo*, *ramses*, *art*, *arepo* and *gizmo-psph*. The different runs produce galaxies with a variety of properties. There are many differences, but also many similarities. For example we find that in all runs *cold flow disks* exist; extended gas structures, far beyond the galactic disk, that show signs of rotation. Also, the angular momentum of warm gas in the halo is much larger than the angular momentum of the dark matter. We also find notable differences between runs. The temperature and density distribution of hot gas can differ by over an order of magnitude between codes and the stellar mass to halo mass relation also varies widely. These results suggest that observations of galaxy gas halos and the stellar mass to halo mass relation can be used to constrain the correct model of feedback.

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**Contributing team(s):** Scylla Team

## 317 – Binary Stellar Systems, X-ray Binaries I

### 317.01 – Unveiling the nature of the He II $\lambda 4686$ periodic minima in $\eta$ Carinae

$\eta$  Carinae is known to be a massive binary system, but some of the

orbital parameters remain uncertain. The nature of the periodic minima seen in several spectral features are associated with periastron passages near stellar conjunction, but its nature has been interpreted either as a low excitation event or as an eclipse of the hotter secondary star by the dense inner wind of the primary. We conducted an intense spectroscopic monitoring of the He II  $\lambda 4686$  emission line across the 2014.6 event using ground- and space-based telescopes. Comparison with results from the past two events confirmed the stability of the equivalent width and radial velocity of this line, as well as the strict periodicity of its minima. In combination with different other measurements, the orbital period is 2022.7 ( $\pm 0.3$ ) d. We adopted a power law model in combination with the total opacity in the line of sight to the apex of the wind-wind collision region obtained from hydrodynamic simulations to reproduce the observed He II  $\lambda 4686$  equivalent width curve. We constrained the orbital inclination to  $135^\circ$ – $153^\circ$  and the longitude of periastron to  $234^\circ$ – $252^\circ$ . Periastron passage occurred on  $T_0(2014.6)=2456874.4$  ( $\pm 1.3$ ) d. With these orbital elements, we successfully reproduced both the equivalent width curve observed from our direct view of the central source and the polar view. This suggests that the He II  $\lambda 4686$  minimum is ultimately caused by an increase in the opacity in the line of sight to the emitting region as the secondary star moves behind the primary star and plunges into denser regions of its wind.

**Author(s):** Mairan Teodoro<sup>14</sup>, Augusto Damineli<sup>3</sup>, Noel Richardson<sup>11</sup>, Anthony F. J. Moffat<sup>11</sup>, Lucas St-Jean<sup>11</sup>, Christopher Michael Post Russell<sup>7</sup>, Theodore R. Gull<sup>7</sup>, Thomas Madura<sup>14</sup>, Karen Pollard<sup>12</sup>, Frederick M. Walter<sup>8</sup>, Adriano Coimbra<sup>5</sup>, Rodrigo Prates<sup>5</sup>, Eduardo Fernández-Lajús<sup>9</sup>, roberto gamen<sup>9</sup>, Gabriel Hickel<sup>10</sup>, William Henrique<sup>10</sup>, Felipe Navarete<sup>3</sup>, Thiago Andrade<sup>3</sup>, Francisco Jablonski<sup>4</sup>, Michael F. Corcoran<sup>14</sup>, Kenji Hamaguchi<sup>1</sup>, Jose H Groh<sup>2</sup>, Desmond John Hillier<sup>13</sup>, Weigelt Gerd<sup>6</sup>

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**Contributing team(s):** SASER Team members: Bernard Heathcote, Paul Luckas (The University of Western Australia), Malcolm Locke (Canterbury Astronomical Society), Jonathan Powles, and Terry Bohlson

### 317.02D – Hydrodynamic Simulations of Close and Contact Binary Systems using Bipolytropes

I will present the results of hydrodynamic simulations of close and contact bipolytropic binary systems. This project is motivated by the peculiar case of the red nova, V1309 Sco, which is indeed a merger of a contact binary. Both the stars are believed to have evolved off the main sequence by the time of the merger and possess a small helium core. In order to represent the binary accurately, I need a core-envelope structure for both the stars. I have achieved this using bipolytropes or composite polytropes. For the simulations, I use an explicit 3D Eulerian hydrodynamics code in cylindrical coordinates. I will discuss the evolution and merger scenarios of systems with different mass ratios and core mass fractions as well as the effects due to the treatment of the adiabatic exponent.

**Author(s):** Kundan Kadam<sup>1</sup>

**Institution(s):** 1. Louisiana State University

### 317.03 – Cool and Luminous Transients from Mass-Losing Binary Stars

We study transients produced by equatorial disk-like outflows from catastrophically mass-losing binary stars with an asymptotic velocity and energy deposition rate near the inner edge which are proportional to the binary escape velocity. As a test case, we present the first smoothed-particle radiation-hydrodynamics calculations of the mass loss from the outer Lagrange point with realistic equation of state and opacities. The mass-losing binary outflows produce luminosities reaching up to  $10^6 L_\odot$  and the effective temperatures are between 500 and 6000 K, which is compatible with those of many of the class of recently-discovered red transients such as V838 Mon and V1309 Sco. Dust readily forms in the outflow, potentially in

a catastrophic global cooling transition. The appearance of the transient is viewing angle-dependent due to vastly different optical depths parallel and perpendicular to the binary plane. We predict a correlation between the peak luminosity and the outflow velocity, which is roughly obeyed by the known red transients.

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### 317.04D – Probing the Structure and Morphology of X-ray and Gamma-ray Binaries Using a Multi-Wavelength, Multi-Mission Approach

This thesis focuses on High-Mass X-ray Binaries and their gamma-ray precursors, consisting of a compact object and an optical companion. Matter lost from the companion is accreted by the compact object where the gravitational potential energy is converted into X-ray radiation. The predominant high-energy emissions in gamma-ray binaries are in the MeV to TeV bandpasses. These are attributed to relativistic jets in microquasars or shocks from winds of the donor star and pulsar powered by rapid rotation of the neutron star.

I use multi-wavelength observations with RXTE, MAXI, Swift, Suzaku, Fermi and ATCA to provide detailed temporal and spectral information on several X-ray binaries and one gamma-ray binary, 1FGL J1018.6-5856.

My survey of the eclipsing HMXBs IGR J16393-4643, IGR J16418-4532, IGR J16479-4514, IGR J18027-2016 and XTE J1855-026 demonstrates that the physical parameters of both stellar components can be constrained. In IGR J16393-4643, spectral types of Bo V or Bo-5 III are found to be consistent with the eclipse duration and Roche-lobe size, but the previously proposed spectral types in IGR J16418-4532 and IGR J16479-4514 were not. Also found to be consistent with the eclipse half-angle and Roche-lobe size were the mass donor spectral types of IGR J18027-2016 and XTE J1855-026.

4U 1210-64 was postulated to be an HMXB powered by the Be mechanism. Long-term observations show distinct high and low states and a  $6.7101 \pm 0.0005$  day modulation. A sharp dip interpreted to be an eclipse is found in the folded light curves. The eclipse half-angle is not consistent with the previously proposed spectral type B5 V, pointing to possible spectral types of Bo V or Bo-5 III.

The gamma-ray binary 1FGL J1018.6-5856, discovered by the Fermi Large Area Telescope, consists of an O6 V((f)) star and a suspected rapidly spinning pulsar. I exploit the 6.5 yr gamma-ray data to search for long-term changes in the properties of the  $16.531 \pm 0.006$  day orbital modulation. The best-fit spectral model consists of a featureless absorbed power law, evidence that 1FGL J1018.6-5856 is a non-accreting system. I find the radio amplitude modulation to decline with increasing frequency, indicating the presence of free-free absorption.

**Author(s):** Joel Barry Coley<sup>1</sup>

**Institution(s):** 1. NASA Goddard

### 317.05D – The search for low-luminosity high-mass X-ray binaries and the study of X-ray populations in the Galactic disk

High-mass X-ray binaries (HMXBs), which consist of a neutron star (NS) or black hole (BH) accreting material from a massive stellar companion, provide valuable insights into the evolution of massive stars and the merger rates of NS/NS, NS/BH, and BH/BH binaries whose gravitational wave signatures will soon be detectable by facilities such as Advanced-LIGO. INTEGRAL discoveries of new classes of lower-luminosity HMXBs, some highly obscured and some showing extreme transient activity, as well as the recent discovery of the very quiescent and only known Be-BH binary, have considerably changed our understanding of clumping in massive stellar winds and the relative importance of different binary evolutionary channels. In order to better characterize the low-luminosity HMXB population, we have performed a survey of a square degree region in the

direction of the Norma spiral arm with Chandra and NuSTAR. These surveys, combined with optical and infrared spectroscopic follow-up of the counterparts of hard X-ray sources, have yielded three HMXB candidates to date. Future radial-velocity follow-up of these candidates, as well as other Be HMXB candidates from the NuSTAR serendipitous survey, will help determine whether these sources truly are HMXBs and, if so, constrain the mass of the compact object in these systems. If confirmed, these HMXB candidates could extend our measurement of the HMXB luminosity function by about two orders of magnitude and provide important constraints on massive binary evolutionary models. In addition, the colliding wind binaries and pulsar wind nebulae discovered in the Norma X-ray survey will help shed light on other aspects of massive stellar evolution and massive stellar remnants. Finally, these surveys provide the opportunity to compare the hard X-ray populations in the Galactic disk and the Galactic Center. While the dominant hard X-ray populations in both of these Galactic regions appear to be cataclysmic variables (CVs), those in the Norma survey tend to have lower plasma temperatures than those in the Galactic Center, suggesting that the white dwarfs in Galactic Center CVs may have typical masses and/or magnetic field strengths that are higher than those of white dwarfs in the disk.

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**Contributing team(s):** NuSTAR Galactic Plane Survey Team

### 317.06 – VERITAS Observations of Gamma-ray Binary Systems

Gamma-ray emitting binary systems constitute a small fraction of the high-energy catalogue, with only five objects confirmed to emit photons above 100 GeV. They comprise a compact object (black hole or neutron star) and a high-mass stellar companion, with gamma-ray emission arising as the result of particle acceleration within the system. The details of how and where this acceleration takes place, and the mechanisms which modulate the subsequent emission, remain unclear. We report here on recent observations of gamma-ray binary systems with the VERITAS observatory.

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**Institution(s):** 1. University of Delaware

**Contributing team(s):** The VERITAS Collaboration

## 318 – AGN, QSO, Blazars: Physics and Models

### 318.01D – Constraining blazar physics with polarization signatures

Blazars are active galactic nuclei whose jets are directed very close to our line of sight. They emit nonthermal-dominated emission from radio to gamma-rays, with the radio to optical emissions known to be polarized. Both radiation and polarization signatures can be strongly variable. Observations have shown that sometimes strong multiwavelength flares are accompanied by drastic polarization variations, indicating active participation of the magnetic field during flares. We have developed a 3D multi-zone time-dependent polarization-dependent radiation transfer code, which enables us to study the spectral and polarization signatures of blazar flares simultaneously. By combining this code with a Fokker-Planck nonthermal particle evolution scheme, we are able to derive simultaneous fits to time-dependent spectra, multiwavelength light curves, and time-dependent optical polarization signatures of a well-known multiwavelength flare with 180 degree polarization angle swing of the blazar 3C279. Our work shows that with detailed consideration of light travel time effects, the apparently symmetric time-dependent radiation and polarization signatures can be naturally explained by a straight, helically symmetric jet pervaded by a helical magnetic field, without the need of any asymmetric

structures. Also our model suggests that the excess in the nonthermal particles during flares can originate from magnetic reconnection events, initiated by a shock propagating through the emission region. Additionally, the magnetic field should generally revert to its initial topology after the flare. We conclude that such shock-initiated magnetic reconnection event in an emission environment with relatively strong magnetic energy can be the driver of multiwavelength flares with polarization angle swings. Future statistics on such observations will constrain general features of such events, while magneto-hydrodynamic simulations will provide physical scenarios for the magnetic field evolution; both can be tested against our model, obtaining further constraints on the particle acceleration mechanism, as well as magnetic field structure and evolution inside the blazar emission region.

**Author(s):** Haocheng Zhang<sup>3</sup>, Markus Boettcher<sup>2</sup>, Hui Li<sup>1</sup>

**Institution(s):** 1. Los Alamos National Laboratory, 2. North-West University, 3. Ohio University

### 318.02 – A Continuum Framework of the Long-Term Optical/Near-Infrared Color Variability of Blazars

We have undertaken a 7-year, multiwavelength program to observe a sample of blazars in various Fermi gamma-ray states, using the Small and Medium Aperture Research Telescope System (SMARTS) 1.3m + ANDICAM instrument in Cerro Tololo, Chile. We present near-daily optical and infrared (OIR) color variability diagrams of these sources and compare the OIR flux and color to the Fermi gamma-ray flux on similar cadence. We then analyze the color variability properties on short and long timescales, as compared to the length of an average gamma-ray flare, to better constrain the physical mechanisms responsible for the variability properties that we observe. By monitoring several activity states, we avoid the selection effects that previous studies have encountered when only observing blazars during flaring states. From this long-term observational data, we develop a schematic representation of the possible color variability behaviors in blazars and how it is related to the thermal disk and non-thermal jet contributions in both Flat Spectrum Radio Quasars and BL Lac objects.

**Author(s):** Jedidah Isler<sup>1</sup>, C. Megan Urry<sup>2</sup>, Charles D. Bailyn<sup>2</sup>, Paolo S. Coppi<sup>2</sup>, Imran Hasan<sup>2</sup>, Emily MacPherson<sup>2</sup>, Michelle Buxton<sup>2</sup>

**Institution(s):** 1. Vanderbilt University, 2. Yale University

### 318.03D – One-Zone Time Dependent Leptonic and Lepto-Hadronic Modeling of Blazars

We investigate the application of one-zone time dependent leptonic and lepto-hadronic models to blazar emission. We choose a set of input parameters for the leptonic model and the lepto-hadronic model to reproduce the broadband spectral energy distributions to the FSRQs 3C 273, 3C 279 respectively. Once we have been able to reproduce the broadband SEDs, we apply perturbations to different input parameters in the form of a Gaussian function of time in order to simulate flaring scenarios to distinguish the leptonic and lepto-hadronic models. We then apply both models to reproduce the broadband SED of the FSRQ 3C 454.3, and then apply a combination of perturbations to both models to reproduce a prominent flare that 3C 454.3 exhibited in Nov. 2010. Our results show that perturbations to any one input parameter can generate observational signatures that represent distinct differences between the leptonic and lepto-hadronic models. We also find that for 3C 454.3, while both models can reproduce the broadband SED, the lepto-hadronic model is favored to reproduce the light curves for the Nov 2010 flare based on flaring scenarios that favor strong magnetic reconnection.

**Author(s):** Chris Scott Diltz<sup>1</sup>

**Institution(s):** 1. Ohio University

### 318.04 – Exceptional X-ray Weak Quasars: Implications for Accretion Flows and Emission-Line Formation

Actively accreting supermassive black holes are found, nearly universally, to create luminous X-ray emission, and this point underlies the utility of X-ray surveys for finding active galactic nuclei

throughout the Universe. However, there are apparent X-ray weak exceptions to this rule that are now providing novel insights, including weak-line quasars (WLQs) and especially analogs of the extreme WLQ, PHL 1811. We have been systematically studying such X-ray weak quasars with Chandra and near-infrared spectroscopy, and I will report results on their remarkable properties and describe implications for models of the accretion disk/corona and emission-line formation. We have found evidence that many of these quasars may have geometrically thick inner accretion disks, likely due to high accretion rates, that shield the high-ionization broad line region from the relevant ionizing continuum. This model can explain, in a simple and unified manner, their weak lines and diverse X-ray properties. Such shielding may, more generally, play a role in shaping the broad distributions of quasar emission-line equivalent widths and blueshifts.

**Author(s):** W. Niel Brandt<sup>4</sup>, Bin Luo<sup>3</sup>, Patrick B. Hall<sup>10</sup>, Jianfeng Wu<sup>7</sup>, Scott F. Anderson<sup>9</sup>, Gordon Garmire<sup>2</sup>, Robert Gibson<sup>5</sup>, Richard Plotkin<sup>7</sup>, Gordon T. Richards<sup>1</sup>, Donald P. Schneider<sup>4</sup>, Ohad Shemmer<sup>8</sup>, Yue Shen<sup>6</sup>

**Institution(s):** 1. Drexel University, 2. Huntingdon Institute, 3. Nanjing Univ., 4. Penn State Univ., 5. SimpliVity Corp., 6. University of Illinois, 7. University of Michigan, 8. University of North Texas, 9. University of Washington, 10. York University

### 318.05 – Weak Emission-line Quasars in the Context of a Modified Baldwin Effect

Based on spectroscopic data for a sample of high-redshift quasars, I will show that the anti-correlation between the rest-frame equivalent width (EW) of the C IV  $\lambda 1549$  broad-emission line and the H $\beta$ -based Eddington ratio extends across the widest possible ranges of redshift ( $0 < z < 3.5$ ) and bolometric luminosity ( $\sim 10^{44} < L < \sim 10^{48}$  erg s<sup>-1</sup>). Given this anti-correlation, hereby referred to as a modified Baldwin effect (MBE), weak emission line quasars (WLQs), typically showing  $EW(C\ IV) < \sim 10$  Å, are expected to have extremely high Eddington ratios ( $L/L_{Edd} > \sim 4$ ). I will present new near-infrared spectroscopy of the broad H $\beta$  line, as well as complementary EW(C IV) information, for all WLQs for which such information is currently available, nine sources in total. I will show that while four of these WLQs can be accommodated by the MBE, the other five deviate significantly from this relation, at the  $> \sim 3\sigma$  level, by exhibiting C IV lines much weaker than predicted from their H $\beta$ -based Eddington ratios. Assuming the supermassive black hole masses in all quasars can be determined reliably using the single-epoch H $\beta$ -method, these results indicate that  $EW(C\ IV)$  cannot depend solely on the Eddington ratio. I will briefly discuss a strategy for further investigation into the roles that basic physical properties play in controlling the relative strengths of broad-emission lines in quasars.

**Author(s):** Ohad Shemmer<sup>1</sup>

**Institution(s):** 1. University of North Texas

### 318.06D – Using diffusion k-means for simple stellar population modeling of low S/N quasar host galaxy spectra

Quasar host galaxies (QHG) represent a unique stage in galaxy evolution that can provide a glimpse into the relationship between an active supermassive black hole (SMBH) and its host galaxy. However, observing the hosts of high luminosity, unobscured quasars in the optical is complicated by the large ratio of quasar to host galaxy light. One strategy in optical spectroscopy is to use offset longslit observations of the host galaxy. This method allows the centers of QHGs to be analyzed apart from other regions of their host galaxies. But light from the accreting black hole's point spread function still enters the host galaxy observations, and where the contrast between the host and intervening quasar light is favorable, the host galaxy is faint, producing low signal-to-noise (S/N) data. This stymies traditional stellar population methods that might rely on high S/N features in galaxy spectra to recover key galaxy properties like its star formation history (SFH). In response to this challenge, we have developed a method of stellar population modeling using diffusion k-means (DFK) that can recover SFHs from rest frame optical data with  $S/N \sim 5 \text{ Å}^{-1}$ . Specifically, we use DFK

to cultivate a reduced stellar population basis set. This DFK basis set of four broad age bins is able to recover a range of SFHs. With an analytic description of the seeing, we can use this DFK basis set to simultaneously model the SFHs and the intervening quasar light of QHGs as well. We compare the results of this method with previous techniques using synthetic data and find that our new method has a clear advantage in recovering SFHs from QHGs. On average, the DFK basis set is just as accurate and decisively more precise. This new technique could be used to analyze other low S/N galaxy spectra like those from higher redshift or integral field spectroscopy surveys.

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**Author(s):** Gregory Mosby<sup>3</sup>, Christina A. Tremonti<sup>3</sup>, Eric Hooper<sup>3</sup>, Marsha J. Wolf<sup>1</sup>, Andrew Sheinis<sup>1</sup>, Joseph Richards<sup>2</sup>

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## 319 – Star Formation

### 319.01 – Feedback During Massive Star Formation

We present models of photoionization of massive protostellar cores, and show the impact of this ionization feedback on the efficiency of star formation and its observational features. Based on the Core Accretion scenario, we construct the collapse model of rotating massive-protostellar cloud cores together with a protostellar evolutionary calculation, including feedback effects from a MHD disk wind, photoionization and radiation pressure. First, the MHD wind creates a bipolar outflow whose opening angle increases over the timescale of mass accretion. The ionizing luminosity dramatically increases after the protostar reaches  $\sim 5$  Msun due to Kelvin-Helmholtz contraction, and the MHD wind is photoionized when the protostellar mass reaches  $\sim 10 - 20$  Msun. As the ionizing and bolometric luminosities increase, the outflow opening angle becomes wider due to radiation pressure feedback. By this combination of feedback processes, the envelope is eroded and the mass infall rate is significantly reduced to that arriving only from the disk-shielded equatorial region. At a protostellar mass of  $\sim 50 - 100$  Msun, depending on the initial core properties, the mass accretion is halted by disk photoevaporation. In this way, feedback significantly reduces the star formation efficiency when forming massive stars from massive cloud cores, which could produce a cutoff at the high-mass end of the initial mass function. Along this evolutionary calculation, we also compute the detailed structure of the photoionized regions using a ray-tracing radiative transfer code and evaluate their emission signatures. Their free-free continuum and recombination line emissions are consistent with the variety of observed radio sources associated with massive protostars, i.e., jets and ultra/hyper-compact HII regions. The comparison between our models and such observations enables us to better define the evolutionary sequence of massive star formation.

**Author(s):** Kei Tanaka<sup>2</sup>, Jonathan C. Tan<sup>2</sup>, Yichen Zhang<sup>1</sup>

**Institution(s):** 1. Universidad de Chile, 2. University of Florida

### 319.02D – Giant Molecular Cloud Collisions as Triggers of Star Formation

We investigate a potentially dominant mechanism for galactic star formation: triggering via collisions between giant molecular clouds (GMCs). We create detailed numerical simulations of this process, utilizing the Enzo code with magnetohydrodynamics (MHD), including non-ideal effects, and adaptive mesh refinement (AMR) to explore how cloud collisions trigger formation of dense filaments, clumps and stars. We implement photo-dissociation region (PDR) based density/temperature/extinction-dependent heating and cooling functions that span the atomic to molecular transition and can return detailed diagnostic information. We first carried out a parameter space study via a suite of 2D simulations, which track the

fate of an initially stable clump embedded within one of the clouds. We have then extended these calculations to 3D, including introduction of initial turbulence into the clouds and magnetically-regulated sub-grid models for star formation. Different magnetic field strengths and orientations are considered, as is the role of cloud collisions at various velocities and impact parameters. We examine the effects of including ambipolar diffusion. Between isolated and colliding cases, the density and kinematic structure are visualized and characterized, in addition to magnetic field configuration. We discuss observational diagnostics of cloud collisions, focusing on  $^{13}\text{CO}(J=2-1)$ ,  $^{13}\text{CO}(J=3-2)$ , and  $^{12}\text{CO}(J=8-7)$  integrated intensity maps and spectra, which we synthesize from our simulation outputs. We find the ratio of  $J=8-7$  to lower- $J$  emission to be a powerful diagnostic probe of GMC collisions. We also analyze magnetic field orientation relative to filamentary structure, comparing to observations within the Galaxy. Finally, we examine the level of star formation activity that is induced by collisions and distinguishing kinematic properties of the stars that form by this mechanism.

**Author(s): Benjamin Wu<sup>3</sup>, Jonathan C. Tan<sup>3</sup>, Sven Van Loo<sup>4</sup>, fumitaka nakamura<sup>2</sup>, Simon Bruderer<sup>1</sup>**

**Institution(s):** 1. *Max Planck Institute for Extraterrestrial Physics*, 2. *National Astronomical Observatory of Japan*, 3. *University of Florida*, 4. *University of Leeds*

### 319.03 – Quantifying the impact of stellar feedback on molecular clouds

Although the origin of molecular cloud turbulence remains debated, one possibility is that stellar feedback injects enough energy to drive observed motions on parsec scales. To investigate this possibility, we use magnetohydrodynamic simulations where we vary the stellar mass-loss rates and magnetic field strength. We generate synthetic  $^{12}\text{CO}(1-0)$  maps assuming that the simulation is at the distance of the nearby Perseus molecular cloud. By comparing different initial conditions and evolutionary times, we are able to identify differences in our synthetic observations. Using a variety of statistical techniques proposed in the literature, we quantify the differences by calculating the first, second, and higher order moment maps of the data cubes, analyzing the power spectrum, and convolving the data with Gaussian wavelets. We find that many turbulent statistics, such as the spectral correlation function, principal component analysis, and delta-variance, are sensitive to changes in mass-loss rates and/or turbulent structure. This demonstrates that stellar feedback influences molecular cloud turbulence and may be characterized using certain statistical metrics.

**Author(s): Ryan Boyden<sup>2</sup>, Eric Koch<sup>1</sup>, Stella Offner<sup>2</sup>**

**Institution(s):** 1. *University of Alberta*, 2. *University of Massachusetts Amherst*

### 319.04 – Boundary-Layer Origin for Jets, and Non-Existence of the Boundary Layer in Young Jet-Producing Protostars

Twenty-five years ago, Pringle suggested a boundary-layer origin for jets from YSOs. The jets were driven by a toroidal magnetic field generated by strong shear in the accretion boundary layer. Such a mechanism is clearly non-magnetocentrifugal in nature.

Nearly fifteen years ago, we suggested a cartoon of the jet-launching mechanism in protostars in which shear, acting upon MHD turbulence generated by the magnetorotational instability (MRI), generated a tangled, toroidal magnetic field capable of driving a jet. This picture, which is also manifestly non-magnetocentrifugal in nature, relied upon a novel model for MRI-driven MHD turbulence based on a viscoelastic, rather than a viscous, prescription for the turbulent stress. Our hypothesis has some clear similarities to Pringle's mechanism, but it relied upon a large envelope surrounding the central star.

An accretion boundary layer has long been recognized as a promising source for protostellar jets in good part because in a standard thin disk, matter loses circa half of all its accretion energy in this layer, but it is problematic to drive a well-collimated outflow from a boundary layer in a thin disk. In this presentation, we argue paradoxically that the "boundary layer" can drive jets when a true

boundary layer, like the thin disk, does not exist. This changes the inner boundary condition for viscous angular momentum flux in the disk.

The standard argument for a thin boundary layer is, we argue, circular. In high accretion-rate systems, or when the gas cannot cool efficiently, there is no reason to suspect the turbulent viscosity in this boundary layer to be small, and therefore neither is the boundary layer. When the boundary layer becomes larger than the central accretor itself, it is arguably no longer a boundary layer, but rather an envelope. It is still, however, a substantial source of power and toroidal MRI-driven magnetic fields.

It is, again, only in relatively hot or high-accretion rate systems in which the boundary layer would be expected to inflate and so disappear. Not coincidentally, it is in such systems, such as Class 0 and Class I protostars, in which we have the strongest evidence for powerful, well-collimated jet outflows.

**Author(s): Peter T. Williams<sup>1</sup>**

**Institution(s):** 1. *unaffiliated*

### 319.05D – Protostellar jets and magnetised turbulence with smoothed particle magnetohydrodynamics

Magnetic fields are an integral component of the formation of stars. During my thesis work, I built new methods to model magnetic fields in smoothed particle magnetohydrodynamics which enforce the divergence-free constraint on the magnetic field and reduce numerical dissipation of the magnetic field. Using these methods, we have performed simulations of isolated protostar formation, studying the production of jets and outflows of material and their effect on transporting angular momentum away from the protostar and reducing the efficiency of star formation. A major code comparison project on the small-scale turbulent dynamo amplification of magnetic fields was performed, using conditions representative of molecular clouds, the formation site of stars. The results were compared against results from grid-based methods, finding excellent agreement on their statistics and qualitative behaviour. I will outline the numerical methods developed, and present the results from our protostar and molecular cloud simulations.

**Author(s): Terrence Tricco<sup>1</sup>**

**Institution(s):** 1. *University of Toronto*

### 319.06 – The SOFIA Massive (SOMA) Star Formation Survey

Massive stars play leading roles in shaping the interstellar and intergalactic media, thus regulating star formation activity and the evolution of galaxies. The formation mechanism of massive stars remains much debated, with the central question being whether it is simply a scaled-up version of low-mass star formation from gas cores or involves more complex, chaotic accretion flows in the crowded centers of concurrently forming star clusters. Using the unique  $\sim 10$  to 40 micron imaging capabilities of SOFIA-FORCAST, we are in the process of observing a large ( $>40$ ) sample of high- and intermediate-mass protostars in a variety of Galactic environments. These observations probe warm dust that is often a signature of irradiated protostellar outflow cavities. Thus analysis of the resulting spectral energy distributions and multi-wavelength images and comparison with radiative transfer models provides powerful constraints on the geometry of dense accretion flows and lower density outflows around these protostars, and thus tests massive star formation theories. We summarize latest results from the SOMA survey and its impact on theoretical modeling.

**Author(s): Jonathan C. Tan<sup>4</sup>, James M. De Buizer<sup>2</sup>, Yichen Zhang<sup>3</sup>, Mengyao Liu<sup>4</sup>, Göran H. L. Sandell<sup>2</sup>, Jan E. Staff<sup>4</sup>, Maria T. Beltrán<sup>1</sup>, Ralph Shuping<sup>2</sup>**

**Institution(s):** 1. *INAF-Osservatorio Astrofisico di Arcetri*, 2. *SOFIA-USRA, NASA Ames*, 3. *Univ. of Chile*, 4. *University of Florida*

### 319.07 – MASSES: An SMA Survey of Protostars Aimed at Understanding How Stars Gain Their Mass

Low-mass stars form from the gravitational collapse of dense molecular cloud cores. While a general consensus picture of this collapse process has emerged, many details on how mass is transferred from cores to stars remain poorly understood. MASSES (Mass Assembly of Stellar Systems and their Evolution with the SMA), an SMA large-scale project, is surveying the complete population of Class 0 and Class I protostars in the nearby Perseus Molecular Cloud in order to reveal the interplay between fragmentation, conservation of angular momentum, and mass outflows in accreting mass and setting the final masses of stars. In this presentation I will highlight key science results from the first 1.5 years of observations.

**Author(s):** Michael Dunham<sup>1</sup>

**Institution(s):** 1. Smithsonian Astrophysical Observatory

**Contributing team(s):** The MASSES Team

## 321 – Extrasolar Planets: Observations II

### 321.01 – Planet Diversity Yields with Space-based Direct Imaging Telescopes

In this presentation, we will estimate the yield for a diversity of planets from future space-based flagship telescopes. We first divide up planets into categories that are based on current observables, and that should impact the spectra we hope to observe in the future. The two main classification parameters we use here are the size of a planet and the energy flux into the planet's atmosphere. These two parameters are measurable or inferable from present-day observations, and should have a strong influence on future spectroscopy observations from JWST, WFIRST (with a coronagraph and/or starshade), and concept flagship missions that would fly some time after WFIRST. This allows us to calculate " $\eta_{\text{planet}}$ " values for each kind of planet. These  $\eta$  values then allow calculations of the expected yields from direct imaging missions, by leveraging the models and prior work by Stark and colleagues (2014, 2015). That work estimated the yields for potentially Earth-like worlds (i.e. of a size and stellar irradiation consistent with definitions of the habitable zone) for telescopes with a variety of observational parameters. We will do the same thing here, but for a wider variety of planets. This will allow us to discuss the implications of architecture and instrument properties on the diversity of worlds that future direct imaging missions would observe.

**Author(s):** Shawn Domagal-Goldman<sup>1</sup>, Ravi Kumar Kopparapu<sup>1</sup>, Eric Hébrard<sup>1</sup>, Chris Stark<sup>2</sup>, Tyler D Robinson<sup>3</sup>, Aki Roberge<sup>1</sup>, Avi Mandell<sup>1</sup>, Michael W. McElwain<sup>1</sup>, Mark Clampin<sup>1</sup>, Victoria Meadows<sup>4</sup>, Giada Arney<sup>4</sup>

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**Contributing team(s):** Advanced Technology Large Aperture Space Telescope Science Team, Exoplanet Climate Group

### 321.02 – Colors of Alien Worlds from Direct Imaging Exoplanet Missions

Future direct-imaging exoplanet missions such as WFIRST will measure the reflectivity of exoplanets at visible wavelengths. Most of the exoplanets to be observed will be located further away from their parent stars than is Earth from the Sun. These "cold" exoplanets have atmospheric environments conducive for the formation of water and/or ammonia clouds, like Jupiter in the Solar System. I find the mixing ratio of methane and the pressure level of the uppermost cloud deck on these planets can be uniquely determined from their reflection spectra, with moderate spectral resolution, if the cloud deck is between 0.6 and 1.5 bars. The existence of this unique solution is useful for exoplanet direct imaging missions for several reasons. First, the weak bands and strong bands of methane enable the measurement of the methane mixing ratio and the cloud pressure, although an overlying haze layer can bias the estimate of the latter. Second, the cloud pressure, once derived, yields an important constraint on the internal heat flux from the planet, and thus indicating its thermal evolution. Third, water worlds having H<sub>2</sub>O-dominated atmospheres are likely to have water clouds located higher than the 10<sup>-3</sup> bar pressure level, and muted spectral

absorption features. These planets would occupy a confined phase space in the color-color diagrams, likely distinguishable from H<sub>2</sub>-rich giant exoplanets by broadband observations. Therefore, direct-imaging exoplanet missions may offer the capability to broadly distinguish H<sub>2</sub>-rich giant exoplanets versus H<sub>2</sub>O-rich super-Earth exoplanets, and to detect ammonia and/or water clouds and methane gas in their atmospheres.

**Author(s):** Renyu Hu<sup>1</sup>

**Institution(s):** 1. Jet Propulsion Laboratory

### 321.03 – Infrared Polarimetry of Self-Luminous Exoplanets with the Gemini Planet Imager

Detecting polarized light from self-luminous exoplanets has the potential to provide key information about rotation, surface gravity, cloud grain size, and cloud coverage. While field brown dwarfs with polarized emission are common, no exoplanet or substellar companion has yet been detected in polarized light. With careful treatment of instrumental polarization, such a detection is now within the capabilities of modern high contrast imaging spectro-polarimeters such as GPI and SPHERE. Here, we present preliminary results from our 2015B GPI pilot program to search for polarized emission from known exoplanets and brown dwarf companions. We describe the effects of speckle noise and instrumental polarization on our analysis methods and discuss our results in the context of substellar cloud models and photometric variability.

**Author(s):** Rebecca M. Jensen-Clem<sup>1</sup>, Max Millar-Blanchaer<sup>8</sup>, Dimitri Mawet<sup>1</sup>, James R. Graham<sup>5</sup>, Heather Knutson<sup>1</sup>, Sloane Wiktorowicz<sup>6</sup>, Marshall D. Perrin<sup>3</sup>, Bruce Macintosh<sup>4</sup>, Sasha Hinkley<sup>7</sup>, J. Kent Wallace<sup>2</sup>

**Institution(s):** 1. Caltech, 2. Jet Propulsion Laboratory, 3. Space Telescope Science Institute, 4. Stanford University, 5. University of California, Berkeley, 6. University of California, Santa Cruz, 7. University of Exeter, 8. University of Toronto

**Contributing team(s):** The GPI Team

### 321.04 – The Gemini Planet Imager Exoplanet Survey and the discovery of the young Jupiter analog 51 Eridani b

The Gemini Planet Imager Exoplanet Survey has been begun in November 2014 and has surveyed more than 100 young nearby stars. I will present an updated status of the survey, including instrument performance and completeness limits. We reported our first new exoplanet discovery, the 20 Myr planet 51 Eri b, in August of 2015. J and H band spectra show that it is among the coolest and lowest-luminosity exoplanets yet imaged, with strong methane absorption and a luminosity consistent with low-entropy formation. I will give an overview of the planet's properties, and results from observations in the second half of 2015.

**Author(s):** Bruce Macintosh<sup>1</sup>

**Institution(s):** 1. Stanford University

**Contributing team(s):** The Gemini Planet Imager Exoplanet Survey

### 321.05 – A Ground-Based Albedo Upper Limit for HD 189733b from Polarimetry

We present 50 nights of polarimetric observations of HD 189733 in B band using the POLISH2 aperture-integrated polarimeter at the Lick Observatory Shane 3-m telescope. This instrument, commissioned in 2011, is designed to search for Rayleigh scattering from short-period exoplanets due to the polarized nature of scattered light. Since these planets are spatially unresolvable from their host stars, the relative contribution of the planet-to-total system polarization is expected to vary with an amplitude of order 10 parts per million (ppm) over the course of the orbit. Non-zero and also variable at the 10 ppm level, the inherent polarization of the Lick 3-m telescope limits the accuracy of our measurements and currently inhibits conclusive detection of scattered light from this exoplanet. However, the amplitude of observed variability conservatively sets a 99.7% confidence upper limit to the planet-induced polarization of the

system of 58 ppm in B band, which is consistent with a previous upper limit from the POLISH instrument at the Palomar Observatory 5-m telescope (Wiktorowicz 2009). A physically-motivated Rayleigh scattering model, which includes the depolarizing effects of multiple scattering, is used to conservatively set a 99.7% confidence upper limit to the geometric albedo of HD 189733b of  $A_g < 0.36$ . This value is consistent with the value  $A_g = 0.226 \pm 0.091$  derived from occultation observations with HST STIS (Evans et al. 2013), but it is inconsistent with the large  $A_g = 0.61 \pm 0.12$  albedo reported by Berdyugina et al. (2011).

**Author(s):** Sloane Wiktorowicz<sup>4</sup>, Larissa Nofi<sup>6</sup>, Daniel Jontof-Hutter<sup>3</sup>, Pushkar Kopparla<sup>1</sup>, Gregory P. Laughlin<sup>5</sup>, Ninos Hermis<sup>5</sup>, Yuk Yung<sup>1</sup>, Mark R. Swain<sup>2</sup>

**Institution(s):** 1. California Institute of Technology, 2. Jet Propulsion Laboratory, 3. Pennsylvania State University, 4. The Aerospace Corporation, 5. University of California, Santa Cruz, 6. University of Hawaii

### 321.06 – Revisiting HD 189733b’s non-LTE Emission

The reported detection of non-LTE emission from the transiting hot Jupiter HD 189733b has proved both intriguing and controversial with published results both confirming and contradicting the original findings. We present new high-resolution L-band spectroscopy of HD 189733b’s secondary eclipse and interpret these new findings in the context of the previous work.

**Author(s):** Robert T. Zellem<sup>1</sup>, Mark R. Swain<sup>1</sup>, Pierre Drossart<sup>2</sup>, Aishwarya Iyer<sup>1</sup>

**Institution(s):** 1. Jet Propulsion Laboratory - California Institute of Technology, 2. Observatoire Paris—Site de Meudon, France

### 321.07 – The Nature of the Super-Earth 55 Cancri e

The transiting super-Earth 55 Cnc e orbits its G type host star with an extremely short period of just under 18 hours. The exceptional brightness of the host star enables unique and highly precise observations of this extreme super-Earth. We have obtained continuous MOST photometry of the system every year since 2011, for a total of over 70 days of observations. In light of recent reports of variability in the transit and eclipse depths of this planet, we analyse our multi-year photometry to explore any differences in the measured transit depth from one observing season to the next. Our analysis also improves the precision on the transit parameters of 55 Cnc e and provides an updated value of the planetary radius. The MOST 2011 discovery data for this intriguing super-Earth exhibits a low-amplitude variation at the orbital period of the planet which cannot be solely explained by scattered light. We present continuing evidence of this effect in subsequent MOST photometry of 55 Cnc, and find that its amplitude and phase change between observing seasons. We also perform a global analysis of the entire MOST data set and present limits on the secondary eclipse, and hence the geometric albedo of 55 Cnc e. We discuss the implications of our new findings in the context of recent results based on Spitzer observations that suggest the presence of volcanism on the planet or an opaque circumstellar torus which modulates the planet’s transit and eclipse depths.

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**Institution(s):** 1. University of British Columbia, 2. University of Chicago

**Contributing team(s):** MOST Science Team

### 321.08 – A Statistical Characterization of Reflection and Refraction in the Atmospheres of sub-Saturn Kepler Planet Candidates

We present the results of our method to detect small atmospheric signals in Kepler’s close-in, sub-Saturn planet candidate light curves. We detect an average secondary eclipse for groups of super-Earth, Neptune-like, and other sub-Saturn-sized candidates by scaling and combining photometric data of the groups of candidates such that the eclipses add constructively. This greatly increases the signal-to-noise compared to combining eclipses for individual planets. We have modified our method for averaging short cadence light curves of

multiple planet candidates (2014, ApJ, 794, 133), and have applied it to long cadence data, accounting for the broadening of the eclipse due to the 30 minute cadence. We then use the secondary eclipse depth to determine the average albedo for the group. In the short cadence data, we found that a group of close-in sub-Saturn candidates (1 to 6 Earth radii) was more reflective (geometric  $A \sim 0.22$ ) than typical hot Jupiters (geometric  $A \sim 0.06$  to 0.11: Demory 2014, ApJL, 789, L20). With the larger number of candidates available in long cadence, we improve the resolution in radius and consider groups of candidates with radii between 1 and 2, 2 and 4, and 4 and 6 Earth radii. We also modify our averaging technique to search for refracted light just before and after transit in the Kepler candidate light curves, as modelled by Misra and Meadows (2014, ApJL, 795, L14).

**Author(s):** Holly A. Sheets<sup>1</sup>, Drake Deming<sup>1</sup>, Giada Arney<sup>2</sup>, Victoria Meadows<sup>2</sup>

**Institution(s):** 1. University of Maryland, 2. University of Washington

## 322 – Dust, Grains, and Pebbles in Protoplanetary Disks

### 322.02 – Constraining Collisional Models of Planetesimals in Debris Disks

Debris disks around main-sequence stars are produced by the ongoing collisional erosion of planetesimals, analogous to Kuiper Belt Objects (KBOs) or comets in our own Solar System. Observations of these dusty belts offer a window into the physical and dynamical properties of planetesimals in extrasolar systems through the size distribution of dust grains. In particular, the millimeter/radio spectral index of thermal dust emission encodes information on the grain size distribution that can be used to test proposed collisional models of planetesimals. We have made sensitive Jansky Very Large Array (JVLA) observations of a sample of 7 nearby debris disks at 9 mm and combine these with archival Australia Telescope Compact Array (ATCA) observations of 8 additional debris disks at 7 mm. Using measurements at (sub)millimeter wavelengths from the literature, we place tight constraints on the millimeter spectral indices and thus grain size distributions of this sample of debris disks. Our analysis gives a weighted mean for the slope of the power-law grain distribution that is close to the classical prediction for a steady-state collisional cascade ( $q=3.5$ ), but not consistent with the steeper distributions predicted by recent models that include more complex fragmentation processes. To interpret this result, we explore the effects of material strengths, velocity distributions, and small-size cutoffs on the steady-state grain size distribution.

**Author(s):** Meredith A. MacGregor<sup>1</sup>, David J. Wilner<sup>2</sup>, A. Meredith Hughes<sup>6</sup>, Amy Steele<sup>5</sup>, Luca Ricci<sup>2</sup>, Sean M. Andrews<sup>2</sup>, Claire J. Chandler<sup>3</sup>, Sarah Tahlí Maddison<sup>4</sup>

**Institution(s):** 1. Harvard University, 2. Harvard-Smithsonian Center for Astrophysics, 3. National Radio Astronomy Observatory, 4. Swinburne University of Technology, 5. University of Maryland, 6. Wesleyan University

### 322.03D – The Role of Disk Volatile Chemistry and Dynamics in Shaping the Compositions of Nascent Planets

The elemental composition of planets define their chemistry, and could potentially be used as beacons for their formation location if the elemental gas and grain ratios of planet birth environments, i.e. protoplanetary disks, are well understood. In disks, the ratios of volatile elements (e.g., C/O) is regulated by the presence of snowlines of major volatiles at different distances from the central star. We explore the effects of dynamical processes, such as radial drift of solids and viscous gas accretion onto the central star, molecular compositions, and the ice morphology of dust grains in disks on the snowline locations of the main C, O and N carriers in a protoplanetary disk, and their consequences for the C/O/N ratio in gas and dust throughout the disk. We find that radial drift and accretion alone can reduce the snow line radii by 40–60% of the

main C and O carriers, i.e.  $\text{H}_2\text{O}$ ,  $\text{CO}_2$  and  $\text{CO}$ , compared to static disks, substantially changing the disk regions where C/O is enhanced over the stellar value. A similar effect is seen for the major nitrogen carriers. We note that N/O enhancements in disk gas can be even more extreme than C/O in the outer disk due to the low volatility of  $\text{N}_2$  compared to all major C and O carriers. I will discuss these results together with the effects of additional dynamical processes, and outline a path toward a coupled drift-desorption-chemistry model that will provide robust quantitative results for volatile snowline locations and C/N/O abundance ratios as the disk evolves in time.

**Author(s):** Ana-Maria Piso<sup>1</sup>, Karin I. Oberg<sup>1</sup>, Tilman Birnstiel<sup>1</sup>, Ruth Murray-Clay<sup>2</sup>

**Institution(s):** 1. Harvard Univ., 2. UCSB

### 322.04 – Pebble Formation, Evolution and Accretion for Inside-Out Planet Formation

The Kepler mission has discovered more than 4000 exoplanet candidates. Many are in systems with tightly packed inner planets. Inside-Out Planet Formation (IOPF) has been proposed to explain these systems. It involves sequential in situ planet formation at the local pressure maximum of a retreating dead zone inner boundary (DZIB). Pebbles accumulate at this pressure trap, which builds up a ring, and then a planet. The planet is expected to grow until it opens a gap, which helps to both truncate pebble accretion and induce DZIB retreat that sets the location of formation of the next planet. The supply rate of pebbles is critical in this model as it sets the formation timescale of each planet. We present a model that describes the behavior of pebbles at the disk midplane, including pebble formation, growth and simple pebble-pebble interactions. The disk is divided into thin rings, in which different sub-populations of pebbles of varying sizes are modeled. In this way, we estimate the pebble supply rate to the inner disk, for given global disk properties. We then also focus on the dynamics of pebble supply to a protoplanet in the vicinity of a disk gap edge, which is being opened up once the planet reaches a critical gap opening mass. Utilizing hydro simulations of this process, we assess how the rate of pebble accretion varies as the planet approaches this mass and discuss implications for the formation of the next pebble ring and protoplanet.

**Author(s):** Xiao Hu<sup>3</sup>, Jonathan C. Tan<sup>3</sup>, Zhaohuan Zhu<sup>2</sup>, Sourav Chatterjee<sup>1</sup>

**Institution(s):** 1. Northwestern University, 2. Princeton University, 3. University of Florida

### 322.05 – Generating potassium abundance variations in the Solar Nebula

In a steadily growing wave from Spitzer through ALMA, observations of protoplanetary disks have shed ever greater light on the environment of planet formation. Nonetheless, the only source of information for the dynamics on the small, turbulent scales which control the accretion flow comes from the history of our own Solar System. The meteoritical record includes chondrites, mixtures of thermally unprocessed matrix and glassy, melted matrix. It is still unknown what mechanism heated to chondrule precursors to the 1700K temperature required to make chondrules. However, their size and composition tells us a lot about the environment in which chondrules formed, and chondrites were assembled. In particular, we show that the volatile depletion commonly (but not universally) seen in chondrules argues that they must have spent a prolonged, orbital-scale period at elevated temperatures around 1000K. This is in significant tension with chondrule cooling estimates of hours to days from laboratory studies, although those studies probe a different temperature scale. Intriguingly, the 1000K temperature scale would allow for sufficient thermal ionization of alkali metals to allow the magneto-rotational instability to act. This argues for a magnetic heating mechanism for chondrule formation. Further, the matrix was not processed at 1000K, which argues for a spatial separation between the chondrule forming, and the chondrite assembly regions.

**Author(s):** Alexander Hubbard<sup>1</sup>

**Institution(s):** 1. American Museum of Natural History

## 323 – Starburst Galaxies II

### 323.01 – Exploring the overabundance of ultraluminous X-ray sources in metal- and dust-poor local Lyman break analogs

We have studied high mass X-ray binary (HMXB) populations within two low-metallicity, starburst galaxies, Haro 11 and VV 114. These galaxies serve as analogs to high-redshift ( $z > 2$ ) Lyman break galaxies, and within the larger sample of Lyman break analogs (LBAs) are sufficiently nearby ( $< 87$  Mpc) to be spatially-resolved by *Chandra*. Previous studies of the X-ray emission in LBAs have found that the 2-10 keV luminosity per star formation rate (SFR) in these galaxies is elevated, potentially because of their low metallicities ( $12 + \log[\text{O}/\text{H}] = 8.3\text{--}8.4$ ). Theoretically, the progenitors of XRBs forming in lower metallicity environments lose less mass from stellar winds over their lifetimes, producing more massive compact objects (i.e., neutron stars and black holes), and thus resulting in more numerous and luminous HMXBs per SFR. In this talk, I present our in-depth study of the only two LBAs that have spatially-resolved 2-10 keV emission with *Chandra* to present the bright end of the X-ray luminosity distribution of HMXBs ( $L_X > 10^{39}$  erg s<sup>-1</sup>; ultraluminous X-ray sources, ULXs) in these low-metallicity galaxies, based on 8 detected ULXs. Comparing with the star-forming galaxy X-ray luminosity function (XLF), Haro 11 and VV 114 host  $\sim 4$  times more  $L_X > 10^{40}$  erg s<sup>-1</sup> sources than expected given their SFRs. We simulate the effects of source blending from crowded lower luminosity HMXBs using the star-forming galaxy XLF and then vary the XLF normalizations and bright-end slopes until we reproduce the observed point source luminosity distributions. Based on this analysis, we find that these LBAs have a shallower bright end slope than the standard XLF.

**Author(s):** Antara Basu-Zych<sup>2</sup>, Bret Lehmer<sup>4</sup>, Tassos Fragos<sup>1</sup>, Ann E. Hornschemeier<sup>2</sup>, Andreas Zezas<sup>5</sup>, Mihoko Yukita<sup>3</sup>, Andrew Ptak<sup>2</sup>

**Institution(s):** 1. Geneva Observatory, 2. Goddard Space Flight Center, 3. Johns Hopkins University, 4. University of Arkansas, 5. University of Crete

### 323.03D – Gas, Dust, and Quenching in Dusty Star-Forming Galaxies in the Early Universe

The most intense star formation in the universe takes place in dusty, star-forming galaxies at high redshifts. Recent observations and circumstantial evidence suggest that these galaxies are the likely progenitors of the earliest generation of massive, quiescent galaxies. I will discuss recent efforts to detect and resolve the gas and dust on sub-kiloparsec scales using observations of gravitationally lensed dusty galaxies discovered by the South Pole Telescope conducted by ALMA and other facilities. These observations demonstrate the richness of the molecular ISM, shed light on the relative distribution of star formation and the gas from which stars form, and offer a unique window into the evolution of dusty galaxies. Finally, I will present new ALMA observations which show signs of feedback on the molecular ISM in dusty star-forming galaxies at  $z \sim 6$ , providing tantalizing evidence of an evolutionary connection between high-redshift dusty galaxies and the first massive, quiescent systems.

**Author(s):** Justin Spilker<sup>1</sup>, Daniel P. Marrone<sup>1</sup>

**Institution(s):** 1. University of Arizona

**Contributing team(s):** SPT SMG Collaboration

### 323.04 – Highest redshift neutral hydrogen image in emission: A CHILES detection of a starbursting spiral

Our current understanding of galaxy evolution still has many uncertainties associated with the details of gas accretion, processing, and removal across cosmic time. The next generation of radio telescopes will image the neutral hydrogen in galaxies over large volumes at high redshifts, which will provide key insights into these processes. We are conducting the COSMOS HI Large Extragalactic Survey (CHILES) with the VLA, which is the first survey to simultaneously observe HI from  $z=0$  to  $z=0.5$ . The full survey consists of 1002 hours of observing time, giving us the sensitivity to image HI in 300 galaxies in the COSMOS field. Here, we report the highest redshift HI detection to date, the LIRG COSMOS

J100054.83+023126.2 at  $z=0.376$  with the first 178 hours of CHILES data. While the optical image shows it to be a large undisturbed spiral, the HI distribution is very extended and offset from the optical center. This could be evidence for interactions with companions or accretion fueling the starburst. In addition, we present follow-up LMT CO observations that reveal it to be gas-rich in molecular hydrogen. This is the first study of the HI and CO for a galaxy beyond the local Universe, which will enable us to start exploring the ISM of LIRGs at higher redshift.

**Author(s):** Ximena Fernandez<sup>3</sup>, Jacqueline H. Van Gorkom<sup>1</sup>, Hansung Gim<sup>4</sup>, Min Su Yun<sup>4</sup>, Emmanuel Momjian<sup>2</sup>

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**Contributing team(s):** CHILES Team

### 323.05D – A High Resolution, Unobscured View of the Active Regions in (Ultra) Luminous Infrared Galaxies from a VLA 33 GHz Survey

I will present a new survey of 33 GHz radio continuum emission from local U/LIRGs carried out using the Karl G. Jansky Very Large Array (VLA). This is the first such survey and it combines high resolution, good sensitivity, and multi-configuration observations that should have sensitivity to emission on all spatial scales. (Ultra) luminous infrared galaxies host some of the most extreme star-forming environments in the local universe, with large reservoirs of molecular gas and dust concentrated in the central few kpc. Our VLA observations allow us to see through the dust in these systems and to resolve the sizes of their active regions, which is essential to understand the surface and volume densities of star formation and gas in these extreme systems. I will present the best size measurements to date of the active regions for our 22 targets. I will show what these sizes imply about gas volume and surface density and infrared luminosity surface densities. I will also lay out the physical implications of these values for the strength of star formation and feedback (especially radiative feedback) in extreme environments.

**Author(s):** Loreto Barcos-Muñoz<sup>10</sup>, Adam K. Leroy<sup>7</sup>, Aaron S. Evans<sup>10</sup>, Lee Armus<sup>2</sup>, James J. Condon<sup>4</sup>, Joseph M. Mazzarella<sup>2</sup>, David S. Meier<sup>5</sup>, Emmanuel Momjian<sup>4</sup>, Eric J. Murphy<sup>2</sup>, Juergen Ott<sup>4</sup>, George C. Privon<sup>8</sup>, Ashley Reichardt<sup>6</sup>, Kazushi Sakamoto<sup>1</sup>, David B. Sanders<sup>9</sup>, Eva Schinnerer<sup>3</sup>, Sabrina Stierwalt<sup>10</sup>, Jason A. Surace<sup>2</sup>, Todd A. Thompson<sup>7</sup>, Fabian Walter<sup>3</sup>

**Institution(s):** 1. Academia Sinica, 2. Caltech, 3. MPA, 4. National Radio Astronomy Observatory, 5. New Mexico Institute of Technology, 6. NRAO - REU, 7. The Ohio State University, 8. Universidad de Concepcion, 9. University of Hawaii, 10. University of Virginia

### 323.06 – Feedback from starbursts: 30 Dorado as a case study

Stellar feedback remains a key uncertain aspect in galaxy formation and evolution theories. In addition to the mechanical energy injection from fast stellar winds and supernovae of massive stars, their radiative transfer feedback (via direct and indirect/dust-processed radiation pressures and photo-ionization) has also been proposed to play a significant role in dispersing dense dusty gas and possibly in driving outflows from starburst regions. To test the relative efficiency of these two forms of the stellar feedback, we study the energetics of the Tarantula Nebula (30 Doradus) in the Large Magellanic Cloud. The nebula consists of various blisters of diffuse hot plasma enveloped by cool gas. Based on the X-ray spectroscopy of the nebula, using a 100 ks Suzaku X-ray observation, we estimate the thermal energy of the enclosed plasma, accounting for its temperature distribution and foreground absorption variation. The estimated thermal energy is far short of the expected fraction of the mechanical energy input from the central young stellar association (NGC 2070) of the nebula, according to the classic superbubble solution, indicating a substantial loss of energy via probably hot electron-dust interaction and cosmic-ray acceleration, as well as the cool shell formation. We further characterize the kinetic energy of dense dusty gas, using a recently published dust mass map and the velocity dispersion inferred from molecular and HI gases in the nebula. However, this component of the kinetic energy appears to be

dominated by the turbulent and bulk motions of HII gas. The total kinetic energy of the nebula is consistent with the expected fraction of the mechanical energy input. Therefore, the radiation transfer feedback does not seem to play a significant role in the expansion of 30 Doradus.

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**Institution(s):** 1. Univ. of Massachusetts

## 324 – Catalogs, Surveys, and Data Viewing

### 324.01 – Introducing Nightlight: A New, Modern FITS Viewer

The field of astronomy distinguishes itself in having standardized on a single file format for the majority of data it produces. Visualization of FITS data, however, has not kept up with modern software design, user interfaces, or user interaction; the simple task of inspecting a file's structure or retrieving a particular value requires writing code. While the file format has its shortcomings, a significant reason many astronomers dislike FITS is not due to the organization of the bytes on disk, but rather the ease of use in accessing or visualizing them. Nightlight is a new desktop application whose aim is to bring a modern interface to FITS files with the polish and design people expect from applications like iTunes. By making it a native Macintosh application, one is able to leverage cutting edge frameworks not available in cross-platform environments that enable GPU acceleration, multithreading, interactive touch interfaces, real-time image processing, desktop metadata indexing, and more. Nightlight is designed to provide a common platform on top of which data or survey specific visualization needs can be built. The initial public release of Nightlight will soon be available; for more information visit <http://www.nightlightapp.io>.

**Author(s):** Demetri Muna<sup>1</sup>

**Institution(s):** 1. Ohio State University

### 324.02 – Synthesizing Understanding from Data with yt

The yt project ([yt-project.org](http://yt-project.org)) is a community-developed platform for constructing and executing analysis tasks on volumetric data. While principally applied to astrophysical simulation data, it has applications in other domains, and is a mechanism for abstracting and applying algorithms independent of the discretization (point/particle, grid, unstructured mesh) mechanism of the underlying data. In this talk, I will demonstrate its functionality for analyzing and visualizing grid, particle (SPH) and octree data, and describe its applications within a broad spectrum of astrophysical problems. Of particular importance in the methodology for development of yt is its community-based nature, with needs-driven development supporting much of its functionality; this talk will conclude with descriptions of the community of practice that surrounds yt, and the mechanisms by which this community supports and is supported by the technical aspects of yt.

**Author(s):** Matthew Turk<sup>1</sup>

**Institution(s):** 1. NCSA & University of Illinois

**Contributing team(s):** The yt project

### 324.03 – Probing the high energy sky above 10 GeV with the Fermi Large Area Telescope

A new window on the universe is opening in the high-energy sky revealed by the increase in acceptance in Fermi's Large Area Telescope (LAT) facilitated by Pass 8 above 10 GeV. Additionally, the low backgrounds and narrow point spread function at these energies mean that the sensitivity of the LAT grows linearly with time. These facts, combined with the long-term stability of the Fermi observatory and the LAT instrument, the availability of long-duration datasets, and the knowledge that some of the universe's most extreme objects emit in this range, are expanding the discovery space of the gamma-ray sky. Additionally, what the LAT discovers in the next few years will strongly influence the observation strategy of current- and next-generation ground based gamma-ray instruments. This contribution will detail these considerations, provide examples of

current studies that they have enabled, and look to the future of high-energy studies with the LAT.

**Author(s):** Jeremy S Perkins<sup>1</sup>

**Institution(s):** 1. NASA/GSFC

**Contributing team(s):** on behalf of the Fermi-LAT Collaboration

### **324.04 – The Grism Lens-Amplified Survey from Space (GLASS): Dissecting reionization, $z \sim 2$ galaxies, and dense environments**

The Grism Lens-Amplified Survey from Space (GLASS) is a large HST cycle-21 program targeting 10 massive galaxy clusters with extensive HST imaging from CLASH and the Frontier Field Initiative. The program consists of 140 primary and 140 parallel orbits of near-infrared WCF3 and optical ACS grism observations, which result in spatially resolved spectroscopy of thousands of galaxies. GLASS has three primary science drivers although a wide variety of other science investigations are possible with the public GLASS data (e.g. SN 'Refsdal'). The key science goals of GLASS are to: 1) shed light on the epoch of reionization, by measuring the Lyman alpha optical depth at  $z > 6$ ; 2) Study gas accretion, star formation, and outflows by spatially mapping resolved star formation and determine metallicity gradients from emission lines of galaxies at  $1.3 < z < 2.3$ ; 3) Explore the environmental dependence of galaxy evolution using the first comprehensive census of spatially resolved star formation in dense environments, i.e., the cluster cores as well as the cluster infall regions. I will present the first results from GLASS. High level data products are publicly available at: <https://archive.stsci.edu/prepds/glass/>

GLASS is supported by NASA through HST program GO-13459

**Author(s):** Tommaso Treu<sup>1</sup>

**Institution(s):** 1. University of California

**Contributing team(s):** GLASS team

### **324.05 – The Discovery of Transient Phenomena by NASA's K2 Mission**

The NASA K2 space mission is photometrically monitoring fields along the ecliptic to achieve a variety of science goals. These goals involve time variable observations of Solar System objects, extrasolar planets, star clusters, supernovae, and more. Because K2 observes each of its fields for just ~80 days, it has a finite baseline over which to acquire observations of photometrically varying astrophysical objects. Thanks to their extended baseline of observations, wide-field ground-based photometric and spectroscopic surveys that have been monitoring the sky for years can provide robust constraints on transiting planets, supernova events, or other transient phenomena that have been newly identified in K2 data. I will discuss the opportunities for synergistic activities between the K2 space mission and such long-running ground-based surveys as HATNet, KELT, SuperWASP, and APOGEE that will maximize the scientific output from these surveys. In particular, I will present results from a search for transient phenomena in K2 data and will use ground-based survey data to aid the characterization of these phenomena. Examples of these phenomena include single planetary transit events and stars with long-duration dimmings caused by an eclipse of a protoplanetary disk. I will also discuss the benefits that upcoming surveys like the NASA Transiting Exoplanet Survey Satellite (TESS) mission and the Large Synoptic Survey Telescope (LSST) will gain from long-term ground-based surveys.

**Author(s):** Knicole D. Colón<sup>1</sup>

**Institution(s):** 1. NASA Ames Research Center

### **324.06 – What is WorldWide Telescope, and Why Should Researchers Care?**

As of 2015, about 20 million people have downloaded the computer program called "WorldWide Telescope," and even more have accessed it via the web, at <http://worldwidetelescope.org>. But, the vast majority of these millions are not professional astronomers. This talk will explain why WorldWide Telescope (WWT) is also a powerful tool for research astronomers. I will focus on how WWT can be, and is, being built-in to Journals, and into day-to-day research

environments. By way of example, I will show how WWT already: allows users to display images, including those in Journals, in the context of multi-wavelength full-sky imagery; allows for the display of which parts of the Sky have been studied, when, how, and for what reason (see <http://adsass.org>); allows, via right-click, immediate access to ADS, SIMBAD, and other professional research tools. I will also highlight new work, currently in development, that is using WWT as a tool for observation planning, and as a display mode for advanced high-dimensional data visualization tools, like glue (see <http://glueviz.org>). WWT is now well-known in the education community (see <http://wwtambassadors.org>), so the explicit goal of this talk will be to make researchers more aware of its full power. I will explain how WWT transitioned, over 8 years, from a Microsoft Research project to its current open-source state (see <https://github.com/WorldWideTelescope>), and I will conclude with comments on the future of WWT, and its relationship to how research should be carried out in the future (see <http://tinyurl.com/aas-potf>).

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**Institution(s):** 1. Harvard-Smithsonian, CfA

### **324.07 – The Pan-STARRS Surveys**

The 4 year Pan-STARRS1 Science Mission has now completed and the final data processing and database ingest is underway. We expect to have the public release of the PS1 Survey data at approximately the time of the AAS Meeting. The full data set, including catalogs (150 Terabyte database), images (2 Petabytes), and metadata, will be available from the STScI MAST archive. The Pan-STARRS1 Surveys include: (1) The 3pi Steradian Survey, (2) The Medium Deep survey of 10 PS1 footprints (7 sq deg each) spaced around the sky; (3) A solar system survey of the ecliptic optimized for the discovery of Near Earth Objects, (4) a Stellar Transit Survey in the galactic bulge; and (5) a time domain Survey of M31.

The characteristics of the Pan-STARRS1 Surveys will be presented, including image quality, depth, cadence, and coverage. Science results span most fields of astronomy from Near Earth Objects to cosmology.

The 2nd mission, the Pan-STARRS NEO Survey, is currently underway on PS1 and it will be supplemented by PS2 observations as PS2 becomes fully operational. We will also report on the status of PS2 and the prospects for future wide field surveys in the Northern Hemisphere.

The Pan-STARRS1 Surveys have been made possible through contributions of the Institute for Astronomy of the University of Hawaii; the Pan-STARRS Project Office; the Max-Planck Society and its participating institutes: the Max Planck Institute for Astronomy, Heidelberg and the Max Planck Institute for Extraterrestrial Physics, Garching; The Johns Hopkins University; Durham University; the University of Edinburgh; Queen's University Belfast; the Harvard-Smithsonian Center for Astrophysics; the Las Cumbres Observatory Global Telescope Network Incorporated; the National Central University of Taiwan; the Space Telescope Science Institute; the National Aeronautics and Space Administration under Grant No. NNX08AR22G issued through the Planetary Science Division of the NASA Science Mission Directorate; the National Science Foundation under Grant No. AST-1238877; the University of Maryland; the Eotvos Lorand University; and the Los Alamos National Laboratory.

**Author(s):** Kenneth C. Chambers<sup>1</sup>

**Institution(s):** 1. Univ. of Hawaii

**Contributing team(s):** Pan-STARRS Team

### **324.08 – The VLA Sky Survey (VLASS): Technical Implementation Plans and Progress**

The VLA Sky Survey (VLASS) was initiated to exploit the science and technical opportunities for a new large radio astronomical survey using the Karl G. Jansky Very Large Array. In March 2015, the proposal for the VLASS underwent a formal Community Review. What emerged from this review is a 5400 hour project to survey the 33885 square degrees of the sky above Declination -40 degrees from

2-4 GHz at 2MHz frequency resolution and 2.5" angular resolution. Over the survey duration of 7 years, each area of the sky will be covered in 3 epochs spaced 32 months apart, to a depth of 0.12mJy/beam rms noise per epoch (0.07mJy/beam combined) in total intensity (Stokes I) and including full polarization. Observations are planned to commence in mid-2016. The raw data will be available in the NRAO archive immediately with no proprietary period and science data products will be provided to the community in a timely manner.

In this presentation we describe the survey design and the Technical Implementation Plan (TIP) for the VLASS. The VLASS Basic Data Products (BDP) that will be produced by the survey team include: raw and calibrated visibility data, quick-look continuum images, single-epoch images and spectral image cubes, single-epoch basic object catalogs, and cumulative "static sky" images and image cubes and basic object catalogs to the full survey depth. Calibration, image processing, and analysis for the VLASS will be carried out through automated pipelines being developed at NRAO. Integral to this workflow is maintaining Quality Assurance throughout the system from telescope to archive. The storage and archive services budgeted for the BDP is 1PB for the data and images combined. Significantly higher storage would be required to serve the highest spectral resolution spectral cubes over the full sky area, and thus devising an affordable strategy for providing these services is critical, for example through "Processing on Demand" based on user query of the archive. We will discuss opportunities for community involvement in VLASS technical areas, including the development of science-ready Enhanced Data Products and Services.

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**Institution(s):** 1. Cornell University, 2. IPAC, 3. NRAO, 4. UC Berkeley, 5. University of Manitoba  
**Contributing team(s):** VLASS Survey Science Group

### 324.09 – The VLA Sky Survey (VLASS): Description and Science Goals

The VLA Sky Survey (VLASS) will cover 80% of the sky to a target depth of 70mJy in the 2-4GHz S-band of the Karl G. Jansky Very Large Array. With a resolution of 2.5 arcseconds, it will deliver the highest angular resolution of any wide area radio survey. Each area of the survey will be observed in three epochs spaced by 32 months in order to investigate the transient radio source population over an unprecedented combination of depth and area, resulting in a uniquely powerful search for hidden explosions in the Universe. The survey will be carried out in full polarization, allowing the characterization of the magneto-ionic medium in AGN and intervening galaxies over a wide range of redshifts, and the study of Faraday rotating foregrounds such as ionized bubbles in the Milky Way. The high angular resolution will allow us to make unambiguous identifications of nearly 10 million radio sources, comprised of both extragalactic objects and more nearby radio sources in the Milky Way, through matching to wide area optical/IR surveys such as SDSS, PanSTARRS, DES, LSST, EUCLID, WFIRST and WISE. Integral to the VLASS plan is an Education and Public Outreach component that will seek to inform and educate both the scientific community and the general public about radio astronomy through the use of social media, citizen science and educational activities. We will discuss opportunities for community involvement in VLASS, including the development of Enhanced Data Products and Services that will greatly increase the scientific utility of the survey.

**Author(s):** Mark Lacy<sup>3</sup>, Stefi Alison Baum<sup>4</sup>, Claire J. Chandler<sup>3</sup>, Shami Chatterjee<sup>1</sup>, Eric J. Murphy<sup>2</sup>, Steven T. Myers<sup>3</sup>  
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**Contributing team(s):** VLASS Survey Science Group

## 326 – The Milky Way, Halo Substructure

### 326.01 – Constraining the Milky Way Mass Profile via HST Proper Motions

The Milky Way (MW) mass is a fundamental quantity for

understanding the MW in a cosmological context. The mass distribution of the MW halo has been traditionally determined by measuring the motions of tracer objects such as halo stars, globular clusters (GCs), and satellite galaxies. Despite various efforts, the MW mass at large Galactocentric radius ( $R_{GC} > 10$  kpc) is poorly known mainly due to the uncertainties in the velocity anisotropy of tracer objects. To remedy this, proper motion (PM) measurements of halo tracers are highly desired. In this talk, I will introduce our HST projects for measuring proper motions of MW satellite objects. I will discuss progress, preliminary results, and implications.

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**Institution(s):** 1. Johns Hopkins University, 2. STScI  
**Contributing team(s):** HSTPROMO Collaboration

### 326.02D – The Milky Way in Stereo: Constraints on the Galactic Gravitational Potential from Multiple Stellar Streams

Stellar streams are powerful constraints of the Galactic gravitational potential, but because the true potential form is unknown, individual streams can produce very biased results. Most potential recovery methods rely on full, observationally expensive, 6D information for the stream member stars. Consequently, current constraints of the Milky Way potential are based on individual streams, with some tension between different streams.

These discrepancies can be resolved by simultaneously modeling multiple stellar streams that have been discovered in the Galactic halo. We use two most prominent cold streams in the Milky Way, tidal tails of the Palomar 5 globular cluster and GD-1 stream, to measure the global properties of our dark matter halo. Based on the analysis of synthetic streams on similar orbits in a realistic dark matter-only simulation, we discuss which new data would most improve our understanding of the Galactic gravitational potential.

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### 326.03 – HALO7D: Disentangling the Milky Way Accretion History with Observations in 7 Dimensions

The Milky Way (MW) is shrouded in a faint metal-poor stellar halo. Its structure and kinematics provide a unique archaeological record of the MW's formation, past evolution, and accretion history. These data also help us constrain the dark matter mass out to large radii (50 to 100 kpc). However, studies of the MW stellar halo are hindered by observational constraints. Beyond  $D \sim 10$  kpc, our knowledge of the MW halo is limited to line of sight velocities and rare tracer populations (blue horizontal branch and red giant branch stars). We aim to address these limitations using highly accurate HST-measured proper motions and very deep (8-24 hour integrations) Keck DEIMOS spectroscopy of MW main sequence turn-off stars in the CANDELS fields. By combining these two datasets, we can obtain 6D phase-space information plus chemical abundances (7 "Dimensions") for our halo stars. This survey, which will be unique even in the era of Gaia, will vastly improve our understanding of the Milky Way structure, evolution and mass in a way that neither the HST proper motions nor Keck spectroscopy can do on their own.

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**Contributing team(s):** HSTPROMO, HALO7D

### 326.04D – Chaos and stellar streams

Cosmological simulations predict that dark matter halos around galaxies should be triaxial in shape with universal density profiles. A significant number of orbits in such systems are chaotic, though it is commonly assumed that chaos is not dynamically relevant for galaxy

halos because the timescales over which chaos is computed to be important are generally long relative to the dynamical time. In recent work, we showed that even when chaos is not important for restructuring the global structure of a galaxy, chaos can greatly enhance the density evolution and alter the morphologies of stellar streams over just a few orbital times by causing streams to 'fan out.' This occurs because the orbits of the stars in stellar streams have small distributions of fundamental frequencies and are therefore sensitive to mild chaos that modulates the frequencies on small-scales over much faster timescales. This suggests that the morphology of tidal streams alone can be used to estimate the significance of chaos along the orbits of the progenitor systems, thereby placing constraints on the global properties of the gravitational potential. I will explain our theoretical understanding of this phenomenon and discuss implications for a recently discovered stellar stream (the Ophiuchus stream) that may be on a chaotic orbit in the inner Milky Way due to the influence of the time-dependent, triaxial potential of the Galactic bar.

**Author(s):** Adrian M. Price-Whelan<sup>1</sup>, Kathryn V. Johnston<sup>1</sup>, Monica Valluri<sup>3</sup>, Sarah Pearson<sup>1</sup>, Andreas Hans Wilhelm Kupper<sup>1</sup>, David W. Hogg<sup>2</sup>

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### 326.05 – Exploring the SHARDS of Disrupted Milky Way Satellites with LAMOST

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) survey has obtained over 5 million stellar spectra through its first three years of operations. We present a method to statistically detect stellar excess structures (which we call "SHARDS", or Stellar Halo Accretion-Related Debris Structures) among more than 10,000 Milky Way halo giant stars observed by LAMOST. This technique uses correlations in velocity-distance phase space, accounting for the LAMOST selection function, to statistically identify stellar excesses relative to a smooth underlying model of Galactic populations. We show that the stellar halo between 20-40 kpc from the Galactic center has a level of substructure similar to model halos built purely from accreted satellites. The detected SHARDS have velocity and metallicity dispersions similar to those predicted by accretion-dominated mock halos. Further work will include characterizing known substructures via their LAMOST detections, and extending the search to include stellar metallicity (and possibly alpha abundances) as an additional signature in searching for SHARDS. This research was supported by NSF grants AST 09-37523 and AST 14-09421, and a Chinese Academy of Sciences President's International Fellowship.

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**Institution(s):** 1. National Astronomical Observatories, Chinese Academy of Sciences, 2. Rensselaer Polytechnic Institute

### 326.06D – Exploring Milky Way Halo Substructures with Large-Area Sky Surveys

Over the last two decades, large-area photometric surveys have provided deep photometric catalogs of stars in the Milky Way. As a result, our understanding of the formation of the Galactic halo has evolved from a simple monolithic collapse model to a much more complex and dynamic structure. The stellar halo is now known to be inhabited by a variety of spatial and kinematic stellar substructures, ranging from stellar clouds and streams to dwarf galaxies, predicted by hierarchical Lambda-CDM models of galaxy formation. In my talk, I will present the latest discoveries of the halo substructures found in the Dark Energy Survey (DES). I will also discuss the spectroscopic follow-up observations of the stellar cloud candidates found in the Two Micron All Sky Survey and the dwarf galaxy candidates found in DES. These newly discovered features can provide a more complete census of our Galaxy's formation history.

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## 328 – Teaching Practices for Undergraduates and Majors

### 328.01 – Providing Real Research Opportunities to Undergraduates

The current approach to undergraduate education focuses on teaching classes which provide the foundational knowledge for more applied experiences such as scientific research. Like most programs, Florida Institute of Technology (Florida Tech or FIT) strongly encourages undergraduate research, but is dominated by content-focused courses (e.g., "Physical Mechanics"). Research-like experiences are generally offered through "lab" classes, but these are almost always reproductions of past experiments: contrived, formulaic, and lacking the "heart" of real (i.e., potentially publishable) scientific research.

Real research opportunities 1) provide students with realistic insight into the actual scientific process; 2) excite students far more than end-of-chapter problems; 3) provide context for the importance of learning math, physics, and astrophysics concepts; and 4) allow unique research progress for well-chosen problems. I have provided real research opportunities as an "Exoplanet Lab" component of my Introduction to Space Science (SPS1020) class at Florida Tech, generally taken by first-year majors in our Physics, Astronomy & Astrophysics, Planetary Science, and Astrobiology degree programs. These labs are a hybrid between citizen science (e.g., PlanetHunters) and simultaneously mentoring ~60 undergraduates in similar small research projects. These projects focus on problems that can be understood in the context of the course, but which benefit from "crowdsourcing". Examples include: dividing up the known planetary systems and developing a classification scheme and organizing them into populations (Fall 2013); searching through folded light curves to discover new exoplanets missed by previous pipelines (Fall 2014); and fitting n-body models to all exoplanets with known Transit Timing Variations to estimate planet masses (Fall 2015). The students love the fact that they are doing real potentially publishable research: not many undergraduates can claim to have discovered new exoplanets!

Based on these experiences, I will present practical insights into successfully organizing real research opportunities. By employing some of these best practices, we can truly educate students and make scientific progress.

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### 328.02 – Online Planetary Science Courses at Athabasca University

Athabasca University offers distance education courses in science, at freshman and higher levels. It has a number of geology and astronomy courses, and recently opened a planetary science course as the first upper division astronomy course after many years of offering freshman astronomy. Astronomy 310, Planetary Science, focuses on process in the Solar System on bodies other than Earth. This process-oriented course uses W. F. Hartmann's "Moons and Planets" as its textbook. It primarily approaches the subject from an astronomy and physics perspective. *Geology 415, Earth's Origin and Early Evolution*, is based on the same textbook, but explores the evidence for the various processes, events, and materials involved in the formation and evolution of Earth. The course provides an overview of objects in the Solar System, including the Sun, the planets, asteroids, comets, and meteoroids. Earth's place in the solar system is examined and physical laws that govern the motion of objects in the universe are looked at. Various geochemical tools and techniques used by geologists to reveal and interpret the evidence for the formation and evolution of bodies in the solar system as well as the age of earth are also explored. After looking at lines of evidence used to reconstruct the evolution of the solar system, processes involved in the formation of planets and stars are examined. The course concludes with a look at the origin and nature of Earth's internal structure. GEOL415 is a senior undergraduate course and enrolls about 15-30 students annually. The courses are delivered online via Moodle and student evaluation is conducted through

assignments and invigilated examinations.

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### 328.03 – Balloon and Button Spectroscopy: A Hands-On Approach to Light and Matter

Without question, one of the most useful tools an astronomer can use to study the universe is spectroscopy. However, for students in introductory physics or astronomy classes, spectroscopy is a relatively abstract concept that combines new physics topics such as thermal radiation, atomic physics, and the wave and particle nature of light and matter. In response to this conceptual hurdle, we have developed an exercise where balloons represent stars, buttons represent photons, and students produce and interpret spectra by sorting buttons of various colors.

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### 328.04 – SCALE-UP Your Astronomy and Physics Undergraduate Courses to Incorporate Heliophysics

Although physics and astronomy courses include heliophysics topics, students still leave these courses without knowing what heliophysics is and how heliophysics relates to their daily lives. To meet goals of NASA's Living With a Star Program of incorporating heliophysics into undergraduate curriculum, UCF Physics has modified courses such as Astronomy (for non-science majors), Astrophysics, and SCALE-UP: Electricity and Magnetism for Engineers and Scientists to incorporate heliophysics topics. In this presentation, we discuss these incorporations and give examples that have been published in NASA Wavelength. In an associated poster, we present data on student learning

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### 328.05 – Astronomy, Visual Literacy, and Liberal Arts Education

With the exponentially growing amount of visual content that twenty-first century students will face throughout their lives, teaching them to respond to it with visual and information literacy skills should be a clear priority for liberal arts education. While visual literacy is more commonly covered within humanities curricula, I will argue that because astronomy is inherently a visual science, it is a fertile academic discipline for the teaching and learning of visual literacy. Astronomers, like many scientists, rely on three basic types of visuals to convey information: images, qualitative diagrams, and quantitative plots. In this talk, I will highlight classroom methods that can be used to teach students to "read" and "write" these three separate visuals. Examples of "reading" exercises include questioning the authorship and veracity of images, confronting the distorted scales of many diagrams published in astronomy textbooks, and extracting quantitative information from published plots. Examples of "writing" exercises include capturing astronomical images with smartphones, re-sketching textbook diagrams on whiteboards, and plotting data with Google Motion Charts or iPython notebooks. Students can be further pushed to synthesize these skills with end-of-semester slide presentations that incorporate relevant images, diagrams, and plots rather than relying solely on bulleted lists.

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### 328.06 – Teaching Introductory Astronomy “Open and Out” & Looking Forward to the 2017 Solar Eclipse

We present a new effort on teaching introductory astronomy addressing the specific challenges facing small colleges including limited resources, changing generational behavior and new technological trends. The approach adopts open source solutions into the developmental learning materials aiming for standardization and wide-scale applicability. In addition we utilize events and resources

outside classroom into the learning. Among examples of the development are laboratory exercises based on the planetarium software *Stellarium* and remediation exercises using Khan Academy instructional videos. As the eventual goal is to move toward greater autonomy the cycles of improvement necessarily require student feedback in an entirely different instructional style based on egalitarian dialogues. We highlight a laboratory exercise on Earth-Moon distance estimation using parallax of the upcoming 2017 solar eclipse to illustrate the “open and out” philosophy. Achievements, limitations and some diagnostics of the current effort are also presented.

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### 328.07 – Enriching Student Learning of Astronomy in Online Courses via Hybrid Texts

Hybrid texts such as *Horizons: Exploring the Universe, Hybrid (with CengageNOW)* and *Universe, Hybrid (with CengageNOW)* are designed for higher education learning of astronomy in undergraduate online courses. In these hybrid texts, quiz and test bank questions have been revised to minimize easy look-up of answers by students via the Internet and discussion threads have been re-designed to allow for student selection of learning and for personalized learning, for example. By establishing connections between the student and the course content, student learning is enriched, students spend more time learning the material, student copying of answers is minimized, and student social engagement on the subject matter is increased. In this presentation, we discuss how Hybrid texts in Astronomy can increase student learning in online courses.

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**Institution(s):** 1. Valencia College

### 328.08 – Pushing Stellarium to the Limit for Astronomy Distance Education

The freeware planetarium program Stellarium ([www.stellarium.org](http://www.stellarium.org)) provides a high quality astronomical simulation which can be stimulating for students of all ages. Athabasca University has been offering distance education astronomy courses using computer simulations of the night sky for nearly three decades. A recurring theme has been the challenge of matching available software to the computers available to students in their homes. Stellarium is useful in this respect in being available as downloadable freeware for Windows, Mac, and linux, and available from third parties for other platforms. Stellarium is useful for giving a qualitative idea of sky movements that take place slowly in nature. A night, or even a year, can be presented in sped up time, or with large time steps allowing to see changes. Our Science-stream freshman course emphasizes quantitative analysis, and Stellarium is also useful for this. Plotting the Sun's position at noon (allowing for Daylight Savings Time) gives an analemma from which the obliquity can be readily calculated. The Moon's daily motion can be measured in degrees with local declination lines as a reference, allowing the eccentricity of its orbit to be demonstrated. Plotting retrograde loops for outer planets corrects the misimpression students sometimes develop that this is a phenomenon restricted to Mars. For both inner and outer planets, the relation of synodic and sidereal periods may be explored quantitatively. Most recently we are exploring the possibility of replacing our HR diagram and Hubble Law plots with data gathered from Stellarium. Data in these is not directly measured as are the variables in planetary motion labs, but an observational feel can be added to labs that otherwise (if done using published tables of data) could seem divorced from observation. Stellarium can help attain a large number of objectives in introductory astronomy education, from truly understanding basic phenomena to making and interpreting quantitative measurements.

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### 328.09 – OrbitMaster: An Online Tool for Investigating Solar System Dynamics and Visualizing

## Orbital Uncertainties in the Undergraduate Classroom

*OrbitMaster* is a 3-D orbit visualization tool designed for the undergraduate astronomy classroom. It has been adapted from AstroArts' interactive *OrbitViewer* applet under the GNU General Public License, as part of the Research-Based Science Education for Undergraduates (RBSEU) curriculum. New features allow the user to alter an asteroid's orbital parameters using slider controls, and to monitor its changing position and speed relative to both Sun and Earth. It detects close approaches and collisions with Earth, and calculates revised distances and impact speeds due to Earth's gravitational attraction. It can also display many asteroid orbits at once, with direct application to visualizing the uncertainty in a single asteroid's orbital parameters. When paired with Project Pluto's *Find\_Orb* orbit determination software and a source of asteroid astrometry, this enables monitoring of changes in orbital uncertainties with time and/or additional observational data. See [http://facstaff.columbusstate.edu/puckett\\_andrew/orbitmaster.html](http://facstaff.columbusstate.edu/puckett_andrew/orbitmaster.html).

A series of undergraduate labs using the *OrbitMaster* applet are available as part of the RBSEU curriculum. In the first lab, students gain hands-on experience with the mechanics of asteroid orbits and confirm Kepler's laws of planetary motion. In the second, they study the orbits of Potentially Hazardous Asteroids as they build their own "Killer Asteroids" and investigate the minimum and maximum speed limits that apply to Earth-impacting objects. In the third and fourth labs, they discover the kinetic energy-crater size relationship, engage in their own Crater Scene Investigation (C.S.I.) to estimate impactor size, and understand the regional consequences of impacts. These labs may be used separately, or in support of a further seven-week sequence culminating in an authentic research project in which students submit measurements to the Minor Planet Center to refine a real asteroid's orbit. As with all RBSEU projects, the overarching goal is for students to learn science by actually *doing* science, and to retain knowledge learned in-context. For more information, see <http://rbseu.uaa.alaska.edu>.

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**Institution(s):** 1. AstroArts Inc, 2. Columbus State University, 3. NASA/JPL, 4. Univ. of Alaska Anchorage

## 333 – The RESolved Spectroscopy Of a Local Volume (RESOLVE) Survey and its Environmental Context (ECO) Poster Session

### 333.01 – Exploring the Origin of HI Profile Asymmetries in the RESOLVE Survey

We present an analysis of the rate of highly (>30%) asymmetric HI profiles using the 21cm census for the RESOLVE survey, a volume-limited census of the  $z=0$  galaxy population spanning diverse environments and complete to baryonic mass  $\sim 10^9 M_\odot$ . In order to constrain whether asymmetric HI profiles arise from tidal interactions, gas accretion, or other possible phenomena, we examine the frequency of strong HI profile asymmetries as a function of environment parameterized by nearest neighbor distance, group halo mass, and location within large-scale structure. We find no link between the rate of highly asymmetric HI profiles and local or global environment, and we compare this result to expectations from simple models of galaxy interactions. We do see an increase in strong HI asymmetries with decreasing halo mass, however it does not exceed the increase expected from decreasing signal-to-noise of the HI observations. These results are tentatively consistent with a picture of isotropic cooling rather than directed cold streams within halos down to masses of  $10^{11} M_\odot$ . However, we argue that two built-in biases affect HI asymmetry measurements. First, the profile asymmetry can be systematically underestimated when using the systemic velocity from the HI profile itself, which particularly affects low-mass galaxies. Second, the profile asymmetry may be overestimated due to confusion from companions below the magnitude limit of the survey. We explore the possibility that analysis of HI profiles with reference to optical rotation curves may

mitigate these biases. This project has been supported by NSF funding for the RESOLVE survey (AST-0955368), the GBT Student Observing Support program, and a UNC Royster Society of Fellows Dissertation Completion Fellowship.

**Author(s):** David Stark<sup>2</sup>, Sheila Kannappan<sup>4</sup>, Kathleen D. Eckert<sup>4</sup>, Kirsten Hall<sup>4</sup>, Martha P. Haynes<sup>1</sup>, Joseph Burchett<sup>3</sup>, Daniel J. Pisano<sup>5</sup>

**Institution(s):** 1. Cornell University, 2. Kavli IPMU, Japan, 3. University of Massachusetts, 4. University of North Carolina, Chapel Hill, 5. West Virginia University

**Contributing team(s):** The RESOLVE team

### 333.02 – Probing Cosmic Gas Accretion with RESOLVE and ECO

We review results bearing on the existence, controlling factors, and mechanisms of cosmic gas accretion in the RESOLVE and ECO surveys. Volume-limited analysis of RESOLVE's complete census of HI-to-stellar mass ratios and star formation histories for  $\sim 1500$  galaxies points to the necessity of an "open box" model of galaxy fueling, with the most gas-dominated galaxies doubling their stellar masses on  $\sim$ Gyr timescales in a regime of rapid accretion. Transitions in gas richness and disk-building activity for isolated or central galaxies with halo masses near  $\sim 10^{11.5} M_\odot$  and  $\sim 10^{12} M_\odot$  plausibly correspond to the endpoints of a theoretically predicted transition in halo gas temperature that slows accretion across this range. The same mass range is associated with the initial grouping of isolated galaxies into common halos, where "isolated" is defined relative to the survey baryonic mass limits of  $> \sim 10^9 M_\odot$ . Above  $10^{11.5} M_\odot$ , patterns in central vs. satellite gas richness as a function of group halo mass suggest that galaxy refueling is valved off from the inside out as the halo grows, with total quenching beyond the virial radius for halo masses  $> \sim 10^{13-13.5} M_\odot$ . Within the transition range from  $\sim 10^{11.5-10^{12}} M_\odot$ , theoretical models predict  $> 3$  dex dispersion in ratios of uncooled halo gas to cold gas in galaxies (or more generally gas and stars). In RESOLVE and ECO, the baryonic mass function of galaxies in this transitional halo mass range displays signs of stripping or destruction of satellites, leading us to investigate a possible connection with halo gas heating using central galaxy color and group dynamics to probe group evolutionary state. Finally, we take a first look at how internal variations in metallicity, dynamics, and star formation constrain accretion mechanisms such as cold streams, induced extraplanar gas cooling, isotropic halo gas cooling, and gas-rich merging in different mass and environment regimes. The RESOLVE and ECO surveys have been supported by funding from NSF grants AST-0955368 and OCI-1156614.

**Author(s):** Sheila Kannappan<sup>2</sup>, Kathleen D. Eckert<sup>2</sup>, David Stark<sup>1</sup>, Claudia Lagos<sup>3</sup>, Zachary Nasipak<sup>2</sup>, Amanda J. Moffett<sup>3</sup>, Ashley Baker<sup>2</sup>, Andreas A. Berlind<sup>4</sup>, Erik A. Hoversten<sup>2</sup>, Mark A. Norris<sup>2</sup>

**Institution(s):** 1. Kavli IPMU, 2. Univ. of North Carolina, 3. University of Western Australia, 4. Vanderbilt

**Contributing team(s):** the RESOLVE team

### 333.03 – Detailed Analysis of Starburst and AGN Activity in Blue E/So Galaxies in RESOLVE

We identify a population of  $\sim 120$  blue E/So galaxies among the  $\sim 1350$  galaxies that are targeted for spectroscopy and have measured morphologies in the highly complete Resolved Spectroscopy Of a Local Volume (RESOLVE) survey. Blue E/Sos are identified as being early type objects morphologically classified between E and So/a that fall on the blue sequence. Most ( $\sim 85\%$ ) of our blue E/Sos have stellar masses  $< 10^{10} M_\odot$ . Using pPXF, we have measured the stellar velocity dispersions (sigma values) from high resolution 485 - 550 nm spectroscopy for  $\sim 15\%$  of the blue E/So sample. Using three variations of the  $M_{BH} - \sigma$  relation, this kinematic subsample is estimated to typically host central black holes within the range  $\log M_{BH} = 4-6 M_\odot$ . Following up on previous suggestions of nuclear activity in the blue E/So population, we investigate nuclear starburst and/or AGN activity occurring within the full sample. Preliminary results from cross-checking known AGN catalogs with the blue E/So sample have revealed nuclear activity in  $\sim 20$  of these galaxies based on heterogeneous criteria (BPT line ratio analysis,

spectral line broadening, etc.), some of which may not entirely distinguish starburst from AGN activity. In an attempt to break the degeneracy between AGN and starburst activity, we perform detailed spectral analysis for a few of the galaxies with kinematic data. We also consider the viability of alternate AGN detection methods based on  $L_{\text{Edd}}$  estimates calculated from the  $M_{\text{BH}}$  estimates. This research has been supported by the National Science Foundation through the CAP REU Program (ACI-1156614) and the RESOLVE Survey (AST-0955368) as well as the National Space Grant College and Fellowship Program and the NC Space Grant Consortium.

**Author(s):** Ashley Bittner<sup>5</sup>, Elaine M. Snyder<sup>5</sup>, Sheila Kannappan<sup>5</sup>, Dara J. Norman<sup>4</sup>, Mark A. Norris<sup>3</sup>, Amanda J. Moffett<sup>1</sup>, Erik A. Hoversten<sup>5</sup>, David Stark<sup>2</sup>

**Institution(s):** 1. ICRAR, 2. IPMU, 3. Max Planck Institute for Astronomy, 4. NOAO, 5. University of North Carolina at Chapel Hill

**Contributing team(s):** the RESOLVE team

### 333.04 – Status of The Dynamical Census of Galaxies and Groups in the RESOLVE Survey

The RESolved Spectroscopy of a Local Volume (RESOLVE) survey is measuring either velocity dispersions or rotation velocities for  $\sim 1500$  galaxies and  $\sim 200$  multi-galaxy groups within  $>50,000$  cubic Mpc of the  $z=0$  universe, above a galaxy baryonic mass limit of  $\sim 10^9$  Msun. Our kinematic census combines multi-slit, IFU, Fabry-Perot, long-slit, and radio linewidth data from the SOAR, SALT, Gemini, AAT, GBT, and Arecibo telescopes, with telescope/instrument combinations optimized for individual galaxy properties. We present a status update of the data taken, particularly focusing on the RESOLVE Early Science region overlapping Stripe 82. We also discuss challenges for dynamical measurements including measuring galaxy inclinations, determining the mix of support from rotational and random motions, and measuring dynamical masses for groups with few members. Finally, we conclude with a preliminary velocity function for the RESOLVE Early Science region. This work has been supported by the NSF through grants AST-0955368 and OCI-1156614, the NC Space Grant Graduate Research Fellowship Program, and a UNC Royster Society of Fellows Dissertation Completion Fellowship.

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**Contributing team(s):** RESOLVE team

### 333.05 – Simulating Compact Elliptical Galaxy Formation by Tidal Stripping for Comparison to the RESOLVE Survey

Observations of compact elliptical galaxies (cEs) have uncovered abnormally high velocity dispersions and surface brightnesses for objects of their mass. These properties indicate that they may be the tidally stripped remnants of larger disk galaxies. We test this tidal stripping scenario using N-body simulations of cE formation with the Gadget-2 code. We track the velocity dispersions of stellar particles within the half-light radius throughout our simulations, which allows us to compare our simulated galaxies with velocity dispersion data for cEs in the RESOLVE survey. We first consider initial conditions similar to published work, which report stripping of a large spiral galaxy (stellar mass  $\sim 10^{11}$  solar masses) to cE size in a cluster potential. We find that the density of the disk galaxy is too high to allow it to lose particles to the less dense cluster. We argue that the initial position of the galaxy with respect to the cluster as well as the large size of the cluster particles in comparison to the size of the galaxy particles artificially heightened the stripping percentages reported in previous work. We hypothesize that only a dwarf galaxy with a shallower density profile can be stripped to cE size, and we present initial efforts to test this idea. We simulate a dwarf galaxy based on a real system in the RESOLVE survey, with stellar mass

$10^9$  solar masses and half-light radius 1.15 kpc. Within  $\sim 700$  pc our dwarf is denser than our cluster, suggesting the stripped remnant should be close to the size of RESOLVE cEs. This radius contains approximately 13% of the total stellar mass of the galaxy, or  $\sim 2 \times 10^8$  solar masses. We therefore expect our stripped remnant to be at least this massive, although the impact parameter of the orbit will determine how much mass is actually removed. We discuss the position of our simulated galaxies compared to RESOLVE cEs in the velocity dispersion vs. mass plane. This research has been supported by National Science Foundation grants to the CAP REU program (ACI-1156614) and the RESOLVE survey (AST-0955368).

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**Contributing team(s):** RESOLVE Team

## 334 – SDSS-IV MaNGA: Mapping Nearby Galaxies at Apache Point Observatory Poster Session

### 334.01 – MaNGA: Target selection and Optimization

The 6-year SDSS-IV MaNGA survey will measure spatially resolved spectroscopy for 10,000 nearby galaxies using the Sloan 2.5m telescope and the BOSS spectrographs with a new fiber arrangement consisting of 17 individually deployable IFUs. We present the simultaneous design of the target selection and IFU size distribution to optimally meet our targeting requirements. The requirements for the main samples were to use simple cuts in redshift and magnitude to produce an approximately flat number density of targets as a function of stellar mass, ranging from  $1 \times 10^9$  to  $1 \times 10^{11} M_{\odot}$ , and radial coverage to either 1.5 (Primary sample) or 2.5 (Secondary sample) effective radii, while maximizing S/N and spatial resolution. In addition we constructed a “Color-Enhanced” sample where we required 25% of the targets to have an approximately flat number density in the color and mass plane. We show how these requirements are met using simple absolute magnitude (and color) dependent redshift cuts applied to an extended version of the NASA Sloan Atlas (NSA), how this determines the distribution of IFU sizes and the resulting properties of the MaNGA sample.

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### 334.02 – The power spectra of non-circular motions in disk galaxies

Using data from the first year of the SDSS-IV/MaNGA survey, we present a preliminary study of the amplitude of non-circular motions in a sample of disk galaxies. We select galaxies that have either a visual classification as a spiral galaxy by the Galaxy Zoo project (Lintott et al. 2011) and/or a measured Sersic index of less than 2.5 from the NASA-Sloan Atlas (nsatlas.org). We also remove high-inclination systems by selecting galaxies with isophotal ellipticity measurements of less than 0.6, implying an inclination of less than 65 degrees. For each galaxy, we fit a tilted-disk model to the observed line-of-sight velocities (Andersen & Bershadsky 2013). The geometric projection of the circularly rotating disk is simultaneously fit to both the ionized-gas (H-alpha) and stellar kinematics, whereas the rotation curves of the two dynamical tracers are allowed to be independent. We deproject the residuals of the velocity-field fit to the disk-plane polar coordinates and select a radial region that is fully covered in azimuth, yet not undersampled by the on-sky spaxel. Similar to the approach taken by Bovy et al. (2015) for the Milky Way, we then compute the two-dimensional power spectrum of this velocity-residual map, which provides the amplitude of non-circular motions at all modes probed by the data. Our preliminary analysis reveals disk-plane non-circular motions in both the stars and ionized-gas with typical peak amplitudes of approximately 20 km/s. Additionally, our initial findings appear to demonstrate that non-circular motions in barred galaxies are stronger in the ionized gas than in the stars, a trend not seen in unbarred galaxies.

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### 334.03 – Identifying Extraplanar Diffuse Ionized Gas in a Sample of MaNGA Galaxies

The efficiency with which galaxies convert gas into stars is driven by the continuous cycle of accretion and feedback processes within the circumgalactic medium. Extraplanar diffuse ionized gas (eDIG) can provide insights into the tumultuous processes that govern the evolution of galactic disks because eDIG emission traces both inflowing and outflowing gas. With the help of state-of-the-art, spatially-resolved spectroscopy from MaNGA (Mapping Nearby Galaxies at Apache Point Observatory), we developed a computational method to identify eDIG based on the strength of and spatial extent of optical emission lines for a diverse sample of 550 nearby galaxies. This sample includes roughly half of the MaNGA galaxies that will become publicly available in summer 2016 as part of the Thirteenth Data Release of the Sloan Digital Sky Survey. We identified signatures of eDIG in 8% of the galaxies in this sample, and we found that these signatures are particularly common among galaxies with active star formation and inclination angles >45 degrees. Our analysis of the morphology, incidence, and kinematics of eDIG has important implications for current models of accretion and feedback processes that regulate star formation in galaxies. We acknowledge support from the Astrophysics REU program at the University of Wisconsin-Madison, the National Astronomy Consortium, and The Grainger Foundation.

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### 334.04 – The Impact of Diffuse Ionized Gas on Emission-line Ratios and Gas Metallicity Measurements

Diffuse Ionized Gas (DIG) is prevalent in star-forming galaxies. Using a sample of galaxies observed by MaNGA, we demonstrate how DIG in star-forming galaxies impact the measurements of emission line ratios, hence the gas-phase metallicity measurements and the interpretation of diagnostic diagrams. We demonstrate that emission line surface brightness (SB) is a reasonably good proxy to separate HII regions from regions dominated by diffuse ionized gas. For spatially-adjacent regions or regions at the same radius, many line ratios change systematically with emission line surface brightness, reflecting a gradual increase of dominance by DIG towards low SB. DIG could significantly bias the measurement of gas metallicity and metallicity gradient. Because DIG tend to have a higher temperature than HII regions, at fixed metallicity DIG displays lower [NII]/[OII] ratios. DIG also show lower [OIII]/[OII] ratios than HII regions, due to extended partially-ionized regions that enhance all low-ionization lines ([NII], [SII], [OII], [OI]). The contamination by DIG is responsible for a substantial portion of the scatter in metallicity measurements. At different surface brightness, line ratios and line ratio gradients can differ systematically. As DIG fraction could change with radius, it can affect the metallicity gradient measurements in systematic ways. The three commonly used strong-line metallicity indicators, R23, [NII]/[OII], O3N2, are all affected in different ways. To make robust metallicity gradient measurements, one has to properly isolate HII regions and correct for DIG contamination. In line ratio diagnostic diagrams, contamination by DIG moves HII regions towards composite or LINER-like regions.

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## 335 – Opening a New Window on Cosmological Structure with Intensity

## Mapping Poster Session

### 335.01 – Advances In Cryogenic Monolithic Millimeter-wave Integrated Circuit (MMIC) Low Noise Amplifiers For CO Intensity Mapping and ALMA Band 2

We will present results of the latest InP HEMT MMIC low noise amplifiers in the 30-300 GHz range, with emphasis on LNAs and mixers developed for CO intensity mapping in the 40-80 GHz range, as well as MMIC LNAs suitable for ALMA Band 2 (67-90 GHz). The LNAs have been developed together with NGC in a 35 nm InP HEMT MMIC process. Recent results and a summary of best InP low noise amplifier data will be presented. This work describes technologies related to the detection and study of highly redshifted spectral lines from the CO molecule, a key tracer for molecular hydrogen. One of the most promising techniques for observing the Cosmic Dawn is intensity mapping of spectral-spatial fluctuations of line emission from neutral hydrogen (H I), CO, and [C II]. The essential idea is that instead of trying to detect line emission from individual galaxies, one measures the total line emission from a number of galaxies within the volume defined by a spectral-spatial pixel. Fluctuations from pixel to pixel trace large scale structure, and the evolution with redshift is revealed as a function of receiver frequency. A special feature of CO is the existence of multiple lines with a well-defined frequency relationship from the rotational ladder, which allows the possibility of cleanly separating the signal from other lines or foreground structure at other redshifts. Making use of this feature (not available to either HI or [C II] measurements) requires observing multiple frequencies, including the range 40–80 GHz, much of which is inaccessible from the ground or balloons. Specifically, the J=1->0 transition frequency is 115 GHz; J=2->1 is 230 GHz; J=3->2 is 345 GHz, etc. At redshift 7, these lines would appear at 14.4, 28.8, and 43.2 GHz, accessible from the ground. Over a wider range of redshifts, from 3 to 7, these lines would appear at frequencies from 14 to 86 GHz. A ground-based CO Intensity mapping experiment, COMAP, will utilize InP-based HEMT MMIC amplifier front ends in the 30 GHz range. Higher frequencies which are difficult to observe from the ground will be necessary to realize the full scientific potential of redshifted CO emission, and results from the latest MMIC LNAs above 40 GHz will be presented here

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### 335.02 – Connecting CO Intensity Mapping to $z > 2$ Galaxies

Intensity mapping, which images a single spectral line from unresolved galaxies across cosmological volumes, is a promising technique for probing the early universe. I will present predictions for the intensity map and power spectrum of the CO(1-0) line from  $z \sim 2.4$ -2.8 galaxies, based on a parameterized model for the galaxy-halo connection, and demonstrate the extent to which properties of high-redshift galaxies can be directly inferred from such observations. Our fiducial prediction should be detectable by a realistic experiment, but motivated by significant model uncertainties, we demonstrate the effect on the power spectrum of varying each parameter in our model. Using simulated observations, we infer constraints on our model parameter space with an MCMC procedure, and show corresponding constraints on the LIR-LCO relation and the CO luminosity function. These constraints would be complementary to current high-redshift galaxy observations, which can detect the brightest galaxies but not complete samples from the faint end of the luminosity function. By probing these populations in aggregate, CO intensity mapping could be a valuable tool for probing molecular gas and its relation to star formation in high-redshift galaxies.

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### **335.03 – Intensity Mapping of the History of Stellar Emission with the Cosmic Infrared Background Experiment-2**

Recent measurements of the near-infrared Extragalactic Background Light (EBL) anisotropy find excess spatial power above the level predicted by known galaxy populations at large angular scales. These anisotropies trace spatial variations in integrated photon production, so measurements of EBL surface brightness fluctuations provide a complete census of the emission from stars summed over cosmic history. As a result, EBL fluctuations contain contributions from objects forming during the Epoch of Reionization (EOR), from the integrated galactic light (IGL), and faint, extended components such as intra-halo light (IHL) from stars tidally stripped from galaxies during merger events. Additional measurements with greater sensitivity, spectral range, and spectral resolution are required to disentangle these contributions.

The Cosmic Infrared Background Experiment 2 (CIBER-2) is an instrument optimized for the measurement of near-infrared EBL anisotropies. As the Earth's atmosphere generates time-varying near-infrared emission, CIBER-2 is launched on a sounding rocket from which it will carry out multiwavelength imaging in six spectral bands that span the visible to near-infrared. The 2.4 square degree images allow CIBER-2 to produce measurements of EBL fluctuations with high fidelity on large angular scales. The Lyman break feature from EOR sources provides a unique spectral feature which can be used to disentangle the high from the low redshift contributions to the anisotropy signal. Measurement in six independent wavebands allows detailed cross-correlation studies to constrain the source of the excess fluctuations at large angular scales. We provide an overview of the CIBER-2 instrument and explain CIBER-2 spectral feature identification and cross-correlation study methodologies.

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### **335.04 – Measuring Galaxy Clustering and the Evolution of [C II] Mean Intensity with Far-IR Line Intensity Mapping during $0.5 < z < 1.5$**

Infrared fine-structure emission lines from trace metals are powerful diagnostics of the interstellar medium in galaxies. We explore the possibility of studying the redshifted far-IR fine-structure line emission using the three-dimensional (3D) power spectra obtained with an imaging spectrometer. The intensity mapping approach measures the spatio-spectral fluctuations due to line emission from all galaxies, including those below the individual detection threshold. The technique provides 3D measurements of galaxy clustering and moments of the galaxy luminosity function. Furthermore, the linear portion of the power spectrum can be used to measure the total line emission intensity including all sources through cosmic time with redshift information naturally encoded. As a case study, we consider measurement of [C II] autocorrelation in the  $0.5 < z < 1.5$  epoch, where interloper lines are minimized, using far-IR/submillimeter balloon-borne and future space-borne instruments with moderate and high sensitivity, respectively. In this context, we compare the intensity mapping approach to blind galaxy surveys based on individual detections. We find that intensity mapping is nearly always the best way to obtain the total line emission because blind, wide-field galaxy surveys lack sufficient depth and deep pencil beams do not observe enough galaxies in the requisite luminosity and

redshift bins. Also, intensity mapping is often the most efficient way to measure the power spectrum shape, depending on the details of the luminosity function and the telescope aperture.

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## **336 – Science Results from the Stratospheric Observatory for Infrared Astronomy (SOFIA) Poster Session**

### **336.01 – 31.5um imaging observations of AGN using SOFIA/FORCAST**

The unified model of active galactic nuclei (AGN) requires a toroidal region of optically and geometrically thick dust obscuring a central engine, accounting for various observed spectral features. Our aim is to investigate the overall torus properties to obtain analytical results for its physical parameters. We present 31.5um photometric observations of 12 nearby Seyfert galaxies from the 2.5m SOFIA telescope using the FORCAST camera. We used Clumpy torus models and a Bayesian approach to fit the IR (1.2-31.5um) nuclear SEDs and high angular resolution mid-IR (8-13um) spectroscopy. We found that the turnover of the torus emission does not occur at wavelengths  $< 31.5\mu\text{m}$ , which we interpret as a lower-limit for the peak torus emission. Including the 31.5um nuclear flux 1) reduces the dispersion of Clumpy torus models at wavelengths  $> 30\mu\text{m}$ , which better constrains the model parameters, 2) generally decreases the radial extent of the torus. We find torus radii ranging from  $\sim 1 - 8.5\text{pc}$ , with an average radius of 2.6pc, which is consistent with interferometric and high-spatial resolution observations.

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**Contributing team(s):** Los Piratas Team

### **336.02 – SOFIA-FORCAST Imaging of Giant HII Regions in Our Galaxy**

We know very little about clustered star formation in comparison to isolated star formation, even though it is believed that most stars form in OB clusters. Giant HII (GHII) regions host the most active areas of OB star formation in the galaxy, and as such are great laboratories for the study of the earliest stages of clustered star formation. An understanding of the link between the large unresolved star forming regions which dominate in external galaxies, require the results from a holistic study like this one of similar regions in our own Galaxy to calibrate their properties. This study uses SOFIA's FORCAST instrument to collect 19.7 um and 37.1 um maps of all 56 GHII regions in the Milky Way, and 8 targets have been observed so far. The 37um maps have the best-ever achieved resolution at that wavelength. The combination of longer wavelength IR data and good spatial resolution allow the detection and characterization of embedded young stellar objects and the colder dust population throughout the GHII regions. These data are being combined with Spitzer/IRAC, Herschel 70 um, and radio (2-6 cm) data already collected for these targets to determine the physical properties of the dust, including dust mass, temperature, and optical depth, derived across the GHII regions.

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### **336.03 – SOFIA/FORCAST Spectroscopy of NGC 7009, the Saturn Nebula**

We present spatially resolved mid-IR spectra of the well-studied Planetary Nebula (PN) NGC 7009 obtained with the FORCAST instrument on board the Stratospheric Observatory for Infrared Astronomy (SOFIA). NGC 7009 has a relatively high "abundance discrepancy factor" - the heavy element abundances derived from optical recombination lines (ORLs) are higher by a factor of about 5

than abundances derived from collisionally excited lines (CELs). One hypothesis to resolve this discrepancy is that two kinds of regions with distinct properties are responsible for the abundance measurements from ORLs and CELs. Lines from [OIV], [SIII], [SIV] and [ArIII] are detected in the FORCAST spectra, which cover the wavelength ranges 8.7--13.9 and 17.7--27.6 microns with moderate spectral resolution ( $R \sim 100$ ). We explore the abundance variations with radial distance from the center of the nebula and their possible correlations with the abundance discrepancy factor.

Starting with our observations and results on NGC 7009 as an example, we present a survey of the capabilities of SOFIA, and describe its potential in the field of infra-red studies of Galactic PNe.

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### 336.04 – Estimating the Internal Luminosities of Protostars with SOFIA/FORCAST

During the last decade, the Spitzer Space Telescope and Herschel Space Telescope enabled large infrared surveys of nearby molecular clouds forming low mass stars. The 70 micron observations obtained by those facilities provide estimates of the internal luminosities of protostars that are reliable to within a factor of 2, in general. Spitzer observations at shorter wavelengths yield estimates that are much less constrained, reliable only to within an order of magnitude, at best. With the Stratospheric Observatory for Infrared Astronomy (SOFIA) routinely operating science flights, this facility may be used to further study protostellar populations. We demonstrate that mid-infrared images obtained with the Faint Object infraRed Camera for the SOFIA Telescope (FORCAST) achieve internal luminosities with reliability comparable to that achieved by 70 micron observations. With its dynamic range and greater angular resolution, FORCAST may be used to characterize protostars that were either saturated or merged with other sources in previous surveys.

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### 336.05 – Massive Protostellar Outflows - Views from ALMA and SOFIA

Massive stars play a key role in the regulation of galactic environment and galaxy evolution. However, there is no consensus on the basic formation mechanism of massive stars. Theories range from *Core Accretion* to *Competitive Accretion* to even *Protostellar Collisions*. Collimated bipolar outflows have been observed from a number of massive protostar candidates. Studies of the morphologies and kinematics of such outflows can help to understand protostellar activities from inner disk to core envelope scales and test basic scenarios of massive star formation. Here we catalog the SiO(5-4) emission associated with massive protostellar outflows within several Infrared Dark Cloud (IRDC) clumps using latest ALMA observations. We also study the morphology of SOFIA-FORCAST images from several nearby massive protostars from the SOMA survey, together with archival Spitzer-IRAC data and Herschel data. We examine centroid shifts of MIR to FIR emission as potential indicators of outflow axes. The spectral energy distributions of these sources are also used to constrain detailed radiative transfer models of massive star formation.

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### 336.06 – Dust in the Winds of Proto-planetary Nebulae: RV Tauri Stars and SRd Variables

We are conducting a SOFIA FLITECAM and FORCAST grism

spectrum survey to examine the mineralogy of the circumstellar dust in a sample of post asymptotic giant branch yellow supergiants that are believed to be the precursors of planetary nebulae. Our sample contains the brightest RV Tauri and SRd stars, including those in the southern hemisphere. This program will produce the first self-consistent sampling of the entire 2.8- 37.1 micron spectral region for a broad cross-section of this class of objects. The wavelength coverage and spectral resolution of the grisms will allow us to produce accurate models of the composition and grain-size distribution of the carbon and silicate materials and to test for the presence of hydrocarbon components in the grain materials. Relationships between the chemical composition of the circumstellar dust and the elemental abundances of the central stars will be investigated. Models of the distribution of dust in the circumstellar environments of these stars can also be constrained by the data. Here we report preliminary results based on observations made during SOFIA Cycles 2 and 3.

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**Contributing team(s):** Additional members of The SOFIA PPN Team (Luke D. Keller, Kenneth H. Hinkle, Michael Jura, Dr. Thomas Lebzelter, Carey M. Lisse, Mark T. Rushton, Judy Mizrahi)

### 336.07 – The Orion Nebula in the Far-Infrared: FIFI-LS/SOFIA Mapped the PDR

The Orion Nebula is the closest massive star forming region allowing us to study the physical conditions in such a region with high spatial resolution. We used the far infrared integral-field spectrometer, FIFI-LS, on-board the airborne observatory SOFIA to study the atomic and molecular gas in the Orion Nebula at medium spectral resolution. The large maps in several fine structure lines obtained with FIFI-LS cover the nebula from the BN/KL-object in the west to the bar in the south-east and gull feature in north-east. The fine structure lines can be used as a diagnostic for the physical conditions of the photon-dominated region (PDR), the interface between the HII-region and the molecular cloud.

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### 336.08 – SOFIA-EXES: Probing the Thermal Structure of M Supergiant Wind Acceleration Zones

There is no standard model for mass loss from cool evolved stars, particularly for non-pulsating giants and supergiants. For the early-M supergiants, radiation pressure, convective ejections, magnetic fields, and Alfvén waves have all been put forward as potential mass loss mechanisms. A potential discriminator between these ideas is the thermal structure resulting from the heating-cooling balance in the acceleration zone - the most important region to study mass loss physics.

We present mid-IR [Fe II] emission line profiles of Betelgeuse and Antares obtained with NASA-DLR SOFIA-EXES and NASA IRTF-TEXES that were obtained as part of a GO program (Harper: Cycle 2-0004) and EXES instrument commissioning observations. The intra-term transitions sample a range of excitation conditions,  $T_{\text{exc}} = 540\text{K}$ ,  $3,400\text{K}$ , and  $11,700\text{K}$ , i.e., from the warm chromospheric plasma, that also emits in the cm-radio and ultraviolet, to the cold inner circumstellar envelope. The spectrally-resolved profiles, when combined with VLA cm-radio observations, provide new constraints on the temperature and flow velocity in the outflow accelerating region. The semi-empirical energy balance can be used to test theoretical predictions of wind heating.

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**Contributing team(s):** EXES Instrument Team, EXES Science Team

### 336.09 – LkHa101, an extreme emission line star with

## **a disk and illuminating an HII region**

We present new results on LkHa101 based on the mid-infrared imaging with FORCAST on SOFIA, CARMA 3 mm imaging, IRTF SpeX medium resolution spectra from 0.8 – 5 micron, and Herschel PACS archive data. These observations, combined with published VLA data reveal that LkHa 101 is still surrounded by a face-on photo-evaporating accretion disk and is illuminating an HII region. The accretion disk is hot  $T > 1000$  K) and mostly ionized. The FORCAST, PACS and CARMA CO(1-0) and  $^{13}\text{CO}(1-0)$  images show a strong interaction between the dense molecular cloud north of LkHa101 and the expanding HII region, but no interaction with the cold foreground cloud providing most of the extinction toward the star.

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**Institution(s):** 1. ALMA, 2. SOFIA-USRA, NASA Ames Research Center

## **336.10 – Mid-infrared high resolution spectrometer for SOFIA**

Mid-infrared spectral range between 20  $\mu\text{m}$  and 120  $\mu\text{m}$  has a number of diagnostic atomic and molecular lines that can probe physical conditions in a variety of objects. In particular, protoplanetary disk clouds, YSO, planetary atmospheres would benefit from a high resolution spectroscopy in that wavelength range. Through its high spectral resolution the instrument would allow to obtain both physical and dynamical information on the clouds. Comprehensive observations of the various phases of gas in the protoplanetary disks with the instrument would allow to advance the knowledge of the processes leading to the formation of planetary systems. Such an instrument with high spectral resolving power and sensitivity would be a powerful addition to the current SOFIA instruments.

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## **336.11 – FORCAST/SOFIA Observations of MWC 297: Constraints on Disk Inclination**

MWC297 is a young, heavily reddened ( $A_V \sim 8$  mag), early type (B1.5V) star that is actively accreting from a disk and driving an ionized, approximately north-south outflow, which in turn is surrounded by an envelope of warm entrained dust. Emission from the dust in the circumstellar disk and envelope produces a strong infrared excess. Analysis of previous near- and mid-IR interferometric imaging has suggested that the accretion disk is compact, with a moderate inclination ( $20 < i < 40$  degrees). We have obtained mid-infrared imaging with FORCAST on SOFIA, which together with previously unpublished VLA data reveal that the northern and southern outflow lobes are well separated and require the disk to be much more edge-on. Simple geometrical modeling of our data indicates the disk must have an inclination  $> 50$  degrees.

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## **337 – Astrophysical Constraints of Dark Matter Properties Poster Session**

### **337.01 – Searching for Dwarf Spheroidal Galaxies with DES and the Fermi-LAT**

The population of Milky Way satellite galaxies includes the least luminous, least chemically evolved, and most dark matter dominated galaxies in the known universe. Due to their proximity, high dark matter content, and lack of astrophysical backgrounds, dwarf spheroidal galaxies are promising targets for the indirect detection of dark matter via gamma rays. Prior to 2015, roughly two dozen dwarf

spheroidal galaxies were known to surround the Milky Way. From combined observations of these objects, the dark matter annihilation cross section has been constrained to be less than the generic thermal relic cross section for dark matter particles with mass  $< 100$  GeV. Since the beginning of 2015, new optical imaging surveys have discovered over twenty new dwarf galaxy candidates, potentially doubling the population of Milky Way satellite galaxies in a single year. I will discuss recent optical searches for dwarf galaxies, focusing specifically on results from the Dark Energy Survey (DES) and the implications for gamma-ray searches for dark matter annihilation with the Fermi Large Area Telescope.

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**Institution(s):** 1. Fermilab

**Contributing team(s):** DES Collaboration, Fermi-LAT Collaboration

### **337.02 – Search for Gamma-ray Emission from Dark Matter Annihilation in the Magellanic Clouds with the Fermi Large Area Telescope**

At a distance of 50 kpc and with a dark matter mass of  $\sim 10^{10} M_\odot$ , the Large Magellanic Cloud (LMC) is a natural target for indirect dark matter searches. We use five years of data from the Fermi Large Area Telescope (LAT) and updated models of the gamma-ray emission from standard astrophysical components to search for a dark matter annihilation signal from the LMC. We perform a rotation curve analysis to determine the dark matter distribution, setting a robust minimum on the amount of dark matter in the LMC, which we use to set conservative bounds on the annihilation cross section. The LMC emission is generally very well described by the standard astrophysical sources, with at most a  $1 - 2\sigma$  excess identified near the kinematic center of the LMC once systematic uncertainties are taken into account. We place competitive bounds on the dark matter annihilation cross section as a function of dark matter particle mass and annihilation channel, and show preliminary results from the nearby Small Magellanic Cloud.

**Author(s):** Matthew Buckley<sup>4</sup>, Eric Charles<sup>5</sup>, Regina Caputo<sup>7</sup>, Jennifer Gaskins<sup>2</sup>, Alyson Brooks<sup>4</sup>, Pierrick Martin<sup>3</sup>, Alex Drlica-Wagner<sup>1</sup>, Geng Zhao<sup>6</sup>

**Institution(s):** 1. Fermilab, 2. GRAPPA, 3. Institut de Recherche en Astrophysique et Planetologie, 4. Rutgers University, 5. SLAC, 6. Stanford, 7. UCSC

### **337.03 – Constraining Self-Interacting Dark Matter: Insights from Equal Mass Mergers of Galaxy Clusters**

While the  $\Lambda\text{CDM}$  model has been wildly successful at explaining structure on large scales, it fails to do so on small scales---dark matter halos of scales comparable to that of galaxy clusters and smaller are more cored and less numerous than  $\Lambda\text{CDM}$  predicts. One potential solution challenges the canonical assumption that dark matter is collisionless and instead assumes that it is collisional, or self-interacting. The most stringent upper limits on the dark matter self-interaction cross section have come from observations of merging galaxy clusters. Self-interactions cause the merging dark matter halos to evolve differently from the galaxies, which are effectively collisionless. It has been hypothesized that this leads to an spatial offset between the peaks in the dark matter and galaxy distributions. We show that in equal mass mergers offsets do not develop except under a narrow range of merger conditions. Mergers with observable offsets have an infall velocity comparable to the escape velocity from a halo---promoting the expulsion of significant mass and the formation of tails---and is head-on. We discuss other observable signatures of self-interactions that may better constrain the dark matter self-interaction cross-section in equal mass cluster mergers.

**Author(s):** Stacy Yeonchi Kim<sup>1</sup>, Annika Peter<sup>1</sup>

**Institution(s):** 1. The Ohio State University

### **337.04 – The dark matter content of Local Group dwarf spheroidals**

Dwarf spheroidal galaxies are the most dark matter dominated objects we have observed in the Universe. By measuring the

dynamics of their stellar populations, we can hope to map out the shapes of their central density profiles, and compare these to expectations from simulations. In this poster, we will present the central kinematics of a range of dwarf galaxies around the Milky Way and Andromeda, taken as part of the PAndAS Keck II DEIMOS survey. We will highlight a number of unusual objects, which have either very high mass to light ratios - indicating they may be promising candidates for indirect detection experiments - or those with exceptionally low central densities, whose kinematic profiles suggest that these systems are out of dynamical equilibrium.

**Author(s): Michelle Collins<sup>1</sup>**

**Institution(s):** 1. University of Surrey

**Contributing team(s):** PAndAS team

### 337.05 – Diversity of Galactic Rotation Curves and Self-interacting Dark Matter

We compile a large sample of rotation curves from the literature with maximum rotation velocity spanning the range of 20-300 km/s. We model each individual system including its stellar, gas and dark matter components. We use a prescription for self-interacting dark matter (SIDM) halos that has been tested against simulations to infer the cross section for elastic scattering between dark matter particles required to explain the large cores. We discuss how the diversity of observed rotation curves and the constancy of the inferred surface density of dark matter may arise in SIDM models.

**Author(s): Andrew Pace<sup>1</sup>**, Kevin Andrade<sup>1</sup>, Manoj Kaplinghat<sup>1</sup>, Sean Tulin<sup>3</sup>, Hai-bo Yu<sup>2</sup>

**Institution(s):** 1. University of California, Irvine, 2. University of California, Riverside, 3. York University

### 337.06 – The Aspen Framework for Dark Matter Substructure Inference from Strong Gravitational Lensing Observations

The properties of the dark matter particle or particles lead to different small scale halo populations, distributions, and evolution over cosmic time. We introduce a new method for characterizing the properties of substructure within galaxies through the power spectrum of potential fluctuations, and demonstrate how complete sets of multiwavelength imaging and time domain observations can be processed directly to infer all facets of the strong gravitational lensing components and source properties, including the dark matter substructure power spectrum constraints. We are able to take advantage of analysis parallels with cosmic background radiation techniques, and furthermore demonstrate how this technique, dubbed The Aspen Framework, reduces to the long-standing approach of working with reduced or derived observable quantities in lensing.

**Author(s): Leonidas A. Moustakas<sup>2</sup>**, Francis-Yan Cyr-Racine<sup>1</sup>, Charles R. Keeton<sup>3</sup>

**Institution(s):** 1. Harvard University, 2. JPL/Caltech, 3. Rutgers University

### 337.07 – Assessing Astrophysical Uncertainties in Direct Detection Experiments Using Galaxy Simulations

Experiments that will directly detect dark matter are strongly dependent on the velocity of the dark matter particle. These experiments are composed of various elements; the heavier the element, the higher the velocity of dark matter must be to register a visible impact. The velocity of the dark matter is set by astrophysics. To date, all direct detection experiments assume that the dark matter in the Milky Way follows a Maxwellian velocity distribution. N-Body simulations that include only dark matter have long shown that this assumption is incorrect. In this work, we use high resolution cosmological simulations of Milky Way-mass galaxies that include dark matter, gas, and stellar physics, in order to explore the additional effect of baryons on the velocity distribution of dark matter in the solar neighborhood. We show that the baryons have a significant impact, altering the predictions from the dark matter-only case, leading to a distribution that is closer to Maxwellian. However, in all of our galaxies, the high velocity tail drops off more steeply

than in the standard Maxwellian. We discuss how the inclusion of baryons change the interpretation of current direct detection experiments.

**Author(s): Alyson Brooks<sup>1</sup>**, Jonathan Sloane<sup>1</sup>, Matthew Buckley<sup>1</sup>

**Institution(s):** 1. Rutgers University

### 337.08 – Inference of Dim Gamma-Ray Point Sources Using Probabilistic Catalogues

Poisson regression of the Fermi-LAT data in the inner Milky Way reveals an extended gamma-ray excess. The anomalous emission falls steeply away from the galactic center and has an energy spectrum that peaks at 1-2 GeV. An important question is whether the signal is coming from a collection of unresolved point sources, possibly recycled pulsars, or constitutes a truly diffuse emission component. Previous analyses have relied on non-Poissonian template fits or wavelet decomposition of the Fermi-LAT data, which find evidence for a population of dim point sources just below the 3FGL flux limit. In order to be able to make conclusions about such a dim population we propose to sample from the catalogue space of point sources in the inner galaxy, where the model dimensionality, i.e., the number of sources, is unknown. Although being a computationally expensive sampling problem, this approach allows us to infer the number, luminosity and radial distribution of the point source population that is consistent with the data while providing a Bayesian evidence for the point source hypothesis, which is independent of the model indicator. This talk will focus on the method of trans-dimensional sampling using the reversible-jump formalism and its application to the inference of a mock point source population. See the poster by Stephen K. N. Portillo for the inferred catalogue using the high latitude Fermi-LAT data.

**Author(s): Tansu Daylan<sup>1</sup>**, Stephen Portillo<sup>1</sup>, Douglas P. Finkbeiner<sup>1</sup>

**Institution(s):** 1. Harvard University

### 337.09 – A Probabilistic Catalogue of Unresolved High Latitude Fermi LAT Sources

Several groups have identified a highly significant and spatially extended excess of GeV gamma-rays in the Inner Galaxy using data from the Fermi LAT. While this signal's properties are consistent with those expected from dark matter annihilation, another interpretation is that it is the emission from a population of unresolved point sources. Motivated by the point source interpretation, we implement a Bayesian method for producing probabilistic catalogues to constrain the population of point sources below the Fermi LAT detection limit. To validate our method, we apply it to the high latitude Fermi LAT data to confirm that the probabilistic catalogue recovers the resolved sources in the Fermi Collaboration's 3FGL catalogue. Then, we compare our constraints on the unresolved point source population at high latitude to those obtained using non-Poissonian template fitting.

**Author(s): Stephen Portillo<sup>1</sup>**, Tansu Daylan<sup>1</sup>, Douglas P. Finkbeiner<sup>1</sup>

**Institution(s):** 1. Harvard University

## 338 – Relativistic Astrophysics, Gravitational Lenses & Waves Poster Session

### 338.01 – Gravitational Lens Modeling of Fields Containing Multiple Projected Cluster-Scale Halos

We have identified new lines of sight that are promising places to search for high-redshift galaxies. These beams contain a total mass well above  $10^{15} M_{\odot}$  distributed among multiple group- and cluster-scale halos. The field J085007.6+360428 includes the massive cluster Zwicky 1953 plus a second massive halo in the foreground, and it features two candidate lensed images of a galaxy with a photometric redshift  $z=5.03$ . We present results from a joint weak and strong lensing analysis of the field that accounts for the full three-dimensional mass distribution and uses a full pixel reconstruction of the lensed images. We find that constraints on various field parameters, specifically cluster mass and concentration,

are considerably improved with the joint approach.

**Author(s):** Catie Ann Raney<sup>4</sup>, Kenneth C Wong<sup>3</sup>, Keiichi Umetsu<sup>1</sup>, Charles R. Keeton<sup>4</sup>, S. Mark Ammons<sup>2</sup>, Ann I Zabludoff<sup>5</sup>, K. Decker French<sup>5</sup>

**Institution(s):** 1. *Institute of Astronomy and Astrophysics, Academia Sinica (ASIAA)*, 2. *Lawrence Livermore National Laboratory*, 3. *National Astronomical Observatory of Japan*, 4. *Rutgers, the State University of New Jersey*, 5. *Steward Observatory, University of Arizona*

### 338.02 – Quantifying Environmental and Line-of-Sight Effects in Models of Strong Gravitational Lens Systems

Mass outside a gravitational lens galaxy--around the lens or projected along the line of sight--can significantly affect the images produced by the lens. We quantify biases and uncertainties in lens-derived quantities, such as the Hubble constant, that are associated with these external effects. Specifically, we build realistic three-dimensional mass configurations and examine different treatments of the environmental and line-of-sight effects. Fitting a simple external shear in the lens plane can account for tidal stretching from perturbing galaxies at the lens redshift or in the background, but cannot fully reproduce the more complicated effects from foreground perturbers. That approach also requires a separate correction for external convergence. A better approach is to employ our new framework for multi-plane lensing, which recovers lens model parameters without bias and to a precision limited only by the lens profile degeneracy and measurement noise. Our framework now accounts for underdense regions along sightline, avoiding biases in the Hubble constant. We show that lens systems with large ellipticities are less sensitive to the lens profile degeneracy than rounder lenses, producing stronger constraints on the Hubble constant.

**Author(s):** Charles R. Keeton<sup>3</sup>, Curtis McCully<sup>1</sup>, Kenneth C. Wong<sup>2</sup>, Ann I. Zabludoff<sup>4</sup>

**Institution(s):** 1. *LCOGT*, 2. *NAOJ*, 3. *Rutgers Univ.*, 4. *Univ. Arizona*

### 338.03 – Prediction of Black Hole and Neutron Star Mesolensing Events

Black holes and neutron stars are ideal gravitational lenses because they have large masses and dim optical magnitudes. Lensing induced by nearby stellar objects, typically within a few kpc, is known as mesolensing. We report on our study of the spatial paths of more than 200 compact objects with measured proper motions. We predict their close approaches on the sky to background stars whose positions and magnitudes have been drawn from the Hubble Source Catalog, and from the 2MASS and USNO-A catalogs. By plotting the paths of the stellar remnants many years into the future we make predictions on when detectable events will occur. The observations provide a way of measuring the masses of the neutron star/black hole lenses. We also investigate possible future lensing events that would be caused if the compact object is orbited by dark companions, including exoplanets. Mesolensing events may be caused by exoplanets even if the compact object is unlikely to produce its own event. Constraints can be derived for planet masses and orbits both in cases with event detections and in cases in which no detection is achieved.

**Author(s):** Alex Harding<sup>3</sup>, Rosanne Di Stefano<sup>1</sup>, Johnson Urama<sup>2</sup>, Dang Pham<sup>1</sup>

**Institution(s):** 1. *Harvard-Smithsonian Center for Astrophysics*, 2. *University of Nigeria Nsukka*, 3. *University of Southampton*

### 338.04 – Using the LCOGT Network To Measure a High-Precision Time Delay in the Four-Image Gravitational Lens HE0435-1223

Accurate measurements of the delays in arrival time of photons between images in multiply-imaged time-varying sources such as strongly-lensed quasars opens new doors to astrophysical constraints

on cosmological parameters, the structure of galaxies and their environments, and the nature of dark matter. The confidence level and accuracy of a time delay measurement in a given gravitational lens system depends on a combination of photometric precision, observational cadence, and the value of the time delay. While many such time differences have been measured, the absolute precision is rarely better than one day. To unlock the greatest potential of time delay probes, a greater than 100-fold improvement in precision is needed.

In this contribution we describe a pilot ground-based campaign with the Las Cumbres Observatory Global Telescope (LCOGT) Network, monitoring the four-image lensed quasar HE0435-1223. The LCOGT Network comprises nine 1-meter and two 2-meter telescopes at five sites, with optical imagers on all telescopes and low-dispersion optical spectrographs on the 2-meter telescopes. The geographical distribution of the network sites allows continuous coverage, and a single scheduler produces an optimal mapping of observation requests to the telescopes. Using network sites in Chile, Australia, and South Africa, we were able to obtain continuous optical images with a six-minute cadence over a period of 50 hours, with only one substantial gap due to bad weather at one site. Using a Bayesian-inference based analysis, we derive two plausible time delays between the leading and second images of the lensed system, with statistical uncertainties of 0.01 days (15 minutes).

**Author(s):** Todd A. Boroson<sup>1</sup>, Leonidas A. Moustakas<sup>2</sup>, Andrew Romero-Wolf<sup>2</sup>, Curtis McCully<sup>1</sup>

**Institution(s):** 1. *LCOGT*, 2. *NASA/JPL*

### 338.05 – Can Palomar Transient Factory Survey Data Be Used to Confirm Gravitationally Lensed Quasar Candidates?

Strongly lensed quasars can be used to study the Hubble constant and the lens mass by measuring time delay and image separation. These objects can require years of data to confirm however, so using data from preexisting surveys could greatly reduce the amount of time required to study them. We attempt to use Palomar Transient Factory survey data to detect variability in strongly lensed quasars and to measure time delays between the quasar images. We test our procedure using known gravitationally lensed quasars with measured time delays.

**Author(s):** Isaac Spitzer<sup>1</sup>, Robert Quimby<sup>1</sup>

**Institution(s):** 1. *San Diego State University*

### 338.06 – Strong Lens Models for 10 Galaxy Clusters from the Sloan Giant Arcs Survey

We present the results from modeling several strong gravitational lenses as part of the Sloan Giant Arcs Survey (SGAS). HST cannot resolve star-formation in galaxies at redshifts  $> \sim 1$  because they are too far away, but by using the magnification by galaxy clusters at these redshifts ( $1 < z < 3$ ) we are able to study them in detail that HST alone cannot achieve. By modeling the lens and determining the mass distribution of the foreground galaxy cluster we can then make an accurate calculation of the mass as well as constrain the dark matter halo that envelops the cluster. With the computed lensing magnification, we can calculate the luminosity, size, star formation rate, and stellar mass of the background galaxies.

**Author(s):** Samuel Dunham<sup>6</sup>, Keren Sharon<sup>6</sup>, Matthew Bayliss<sup>1</sup>, Hakon Dahle<sup>7</sup>, Michael Florian<sup>4</sup>, Michael Gladders<sup>4</sup>, Traci Johnson<sup>6</sup>, Katherine Murray<sup>6</sup>, Jane R. Rigby<sup>2</sup>, Katherine E. Whitaker<sup>5</sup>, Eva Wuyts<sup>3</sup>

**Institution(s):** 1. *Colby College*, 2. *Goddard Space Flight Center*, 3. *Max Planck Institute for Extraterrestrial Physics*, 4. *University of Chicago*, 5. *University of Massachusetts*, 6. *University of Michigan*, 7. *University of Oslo*

### 338.07 – Characterizing the zone of influence of dark matter clumps on image positions and flux ratios in gravitational lensing systems

The Cold Dark Matter (CDM) model of the universe predicts that there should be hundreds to thousands of clumps surrounding a

massive galaxy. However, observations have shown that we only see dozens of dwarf galaxies and not the hundreds to thousands that are predicted. This means that either the CDM model prediction is wrong, or most of the substructure consists of dark matter that cannot be observed directly. Massive galaxies serve as natural gravitational lenses throughout the universe that allow us to indirectly observe these dark matter perturbations. Strong gravitational lensing occurs when these massive elliptical galaxies have the critical density required to bend light from a source located behind it and produce multiple images of that same source. Dark matter clumps located near these multiple images affect their positions and flux ratios. We used lensing simulations to quantify how dark matter clumps affect image properties and to characterize this zone of influence through color maps of chi-squared values. Our results showed regions around each of the image positions that display significant perturbations for low mass clumps. For higher mass clumps, however, these distinct regions bleed together. We found that there is a correlation between the mass of the dark matter clump and the area it perturbs. This research has been supported by NSF grant PHY-1263280.

**Author(s):** Jyothisraj Johnson<sup>1</sup>, Charles R. Keeton<sup>2</sup>, Sean Brennan<sup>2</sup>

**Institution(s):** 1. Hunter College, 2. Rutgers University

### 338.08 – Advanced LIGO and Multi-Messenger Transient Searches

The first Advanced LIGO observing run, which began in September 2015, is on track to extend the volume\*time reach of the gravitational wave (GW) detector network by an order of magnitude by the end of the year. Searches for transient GW signals from compact binary mergers and other possible sources are a central part of the LIGO-Virgo science program. To enhance those searches and to try to place any detected signals into an astronomical context, we have undertaken an extensive program of partnering with observers to enable prompt transient survey correlations and follow-up observations at all wavelengths, from optical and radio telescopes on the ground to astroparticle detectors to space missions including Fermi and Swift. I will summarize the data collected from the first Advanced LIGO observing run, the transient searches being carried out, and the multi-messenger observing effort.

**Author(s):** Peter S. Shawhan<sup>1</sup>

**Institution(s):** 1. Univ. of Maryland

**Contributing team(s):** LIGO Scientific Collaboration, Virgo Collaboration

### 338.09 – Tracking Spectral Noise Lines in Advanced LIGO Data

The Advanced LIGO detectors are expected to make gravitational wave observations possible within the next few years. However, sharp spectral noise lines continue to obscure the data, and it is unknown if or how these lines wander over time. Therefore, we are developing a method that will track the frequencies of the various noise sources which appear in our data. Using Python for scripting, we utilize various signal processing techniques to identify the exact frequencies of the noise sources present in our time series. We then heterodyne to determine if and how a given spectral line wanders in frequency over time. This technique will provide beneficial insight for improving the quality of the data and the sensitivity to gravitational waves from spinning neutron stars and other astrophysical sources.

**Author(s):** Gillian Dora Beltz-Mohrmann<sup>2</sup>, Alan J. Weinstein<sup>1</sup>, Jonah Kanner<sup>1</sup>

**Institution(s):** 1. California Institute of Technology, 2. Wellesley College

### 338.10 – Towards Observational Astronomy of Jets in Active Galaxies from General Relativistic Magnetohydrodynamic Simulations

We carry out the process of "observing" simulations of active galactic nuclei (AGN) with relativistic jets (hereafter called jet/accretion disk/black hole (JAB) systems) from ray tracing between image

plane and source to convolving the resulting images with a point spread function. Images are generated at arbitrary observer angle relative to the black hole spin axis by implementing spatial and temporal interpolation of conserved magnetohydrodynamic flow quantities from a time series of output datablocks from fully general relativistic 3D simulations. We also describe the evolution of simulations of JAB systems' dynamical and kinematic variables, e.g., velocity shear and momentum density, respectively, and the variation of these variables with respect to observer polar and azimuthal angles. We produce, at frequencies from radio to optical, fixed observer time intensity and polarization maps using various plasma physics motivated prescriptions for the emissivity function of physical quantities from the simulation output, and analyze the corresponding light curves. Our hypothesis is that this approach reproduces observed features of JAB systems such as superluminal bulk flow projections and quasi-periodic oscillations in the light curves more closely than extant stylized analytical models, e.g., cannonball bulk flows. Moreover, our development of user-friendly, versatile C++ routines for processing images of state-of-the-art simulations of JAB systems may afford greater flexibility for observing a wide range of sources from high power BL-Lacs to low power quasars (possibly with the same simulation) without requiring years of observation using multiple telescopes. Advantages of observing simulations instead of observing astrophysical sources directly include: the absence of a diffraction limit, panoramic views of the same object and the ability to freely track features. Light travel time effects become significant for high Lorentz factor and small angles between observer direction and incident light rays; this regime is relevant for the study of AGN blazars in JAB simulations.

**Author(s):** Richard Anantua<sup>1</sup>

**Institution(s):** 1. Stanford University

**Contributing team(s):** Roger Blandford, Jonathan McKinney and Alexander Tchekhovskoy

### 338.11 – New Constraints on Quantum Gravity from X-ray and Gamma-Ray Observations

One aspect of the quantum nature of spacetime is its "foaminess" at very small scales. Many models for spacetime foam are defined by the accumulation power  $\alpha$ , which parameterizes the rate at which Planck-scale spatial uncertainties (and the phase shifts they produce) may accumulate over large path-lengths. Here  $\alpha$  is defined by the expression for the path-length fluctuations,  $\delta l$ , of a source at distance  $l$ , where  $\delta l \propto l^{1-\alpha} l_p$ , with  $l_p$  being the Planck length. We reassess previous proposals to use astronomical observations of distant quasars and AGN to test models of spacetime foam. We show explicitly how wavefront distortions on small scales cause the image intensity to decay to the point where distant objects become undetectable when the path-length fluctuations become comparable to the wavelength of the radiation. Chandra X-ray observations set a constraint  $\alpha > 0.58$ , which rules out the random walk model (with  $\alpha = 1/2$ ). Much firmer constraints can be set with Fermi detections of quasars at GeV energies, and at TeV energies with ground-based Cherenkov telescopes:  $\alpha > 0.67$  and  $\alpha > 0.72$ , respectively. These limits seem to rule out  $\alpha = 2/3$ , the model of some physical interest.

**Author(s):** Eric S. Perlman<sup>1</sup>, Saul A. Rappaport<sup>2</sup>, Wayne A. Christiansen<sup>4</sup>, Jack Ng<sup>4</sup>, John DeVore<sup>5</sup>, David A. Pooley<sup>3</sup>

**Institution(s):** 1. Florida Institute of Technology, 2. Massachusetts Institute of Technology, 3. Trinity University, 4. University of North Carolina, 5. Visidyne, Inc.

### 338.12 – Telescope Technology Development Results for a Space-Based Gravitational-Wave Observatory

Space-based Gravitational-wave Observatories will enable the systematic study of the low-frequency band (0.0001 - 1 Hz) of gravitational waves, where a rich array of astrophysical sources is expected. Optical telescopes play an important role in these observatories by enabling displacement measurements between pairs of freely falling proof masses. The telescopes deliver laser light efficiently from one spacecraft to another over million-kilometer scale separations and must transmit and receive light simultaneously. Transmitting and receiving at the same time puts tight constraints on the scattered light performance. In addition, the required displacement measurement accuracy requires  $\sim 1 \text{ pm}/\sqrt{\text{Hz}}$

pathlength stability through the telescope in the measurement band. We report preliminary measurements on a prototype telescope.

This work was funded in part by NASA SAT grant 11-SAT11-0027.

**Author(s):** Jeffrey C. Livas<sup>1</sup>, Shannon R Sankar<sup>1</sup>  
**Institution(s):** 1. NASA Goddard Space Flight Center

### 338.13 – Potential Usefulness of Flash-Induced Superluminal Light-Echo Pairs

Astronomical flashes can create transient light-echo pair phenomena that have never yet been seen but might result in useful information, if found. Toward this end, it is first proven that all light-echo spots are intrinsically superluminal. The radial component of spot speeds toward an observer, however, may be subluminal, and spot pair creation and annihilation events will be observable, in theory, when spots cross the radial superluminal speed boundary. If found, these light-echo pairs could connect angular speeds to spatial speeds, which in turn could result in the recovery of absolute sizes, three-dimensional spatial orientations, and distances to astronomical objects. A hypothetical example is given.

**Author(s):** Robert J. Nemiroff<sup>1</sup>, Qi Zhong<sup>1</sup>  
**Institution(s):** 1. Michigan Technological Univ.

### 338.14 – Light Echoes from Linear Filaments in Astronomical Settings

Stellar flashes are known to create light echoes by scattering off ambient dust. Here light echoes from straight, linear, one-dimensional dust filaments are specifically considered in detail. On an infinite straight filament, a flash will necessarily create a superluminal spot pair creation event. The actual and perceived locations, speeds, and relative brightnesses of these diverging spot pairs are computed. On filaments of finite length, only one light spot will typically be seen. Geometries where this spot appears to move angularly toward the flash are shown to be possible. It is also shown that it is possible to completely orient a linear filament in three-dimensional space by recording two separated detections of the light-echo spot. Recoverable information in theory and in practice will be reviewed.

**Author(s):** Qi Zhong<sup>1</sup>, Robert J. Nemiroff<sup>1</sup>  
**Institution(s):** 1. Michigan Technological University

### 338.15 – Black Hole Science using Current and Future Pulsar Timing Array Constraints on Continuous Gravitational Waves

Pulsar timing arrays have already placed constraints on the strain amplitude of continuous gravitational waves coming from supermassive black hole binaries. To date, the implications of these constraints for specific nearby galaxies have yet to be studied. We incorporate independent measurements of supermassive black hole masses in specific galaxies and leverage this additional information to further constrain whether or not those galaxies could host a detectable supermassive black hole binary. We include projected masses of the supermassive black holes in galaxies that are part of the MASSIVE survey, which includes the most massive, nearby galaxies. We argue that the galaxies considered in this work are among the most likely to host an individually-resolvable supermassive black hole binary, and we find that pulsar timing already places constraints on the existence of a binary in several of these galaxies. Additionally, with these nearby galaxies in mind we calculate specifications that future PTAs would need to reach in order to constrain even more prospective binaries hosted within the sample galaxies.

**Author(s):** Katharine Schutz<sup>1</sup>, Chung-Pei Ma<sup>1</sup>  
**Institution(s):** 1. UC Berkeley

### 338.16 – Determining Reliability of Existing Gravitational Waveforms in Parameter Estimation for Binary Black Holes

Gravitational Waves (GWs) were predicted by Einstein's Theory of

General Relativity as ripples in space-time that propagate outward from a source. Strong GW sources consist of compact binary systems such as Binary Neutron Stars (BNS) or Binary Black Holes (BBHs) that experience orbital shrinkage (inspiral) and eventual merger. Indirect evidence for the existence of GWs has been obtained through radio pulsar studies in BNS systems. A study of BBHs and other compact objects has limitations in the electromagnetic spectrum, therefore direct detections of GWs will open a new window into their nature. The effort targeting direct GWs detection is anchored on the development of a detector known as Advanced LIGO (Laser Interferometer Gravitational Wave Observation). Although detecting GW sources represents an anticipated breakthrough in physics, making GW astrophysics a reality critically relies on our ability to determine and measure the physical parameters associated with GW sources. We use Markov Chain Monte Carlo (MCMC) simulations on high-performance computing clusters for parameter estimation on high dimensional spaces (GW sources - 15 parameters). The quality of GW parameter estimation greatly depends on having the best possible knowledge of the expected waveform. Unfortunately, BBH GW production is very complex and our best waveforms are not valid across the full parameter space. With large-scale simulations we examine quantitatively the limitations of these waveforms in terms of extracting the astrophysical properties of BBH GW sources. We find that current waveforms are inadequate for BBH of unequal masses and demonstrate that improved waveforms are critically needed.

**Author(s):** Cesar Bustos<sup>1</sup>, Ben Sandeen<sup>2</sup>, Shriram Chennakesavalu<sup>2</sup>, Tyson Littenberg<sup>1</sup>, Ben Farr<sup>3</sup>, Vassiliki Kalogera<sup>2</sup>  
**Institution(s):** 1. Northeastern Illinois University, 2. Northwestern University, 3. University of Chicago

### 338.17 – Simulating magnetospheres with numerical relativity: The GiRaFFE code

Numerical Relativity has shown success over the past several years, especially in the simulation of black holes and gravitational waves. In recent years, teams have tackled the problem of the interaction of gravitational and electromagnetic waves. But where there are plasmas, the simulations often have trouble reproducing nature. Neutron stars, black hole accretion disks, astrophysical jets—all of these represent extreme environments both gravitationally and electromagnetically.

**We are creating the first open-source, dynamical spacetime general relativity force-free electrodynamics code: GiRaFFE.**

We present here the performance of GiRaFFE in testing. With this code, we will simulate neutron star magnetospheres, collisions between neutron stars and black holes, and particular attention will be paid to the production of jets through the Blandford-Znajek mechanism.

GiRaFFE will be made available to the community.

**Author(s):** Maria Babiuc-Hamilton<sup>1</sup>, Zach Etienne<sup>2</sup>  
**Institution(s):** 1. Marshall University, 2. West Virginia University

## 339 – Intergalactic Medium, QSO Absorption Line Systems Poster Session

### 339.01 – Connecting the Silicate Dust and Gas Properties of Distant Galaxies Using Quasar Absorption Systems

We present recent results from our program investigating the silicate dust properties in distant galaxies using quasar absorption systems. The dust and gas properties of distant galaxies can be characterized by studying the absorption features produced by them along the sightlines to luminous background quasars. Based on our prior finding that silicate dust absorption in  $z < 1.5$  quasar absorption systems exhibits a range of optical depths and absorption feature substructures, suggestive of silicate grain property variations, we are investigating silicate dust absorption in quasar absorption systems toward quasars with archival Spitzer Space Telescope Infrared Spectrograph (IRS) spectra. We present our measurements of the 10 and/or 18 micron silicate dust absorption feature(s) in these systems,

and discuss constraints on the grain properties, such as composition and crystallinity, based on the shape and substructure present in these features. We also investigate the correlations between the silicate dust properties and the reddening. Connections between the silicate dust and gas phase metal absorption properties can also be probed for some of our targets with archival ground-based spectra. These relationships will yield valuable insights into the star formation history and evolution of metals and dust. This work is supported by NASA through ADAP grant NNX14AG74G and by an award issued by JPL/Caltech, and from US-NSF grant AST-1108830 to the University of South Carolina.

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**Institution(s):** 1. *Georgia Southern University*, 2. *NASA-GSFC*, 3. *Osservatorio Astronomico di Trieste*, 4. *University of Chicago*, 5. *University of South Carolina*

### 339.02 – The Lyman continuum escape fraction of low mass star-forming galaxies at $z \sim 1$ .

Star-forming galaxies (SFGs) in the high redshift universe ( $z > 6$ ) are believed to ionize neutral hydrogen in the intergalactic medium during the epoch of reionization. We tested this assumption by studying likely analogs of these SFGs in archival HST grism spectroscopy with GALEX UV and ground-based optical images at the redshift range in which we can directly measure the rest-frame Lyman continuum ( $\lambda < 912 \text{ \AA}$ , LyC) emission. We selected  $\sim 1400$  SFGs for study on the presence of strong H $\alpha$  emission and strongly selected against those SFGs whose GALEX FUV photometry could be contaminated by low redshift interlopers along the line of sight to produce a sample of  $\sim 600$   $z \sim 1$  SFGs. We made no unambiguous detection of escaping Lyman continuum radiation in individual galaxies in this sample, and stacked the individual non-detections in order to constrain the absolute Lyman continuum escape fraction,  $f_{\text{esc}} < 2\%$  ( $3\sigma$ ). We sub-divided this sample and stacked SFGs to measure upper limits to  $f_{\text{esc}}$  with respect to stellar mass, luminosity and relative orientation. For  $z \sim 1$  high H $\alpha$  equivalent width ( $\text{EW} > 200 \text{ \AA}$ ) SFGs, we found for the first time an upper limit to  $f_{\text{esc}} < 9\%$ . We discuss the implications of these limits for the ionizing emissivity of high redshift SFGs during the epoch of reionization. We conclude that reionization by SFGs is only marginally consistent with independent Planck observations of the CMB electron scattering opacity unless the LyC escape fraction of SFGs increases with redshift and an unobserved population of faint ( $M_{\text{UV}} < -13$  AB) SFGs contributes significantly to the UV background.

**Author(s):** Michael J. Rutkowski<sup>8</sup>, Claudia Scarlata<sup>8</sup>, Francesco Haardt<sup>7</sup>, Brian D. Siana<sup>6</sup>, Marc Rafelski<sup>2</sup>, Alaina L. Henry<sup>2</sup>, Matthew Hayes<sup>4</sup>, Mara Salvato<sup>3</sup>, Anthony Pahl<sup>8</sup>, Vihang Mehta<sup>8</sup>, Melanie Beck<sup>8</sup>, Matthew Arnold Malkan<sup>5</sup>, Harry I. Teplitz<sup>1</sup>

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### 339.03 – Time-Resolved Spectral Analysis of Blazar 0716+714

As electromagnetic (EM) waves from sources such as blazars travel through the intergalactic medium (IGM), they are slowed by electrons; a phenomenon called dispersion delay [2]. We study the propagation effects in emissions of EM waves from blazar source BL 0716+714 by estimating the average electron density, or dispersion measure (DM), of the IGM on a line of sight to the blazar. Measuring the variations in these effects with time allow us to understand the properties of the intervening material. Toward this goal we analyzed months of archived observations of BL 0716+714 taken by the Allen Telescope Array (ATA). The ATA's correlator produces cross-power vs. frequency spectra for every baseline (distance between a pair of antennas) in ten-second intervals. To reduce this immense load of data we used a technique based on interferometry called bispectrum, which does not depend on complicated array calibration and simplifies our work. The bispectrum multiplies baselines, three at a time, so that they form a closed loop, then the cube root of spectra are averaged [1]. This technique is independent of phase errors associated with any individual antenna and has a better SNR ratio

than simply taking the average of all the baselines. We developed a numerical analysis program that takes in archived blazar files containing correlation data, computes the bispectrum, and outputs FITS images for each day of observations. The results show that our observations do not have sufficient sensitivity to reveal blazar variations in the frequency ranges that were studied. It is suggested that future observations at higher frequencies and/or with another telescope having greater sensitivity would reveal the time/frequency dependence of emission structure that would allow measurements of electron content. This work shows that but bispectrum is a useful tool for rapid characterization of interferometer data that does not require interferometer calibration which could introduce artifacts into radio light curves.

#### References:

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- [2] Rani B. et al. (2013) *A&A*, ms, 1-25.

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### 339.04 – The Partial Project: An XQ-100 Survey of pLLSs at $z \sim 3$

Using the XQ-100 dataset of VLT/X-Shooter spectra, we present a statistical study of partial Lyman-limit systems (pLLSs) at  $z \sim 3$ , providing insight into the properties and characteristics of the optically-thin circumgalactic medium (CGM) over this epoch. These systems contribute significantly to the mean free path for ionizing radiation in the  $z \sim 3$  universe and probe the enriched CGM on (presumed) scales of tens to hundreds of kpc. The high-quality observations (S/N  $\sim 20$  and R  $\sim 10,000$ ) give rise to a log NHI detection limit of 16.8, allowing our study to place the strongest constraints to date on the population of pLLSs at  $z \sim 3$ .

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**Contributing team(s):** XQ-100 Team

### 339.05 – Cosmic Dawn Science Interest Group

Cosmic Dawn was identified as one of the three science objectives for this decade in the *New Worlds, New Horizons* Decadal report, and it will likely continue to be a research focus well into the next decade. Cosmic Dawn refers to the interval during which the Universe transitioned from a nearly completely neutral state back to a nearly fully ionized state and includes the time during which the first stars formed and the first galaxies assembled.

The Cosmic Dawn Science Interest Group (SIG) was formed recently under the auspices of the Cosmic Origins Program Analysis Group (COPAG). The Cosmic Dawn SIG focusses on the science cases, observations, and technology development needed to address the "great mystery" of Cosmic Origins. The reach of this SIG is broad, involving the nature of the first stars and the detectability of gamma-ray bursts at high redshifts, the extent to which the first galaxies and first supermassive black holes grew together, and the technology required to pursue these questions.

For further information, consult the Cosmic Dawn SIG Web site <http://cd-sig.jpl.nasa.gov/> and join the mailing list (by contacting the author).

Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

**Author(s):** T. Joseph W. Lazio<sup>1</sup>

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**Contributing team(s):** Cosmic Origins Program Analysis Group

### 339.06 – A Detailed Analysis of the Multi-Velocity

## Components of strong HI-selected absorbers in the Halos of $z \sim 0.5$ Galaxies

One driving force of galaxy evolution is the presence and circulation of material throughout the extended gaseous environment of a galaxy, the circumgalactic material (CGM). In the Milky Way, high-velocity clouds (HVC) are well studied systems that trace outflows, inflows, and recycled material throughout the CGM. We examine archival QSO spectra from HST/COS in an effort to similarly identify absorption systems with high-velocity absorption relative to the rest-frame of a strong HI-selected absorber in order to dissect the various components and their origins in the halos of  $z \sim 0.5$  galaxies.

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## 339.07 – The Quasar 2175 \AA\ Dust Absorbers in the Sloan Digital Sky Survey Data Release Twelve

We report detection of quasar 2175 \AA\ dust absorber (2DA) candidates in Sloan Digital Sky Survey (SDSS) Data Release Twelve (DR12). These dust absorbers are searched from 39,242 Mg II absorbers with the absorption redshift  $0.7 \leq z(\text{abs}) \leq 2.67$ . The redshift range is chosen to allow 2DAs to be covered within SDSS spectrograph operation wavelength range ( $\sim 3650\text{--}10,400$  \AA). We optimized our previously developed searching and identification procedures. The parameterized extinction curve is applied to fit the observation spectra with DR12 composite spectra (blue, average and red) in the rest-frame of Mg II absorbers. The best fitted spectra are used to extract bump parameters (width, depth and location). Only absorbers with bump strength above the  $3\sigma$  level are chosen as 2DA candidates and used for statistical study. A total of over 400 2DA candidates have been identified as the first complete sample of 2DAs. In this sample, the bump strengths of most candidates are similar to the absorption bump observed in the Large Magellanic Clouds (LMC) and significantly weaker than those in the Milky Way (MW). The UV bump strength decreases with redshift. The UV bump strength is projected to evolve to the MW value at the present time. A subsample of these absorbers were observed with the MMT and Keck. All of them show strong dust depletion and high metallicity. Our results support a steadily increasing chemical enrichment of the ISM in quasar 2175 absorbers, unlike DLAs which show very weak redshift evolution.

**Author(s):** Yinan Zhao<sup>4</sup>, Jian Ge<sup>4</sup>, Jingzhe Ma<sup>4</sup>, Teng Hu<sup>4</sup>, Shaohua Zhang<sup>4</sup>, Peng Jiang<sup>5</sup>, Jason X. Prochaska<sup>3</sup>, Hongyan Zhou<sup>1</sup>, Tuo Ji<sup>1</sup>, W. Niel Brandt<sup>2</sup>

**Institution(s):** 1. Polar Research Institute of China, 2. The Pennsylvania State University, 3. UCO/Lick Observatory, 4. University of Florida, 5. University of Sciences and Technology of China

## 339.08 – A Bayesian Method For Finding Galaxies That Cause Quasar Absorption Lines

We present a study of candidate absorber-galaxy pairs for 39 low redshift quasar sightlines ( $0.06 < z < 0.85$ ) using a statistical approach to match absorbers with galaxies near the quasar lines of sight. Of the 75 quasars observed with HST/Cosmic Origins Spectrograph (COS) and archived on the Mikulski Archive for Space Telescopes (MAST), 39 overlap with the footprint of the Sloan Digital Sky Survey (SDSS). We downloaded the COS line lists for these quasar spectra from MAST and queried the SDSS DR12 database for photometric data on all galaxies within 1 Mpc of each of these quasar lines of sight. We calculated photometric redshifts for all the SDSS galaxies using the Bayesian Photometric Redshift code. We used all these absorber and galaxy data as input into an absorber-galaxy matching code which also employs a Bayesian scheme, along with known statistics of the intergalactic medium and circumgalactic media of galaxies, for finding the most probable galaxy match for each absorber. We compare our candidate absorber-galaxy matches to existing studies in the literature and explore trends in the absorber and galaxy properties among the matched and non-matched

populations. This method of matching absorbers and galaxies can be used to find targets for follow up spectroscopic studies.

**Author(s):** Emileigh Suzanne Shoemaker<sup>1</sup>, David Andrew Laubner<sup>1</sup>, Jennifer E. Scott<sup>1</sup>

**Institution(s):** 1. Towson University

## 339.10 – Magnetic Turbulence and Line Broadening in Simulations of Lyman-Alpha Absorption

We use the Illustris cosmological AREPO simulations to study the effects of gas turbulence and magnetic fields on measurements from the Lyman-Alpha forest. We generate simulated Lyman-Alpha spectra and plot the distributions of Column Density (CDD) and Doppler Width (b) both by adhering to the canonical method of fitting Voigt profiles to absorption lines and by directly measuring the column density and equivalent widths from snapshot data.

We investigate the effects of additional unresolved gas turbulence in Illustris by adding an additional broadening term to the line profiles to mimic turbulent broadening. When we do this, we find a measurable effect in the CDD and an offset in the mean of the b distribution corresponding to the additional turbulence. We also compare different MHD runs in AREPO we find that the CDD can measurably differentiate between magnetic seed field at redshifts as low as  $z=0.1$ , but we do not find that the b distribution is affected at a detectable level. Our work suggests that the effects of turbulence and magnetic fields from  $z=2\text{--}0.1$  can potentially be measured with these diagnostics. This work was supported in part by the NSF REU and DoD ASSURE programs under NSF grant no. 1262851 and by the Smithsonian Institution.

**Author(s):** Alex Gurvich<sup>1</sup>, Blakesley K. Burkhart<sup>2</sup>, Simeon Bird<sup>2</sup>

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## 340 – Gamma Ray Bursts Poster Session

### 340.01 – Enhancing Fermi's Capability for Time Domain Astrophysics

All sky monitors, such as the Fermi Gamma-Ray Space Telescope, play a crucial role in detecting transient and variable non-thermal sources for follow up observations by narrow field observatories. In this poster, we describe recent and upcoming improvements in onboard processing, ground analysis pipelines and observatory operations that will increase the sensitivity to these objects on timescales of seconds to days and reduce the latency for the information to be disseminated to the scientific community. Finally, we will provide examples of some of the expected science returns from these improvements.

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**Institution(s):** 1. NASA's GSFC

**Contributing team(s):** Fermi-LAT team

### 340.02 – On the Redshift Distribution of Gamma-ray Bursts in the SWIFT ERA: Revisited

Gamma-ray bursts (GRBs) are brief flashes of gamma-rays occurring at an average rate of a few per day throughout the universe, and it is generally assumed that GRB follows star formation rate. The ultimate energy source of a GRB is believed to be associated with an exploding star that is in a process of forming a black hole, and a high amount of energy is expected to be released during this process. Evidence of jetted GRBs (jet opening-angle) can also be observed from radio and optical observations of achromatic breaks in the afterglow light curves. Two different redshift (z) distributions were observed from different space observatories, the Swift and preSwift missions, however, the jet opening-angle distribution was determined only by the pre-Swift satellites prior to 2007. Le & Dermer (2007) developed a flat GRB spectrum model for long-duration GRBs to fit the redshift (z) and the jet opening angle distributions measured with earlier GRB missions, and showed that GRBs do not follow star formation rate. However, their fitted results were obtained without using the opening-angle distribution from the

Swift sample. In this study we revisited the calculation done by Le & Dermer by refitting the redshift and the jet opening angle distribution measured from both pre-Swift and Swift satellites. We further explored how the broken power-law GRB spectrum affect the overall fitting of the redshift and the jet opening-angle distributions, and the results will be presented in this paper.

**Author(s):** Vedant Mehta<sup>1</sup>, Truong V. Le<sup>1</sup>  
**Institution(s):** 1. Berry College

### 340.03 – Gamma Ray Burst 150518a measured at different wavelengths

Gamma Ray Burst (GRB's), extremely energetic flashes of Gamma Rays, are caused by either deaths of massive unstable stars or colliding binary neutron stars. A unique burst, GRB 150518a, had two recorded bursts fifteen minutes apart which is very rare and is considered to be ultra-long, lasting around thirty minutes total and is associated with a Supernova explosion. GRB 150518a is also extremely close compared to the average burst being measured to have a redshift of .2, this is important to note because GRB's measuring less than a redshift of .3 only are seen every ten years. Gamma rays are emitted by supernovae, neutron stars, black holes, and quasars and by studying GRB's it allows us to see more deeply into how these objects function. The first few days of GRB 150518a's detected afterglow was plotted in different wavelengths, including optical, x-ray, radio, and infrared, in flux versus time. Data is continuously being added as time goes on. This research is funded by the NSF, grant number 1358990.

**Author(s):** Elizabeth Ann Apala<sup>1</sup>, Alicia Margarita Soderberg<sup>2</sup>, Michael West<sup>3</sup>  
**Institution(s):** 1. East Central University, 2. Harvard University, 3. Lowell Observatory

### 340.04 – Radio and X-ray observations of the Ultra-long GRB 150518A

Gamma Ray Burst (GRB) 150518A, discovered on 2015 May 18 by the MAXI and KONUS-Wind satellites, lasted for about 1000s, making it an important addition to the recently established class of very long duration GRBs. We report on the JVLA radio observations of the afterglow of GRB 150518A. Additionally, we report the analysis of X-ray afterglow observations by Swift-XRT. Multi-band light curves of the radio afterglow display an unusual, conspicuous rise around 10 days after the burst, possibly due to enhanced mass-loss from the progenitor in the final stages of evolution before the GRB. The X-ray afterglow spectrum is significantly soft (photon index  $\Gamma_x > 3$ ) and heavily absorbed ( $N_{Hx,i} > 8 \times 10^{21} \text{ cm}^{-2}$ ). These properties suggest peculiar behavior that is different from the predictions of the standard fireball model of GRBs. In the light of these properties, we compare different models of progenitors for very long duration GRBs. This work was supported in part by the NSF REU and DoD ASSURE programs under NSF grant no. 1262851 and by the Smithsonian Institution.

**Author(s):** Louis Johnson<sup>2</sup>, Atish Kamble<sup>1</sup>, Raffaella Margutti<sup>1</sup>, Alicia Margarita Soderberg<sup>1</sup>  
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**Contributing team(s):** Supernova Forensics

## 341 – The Milky Way, The Galactic Center Poster Session

### 341.01 – Understanding the Formation of Young Stars in the Central 0.5 pc of the Galaxy: Methods for Extending the IMF to 16 mag

We test and analyze an existing statistical typing method, presented in Do et al. 2013, and further apply that method to construct a luminosity function which extends to a luminosity of  $K' = 16.0$  mag. These methods are implemented on data sets collected using the near-infrared integral field spectrograph OSIRIS on Keck II. Previously, the data has allowed for separation of early-type stars ( $\sim 4\text{--}6$  Myr) from late-type stars ( $> 1$  Gyr) down to  $K' = 15.5$  mag. We

further confirm the ability of the spectral typing method to accurately differentiate between early- and late-type stars to  $K' = 15.5$  mag, and also demonstrate the effectiveness of the method at magnitudes to  $K' = 16.0$  mag. We examine the luminosity function using these dim, 16 mag stars and establish that their luminosity function indicates a mass function which is less top-heavy than previously derived, but which is still not in agreement with the Salpeter model. Our conclusions call for further observational evidence for lower mass stars, beyond 16.0 mag.

**Author(s):** Hannah Lewis<sup>1</sup>, Andrea M. Ghez<sup>2</sup>, Tuan Do<sup>2</sup>, Samantha Chappell<sup>2</sup>, Jessica R. Lu<sup>3</sup>  
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**Contributing team(s):** The Galactic Center Group

### 341.02 – Studying Star Formation in the Central Molecular Zone using 22 GHz Water and 6.7 GHz Methanol Masers

The inner 400 pc of our Galaxy, or the so-called the central molecular zone (CMZ), has a unique environment with a large mass of dense, warm molecular gas. One of the premier questions is how star formation (SF) differs in this unique environment from elsewhere in the Galaxy. We intend to address this issue by identifying improved numbers and locations of early sites of SF. We have conducted high resolution surveys of the CMZ, looking for early SF indicators such as 22 GHz water and 6.7 GHz methanol masers. We present the initial water maser results from the SWAG survey and methanol results from the first full VLA survey of 6.7 GHz methanol masers in the CMZ. These surveys span beyond the inner  $1.2^\circ \times 0.5^\circ$  of the Galaxy, including Sgr B through Sgr C. The improved spatial and spectral resolutions ( $\sim 26''$  and  $2 \text{ km s}^{-1}$ ) and sensitivity ( $\text{RMS} \sim 10 \text{ mJy beam}^{-1}$ ) of our ATCA observations have allowed us to identify over 140 water maser candidates in the SWAG survey. This is a factor of 3 more than detected from prior surveys of the CMZ. The preliminary distribution of these candidates appears to be uniform along Galactic longitude. Should this distribution persist for water masers associated with star formation (as opposed to those produced by evolved stars), then this result would imply a more uniform distribution of recent SF activity in the CMZ. Prior works have shown that  $2/3$  of the molecular gas mass is located at positive Galactic longitudes, and young stellar objects (YSOs) identified by IR SEDs are located predominantly at negative Galactic longitudes. A combination of these results can provide insight on the evolution of SF within the CMZ. We are currently comparing the water maser positions to other catalogs (ex. OH/IR stars) in order to distinguish between the mechanisms producing these masers. We are also currently working on determining the distribution of 6.7 GHz methanol masers. These masers do not contain the same ambiguity as water masers as to their source and are only produced by high mass star formation. Finally we have also conducted the first on-the-fly (OTF) VLA survey of 22 GHz water masers spanning the inner  $2.0^\circ \times 0.5^\circ$ , with  $0.3''$  and  $0.4 \text{ km s}^{-1}$  spatial and spectral resolutions.

**Author(s):** Matthew Rickert<sup>3</sup>, Farhad Yusef-Zadeh<sup>3</sup>, Juergen Ott<sup>1</sup>, David S. Meier<sup>2</sup>  
**Institution(s):** 1. National Radio Astronomy Observatory (NRAO), 2. New Mexico Institute of Mining and Technology, 3. Northwestern University  
**Contributing team(s):** SWAG

### 341.03 – Hidden Star Formation in High-Velocity Gas Clouds in Clump 2 near the Edge of the CMZ

The inner Galaxy can be divided into two main regions, the Central Molecular Zone (CMZ; Morris and Serabyn 1996) and the Galactic Bar region. Gas and dust moves from the end points of the Galactic Bar on dust lanes towards the CMZ, where it merges with the gas and dust located on a 100-pc molecular ring. The stream of gas and dust on the dust lanes is not continuous, but fragments into irregularly separated clumps of varying sizes. One of the most significant aggregations of clumps is the Clump 2 region (Roogour 1964, Bania 1977). Although the gas and dust clouds in this region are very dense, they were always considered quiet with no ongoing star formation. Selected regions of Clump 2 were the targets of Herschel HIFI and

PACS observations of CO J=7-6, CI, CII, OI, NII, and OIII as part of the Herschel Inner Galactic Gas Survey (HIGGS). This poster will present an update of the ongoing data analysis, which may have yielded some surprising results.

**Author(s):** Volker Tolls<sup>1</sup>, Howard Alan Smith<sup>1</sup>, Antony A. Stark<sup>1</sup>, Christopher L. Martin<sup>2</sup>

**Institution(s):** 1. *Harvard-Smithsonian, CfA*, 2. *The Kavli Foundation*

**Contributing team(s):** HIGGS Team

### 341.04 – Using Formaldehyde to Create High Resolution Temperature Maps of CMZ Clouds

80% of the dense molecular gas in our Galaxy resides in the central few hundred parsecs, known as the Central Molecular Zone (CMZ). From our understanding of star formation, we would expect a comparatively high star formation rate in this region, but the estimates so far indicate that only 5-10% of the star formation in our Galaxy occurs there. There are a number of physical effects that may be causing this, but we particularly wish to investigate the role of the temperature of the gas - which initial estimates put at an average of 50-100 K or about a factor of 5 higher than elsewhere in the disk. Armed with the data taken by the SMA Legacy Survey of the CMZ, we aim to compare parameters two transition lines for the dense gas tracer H<sub>2</sub>CO which are particularly sensitive to temperature to measure the gas temperature on 0.2 pc scales. Ultimately we provide a high resolution temperature map for a set of clouds in the CMZ dubbed “the three little pigs” to provide an initial comparison with similar work done with ammonia tracers in order to pave the way for a high resolution temperature map of the entire CMZ.

**Author(s):** Jimmy Castaño<sup>1</sup>

**Institution(s):** 1. *Harvard College*

### 341.05 – GBT Search for HI Clouds Tracing the Nuclear Wind of the Milky Way

We present 21cm HI observations of the Galactic Center (GC) from a survey that is studying the neutral gas embedded in the Fermi Bubble. Using the 100-meter Green Bank Telescope (GBT), this work expands upon the previous ATCA survey of the central 5x5 sq. deg of the GC. In the GBT data we find almost 300 clouds in HI emission that are likely to be associated with the nuclear wind. This increases the known population by a factor ~3, and includes the highest velocity clouds found at the observed galactic latitudes. Neutral clouds likely associated with the hot wind are found to distances of 1.4 kpc from the nucleus, and the average mass in HI is about 300 Msun. Analysis of the cloud kinematics provide limits on the wind velocity, opening angle, and lifetime of neutral clouds in a hot wind.

**Author(s):** Kevin Corneilus Harrington<sup>3</sup>, Felix J. Lockman<sup>2</sup>, Naomi M. McClure-Griffiths<sup>1</sup>, Alyson Ford<sup>2</sup>, Ryan Endsley<sup>4</sup>

**Institution(s):** 1. *Australian National University*, 2. *NRAO*, 3. *University of Massachusetts-Amherst*, 4. *Washington University in St. Louis*

### 341.06 – Widespread Hot Ammonia in the Central Kiloparsec of the Milky Way

The Central Molecular Zone (CMZ) of our Milky Way consists of the inner 300-500 pc of our galaxy and is one of the most extreme environments for molecular gas in our galaxy. Previous work has found highly-excited ammonia up to J,K = 9,9 (E<sub>upper</sub> = 840 K) throughout molecular clouds in the CMZ, and characterized a temperature of T = 300-400 K for three of these clouds, all lying within 40 pc of the central supermassive black hole. The mechanism responsible for heating this gas remains uncertain. We extend this work to characterize the temperature for a larger sample of 15 clouds in the CMZ by observing ammonia lines up to J,K = 13,13 using the 100m Robert C. Byrd Green Bank Telescope. With this larger sample, we do not find a correlation between temperature and radius; however, we identify some of the most extreme molecular gas temperatures (T>400K) detected in the Galactic Center thus far, and confirm that these high temperatures are not exclusively associated with actively star-forming clouds. We also report the first detection

of highly-excited ammonia up to J,K = 11,11 from a non-star-forming cloud outside of the CMZ: Bania's clump 2 at a Galactocentric radius of ~ 450 pc.

**Author(s):** Tierra Candelaria<sup>2</sup>, Elisabeth Mills<sup>2</sup>, David S. Meier<sup>3</sup>, Juergen Ott<sup>2</sup>, Jeffrey Gary Mangum<sup>2</sup>, Karl Menten<sup>1</sup>, Peter Schilke<sup>5</sup>, Christian Henkel<sup>1</sup>, John Black<sup>4</sup>

**Institution(s):** 1. *Max Planck Institute of Radio Astronomy*, 2. *National Radio Astronomy Observatory*, 3. *New Mexico Institute of Mining and Technology*, 4. *University of Chalmers*, 5. *University of Koln*

### 341.08 – First Results from the SMA Legacy Survey of the Central Molecular Zone

The Central Molecular Zone (CMZ) is home to the largest reservoir of dense molecular gas in our Galaxy. Analogous to high-redshift galaxies in its gas density and level of turbulence, the CMZ, at a distance of only 8.4 kpc, is our nearest laboratory to understand extreme star formation throughout the universe. We exploit the high angular resolution, large bandwidth, and wide-field mapping capabilities of the Submillimeter Array (SMA) to conduct the first large-scale, high-resolution survey of this uniquely interesting star-forming environment in the Milky Way. Over the course of 3 years, we are mapping 240 sq. arcminutes of the highest column density gas in the CMZ at 0.2 pc resolution in both 1.3 mm cold dust continuum and a variety of spectral lines (including tracers of dense gas, hot core chemistry, shocks, and outflows). We present here early highlights of the survey from years 1 and 2, including evidence for tidal compression of clouds at pericenter passage by Sgr A\* and the consequent formation of massive clusters. We observe widespread shocks, high densities, and high turbulence in clouds at pericenter passage, but no active star formation, while clouds further downstream show progressively more evolved star formation.

**Author(s):** Cara Battersby<sup>1</sup>

**Institution(s):** 1. *Harvard-Smithsonian Center for Astrophysics*

### 341.09 – Estimating Circumnuclear Disk temperatures using ALMA data

The Circumnuclear Disk (CND) is a gas disk with an inner radius of approximately 1.5-2 pc surrounding Sagittarius A\*, the supermassive black hole at the center of our galaxy. Observations of the CND were made using the ALMA telescope in bands 3 and 6 with a spatial resolution of 1-3 km/s. Two noteworthy clumps of molecular gas were detected. These clumps possess high abundances of CH<sub>3</sub>CCH but no CH<sub>3</sub>CN was detected. Via the population diagram method we derived CH<sub>3</sub>CCH column densities and temperatures for both sources. We then discuss the physical and chemical nature of the gas clumps. Future work will constrain temperature values across the entire CND. Along with HC<sub>3</sub>N observations, this work will yield refined values of the gas density and mass of the CND. This is essential for finding its future impact on star formation and black hole accretion.

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### 341.10 – De-cloaking the Galactic Center

We present a preliminary extinction map of the Galactic Center, made by using the Raleigh-Jeans Color Excess method (Majewski et al, 2011) and a Bayesian approach. The Galactic Center, due to its high density of stars, contains the Milky Way Galaxy's majority of massive stars and their black hole/neutron star remnants. These cosmic laboratories challenge our understanding of the most extreme physical environments in the universe. However, the extinction from

the intervening gas and dust is extremely high ( $A_V \sim 30$ ), and cloaks these objects from view in visible wavelengths. Near-infrared wavelengths are less susceptible to extinction from gas and dust by factors of several magnitudes, but still suffer from differential reddening at very small scales; eg, 5 arcseconds (Gosling et al MNRAS 2009). De-reddening the GC further broadband imaging surveys of all types, such X-ray binary IR counterpart or transient searches being carried out by CIRCE on the GTC. Furthermore, MIRADAS, with its multiplexing capability and high resolution, will take advantage of these extinction maps as well to probe the chemodynamics and structure of the inner Milky Way when it goes on-sky in 2018/2019.

**Author(s):** Richard Deno Stelter<sup>1</sup>, Stephen S. Eikenberry<sup>1</sup>  
**Institution(s):** 1. University of Florida

### 341.11 – Tracing the Galactic Center using Bremsstrahlung, Synchrotron, and Thermal Emission

The center of our Milky Way Galaxy, better known as the Galactic Center, is host to many important and influential landmarks, including the supermassive black hole Sgr A\*, stellar complexes like Sgr B, and many young ultraviolet light producing stars. The stellar radiated output produced by these stars is absorbed by the dust and gas present in the ambient medium around these stars. This radiation produced by stars gives rise to ionized H II regions, which then emit through bremsstrahlung emission (free-free emission). Bremsstrahlung emission occurs when electrons scatter off ions without being captured, so they are free before and after interaction. Another emission component seen in the Galactic Center is synchrotron emission, which is produced by energetic electrons generated from the jet of the supermassive black hole and supernova remnants, spiraling around magnetic field lines. Any object that is hot gives off light, or thermal emission. When the ultraviolet radiation from stars is absorbed by the dust, the dust is heated, and then re-radiates as thermal emission at far-infrared wavelengths. Using the three previous emission components, this environment was analyzed in order to identify three main features in the Galactic Center: ionized gas, magnetic fields and dust. Bremsstrahlung emission was used to trace H II regions (ionized gas), synchrotron emission was used to trace magnetic field lines, and thermal emission was used to trace the dust. After tracing these spectral features, they were displayed, resulting in a map of the Galactic Center showing all three of these features that can be used for further analysis in the near future.

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**Institution(s):** 1. NASA Goddard Space Flight Center, 2. University of Maryland, College Park

### 341.12 – Orbital kinematics of edge-on bars with and without supermassive black holes

Observations of external disk galaxies with bars frequently show boxy or peanut shaped bulges, which have a distinct X-shaped structure when the system is viewed edge-on. Such features are also well documented in N-body simulations, where they arise from the buckling of the bar. The precise nature of the orbits that create this structure is still uncertain. Some studies argue that the bulge/X-shape structure is formed and supported by resonant 2:1 “banana” orbit family, while other argue that they arise from 5:3 “brezel” orbits. Here we examine a set of N-body models of a barred disk galaxy (with and without a central black hole). We generate 2-D maps of projected kinematics both for specific orbit families as well as the full simulation of the bars at different orientations. By examining the line-of-sight velocities, velocity dispersions and 3rd and 4th Gauss-Hermite polynomials we attempt to deduce the type of orbits most likely to produce the X-shaped features. We also generate mock kinematics for the Milky Way bar and predict the kinematical features associated with the X-shape that will be observed with upcoming stellar surveys.

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**Institution(s):** 1. Shanghai Astronomical Observatory, 2. University of Central Lancashire, 3. University of Michigan

### 341.13 – The Monte Carlo Milky Way: reverse engineering the dense gas structure of the Galaxy with ATLASGAL

The APEX Telescope Large Area Survey of the Galaxy (ATLASGAL) is the most sensitive sub-millimetre survey of the inner Galaxy, covering 420 square degrees of the Galactic plane at a wavelength of 870  $\mu\text{m}$ . As with nearly any survey, however, ATLASGAL presents an incomplete view of the Milky Way, as it is biased by observational limitations which can distort our view of both the structure and distribution of the dense molecular gas.

In order to better understand the structure of matter in the Galaxy, we have used Monte Carlo methods to simulate the distribution of dense gas from a grid of input models. By taking account of the observational limitations of the survey, we are able to compare the output from these models with the results obtained from the observations and determine the most likely distribution of dense gas. We investigate a number of spiral arm models, and discuss the results in the context of their role in massive star formation in the Galaxy.

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**Institution(s):** 1. Max Planck Institute for Radio Astronomy, 2. Wartburg College

### 341.14 – Probing Metallicity across the Milky Way Disk with the VLA

HII regions are sites of recent star formation where massive stars have ionized the surrounding gas. They are bright at radio wavelengths and can be detected throughout the Galactic disk. The Green Bank Telescope (GBT) HII Region Discovery Survey (HRDS) doubled the number of known HII regions in the first Galactic quadrant using radio recombination line (RRL) and free-free radio continuum emission at 8-10 GHz. The physical (electron) temperature, a proxy for metallicity, is derived from the line-to-continuum ratio. The metallicity is the abundance of metals, elements heavier than helium, and their distribution in the Milky Way provides information about Galactic evolution. These metallicities correspond to present day values because HII regions are relatively young ( $< 10$  Myr). Here we discuss Very Large Array (VLA) RRL and continuum observations of 21, distant HRDS HII regions. The VLA provides a more sensitive and accurate measure of the radio continuum and therefore better determination of the metallicity. The data were reduced both manually and via a pipeline using CASA. We compare our results with our GBT data in preparation for a larger VLA HII region survey.

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### 341.15 – Extreme Runaway Dwarf Carbon Stars

The dwarf carbon (dC) star SDSS J112801.67+004034.6 has already been noted to have an unusually high radial velocity. We present new spectroscopic and proper motion observations which imply a remarkable galactocentric velocity,  $\sim 500$  km/s. Unlike almost all high velocity and hypervelocity stars, significant motion is in this case confidently detected in both radial velocity and also proper motion, not simply in one or the other. Several other SDSS dC stars are also inferred to have very high galactocentric velocities, again each based on both high heliocentric radial velocity and also confidently detected proper motions. Cool, relatively nearby ( $\sim 2$  kpc) stars with velocities this large are rare.

Most mechanisms that produce extreme stellar acceleration involve passage near the galactic center, but the large orbital angular momenta of these objects preclude this explanation. Ejection of a binary from a supernova may be a possibility, and may be appealing as dC stars are thought to obtain their photospheric  $\text{C}_2$  via mass transfer from a more highly evolved companion.

**Author(s):** Kathryn A. Plant<sup>1</sup>, Bruce H. Margon<sup>1</sup>, Puragra Guhathakurta<sup>1</sup>, Gregory P. Laughlin<sup>1</sup>, Jeffrey A. Munn<sup>2</sup>

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### 341.16 – Carbon Abundance Plateaus among Carbon-Enhanced Metal-Poor Stars

A substantial fraction of low-metallicity stars in the Milky Way, the Carbon-Enhanced Metal-Poor (CEMP) stars, exhibit enhancements of their carbon-to-iron relative to the solar value ( $[C/Fe] > +0.7$ ). They can be divided into several sub-classes, depending on the nature and degree of the observed enhancements of their neutron-capture elements, providing information on their likely progenitors. CEMP-s stars (which exhibit enhanced s-process elements) are thought to be enhanced by mass transfer from an evolved AGB companion, while CEMP-no stars (which exhibit no over-abundances of neutron-capture elements) appear to be associated with explosions of the very first generations of stars. High-resolution spectroscopic analyses are generally required in order to make these sub-classifications.

Several recent studies have suggested the existence of bimodality in the distribution of absolute carbon abundances among CEMP stars -- most CEMP-no stars belong to a low-C band ( $A(C) \sim 6.5$ ), while most CEMP-s stars reside on a high-C band ( $A(C) \sim 8.25$ ). The number of CEMP stars considered by individual studies is, however, quite small, so we have compiled all available high-resolution spectroscopic data for CEMP stars, in order to further investigate the existence of the claimed carbon bi-modality, and to consider what can be learned about the progenitors of CEMP-s and CEMP-no stars based on the observed distribution of  $A(C)$  on the individual plateaus.

We acknowledge partial support from the grant PHY 14-30152; Physics Frontier Center/JINA Center for the Evolution of the Elements (JINA-CEE), awarded by the US National Science Foundation.

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**Institution(s):** 1. University of Notre Dame, 2. Xi'an Jiao Tong University

### 341.17 – Preliminary Results of Detailed Chemical Abundance Analysis of Milky Way Satellite Galaxy Reticulum II Discovered in the Dark Energy Survey

We present preliminary results from abundance analysis of stars in Milky Way satellite galaxies found in the Dark Energy Survey (DES). DES has discovered 16 candidate satellite galaxies of the Milky Way in its first two years of operation. Since January 2015, three candidates have subsequently been revealed to be dark matter-dominated by spectroscopic follow-up studies of their kinematics, confirming their status as satellite galaxies. Spectroscopic follow-up of the remaining 13 candidates is underway. We have analyzed high resolution VLT/GIRAFFE spectra of member stars in one of these satellite galaxies, Reticulum II. Using equivalent width measurement and spectral synthesis methods, we measure the abundances of Iron and other species in order to begin to understand the chemical content of these Milky Way satellites.

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**Institution(s):** 1. Texas A&M University  
**Contributing team(s):** Dark Energy Survey Milky Way Science Group

### 341.18 – Uncovering debris in the Milky Way

In our current cosmological model, typical Milky Way mass galaxies should experience many mergers over their lifetimes. We have developed new chemo-dynamical techniques to hunt for accreted stars - the stellar debris from satellite galaxies - in the Milky Way and its disk. We have applied our template to data from the Gaia-ESO Survey - an extraordinary new resource. I will discuss our latest results, including, for the first time, a new signature with which we can directly detect the Milky Way's last major merger some 8-10 billion years ago.

**Author(s):** Gregory R. Ruchti<sup>1</sup>, Justin Read<sup>2</sup>  
**Institution(s):** 1. Lund University, 2. University of Surrey  
**Contributing team(s):** the Gaia-ESO Consortium

### 341.19 – Using A New Model for Main Sequence Turnoff Absolute Magnitudes to Measure Stellar Streams in the Milky Way Halo

Statistical photometric parallax is a method for using the distribution of absolute magnitudes of stellar tracers to statistically recover the underlying density distribution of these tracers. In previous work, statistical photometric parallax was used to trace the Sagittarius Dwarf tidal stream, the so-called bifurcated piece of the Sagittarius stream, and the Virgo Overdensity through the Milky Way. We use an improved knowledge of this distribution in a new algorithm that accounts for the changes in the stellar population of color-selected stars near the photometric limit of the Sloan Digital Sky Survey (SDSS). Although we select bluer main sequence turnoff stars (MSTO) as tracers, large color errors near the survey limit cause many stars to be scattered out of our selection box and many fainter, redder stars to be scattered into our selection box. We show that we are able to recover parameters for analogues of these streams in simulated data using a maximum likelihood optimization on MilkyWay@home. We also present the preliminary results of fitting the density distribution of major Milky Way tidal streams in SDSS data. This research is supported by generous gifts from the Marvin Clan, Babette Josephs, Mani Limlamai, and the MilkyWay@home volunteers.

**Author(s):** Jake Weiss<sup>1</sup>, Heidi Jo Newberg<sup>1</sup>, Matthew Arsenault<sup>1</sup>, Torrin Bechtel<sup>5</sup>, Travis Desell<sup>4</sup>, Matthew Newby<sup>3</sup>, Jeffery M. Thompson<sup>2</sup>  
**Institution(s):** 1. Rensselaer Polytechnic Institute, 2. Southern Vermont College, 3. Temple University, 4. University of North Dakota, 5. University of Wisconsin-Madison

### 341.20 – Inferring the Gravitational Potential of the Milky Way

We present a simple numerical algorithm to infer the gravitational potential of a galaxy from the observed positions and velocities of stars. The method is novel in that it works directly in Cartesian phase space and thus does not require any assumptions about the integrability of the Hamiltonian, as some other methods do. We have tested the algorithm on a two-dimensional logarithmic potential with good results and hope to be able to extend the algorithm to infer the Milky Way's potential from the full Gaia dataset.

**Author(s):** Casey Chu<sup>1</sup>, Yoram Lithwick<sup>2</sup>, Fabio Antonini<sup>2</sup>  
**Institution(s):** 1. Harvey Mudd College, 2. Northwestern University

## 342 – Evolution of Galaxies Poster Session

### 342.01 – Modeling Galaxy CO Simulations as an Observer

Our new ability to comprehensively model CO emission from  $J=1-0$  to  $J=13-12$  is one legacy of the SPIRE FTS onboard the Herschel Space Observatory. Much attention has been paid to this dataset by both theorists and observers, due to these lines' ability to probe the warm, highly excited molecular gas that may be associated with star formation. We are investigating the CO excitation ladders produced by the numerical simulations of disc galaxies and galaxy mergers (Narayanan and Krumholz 2014). Using one- and two-component non-LTE RADEX models, we compare the physical conditions derived from modeling the unresolved CO as SPIRE observers would with the known gas properties and distributions of the simulations. Our goal is to better understand the meaning of the derived physical conditions when modeling unresolved continuous gas distributions as discrete physical components over the CO ladder.

**Author(s):** Julia R. Kamenetzky<sup>3</sup>, George C. Privon<sup>2</sup>, Desika Narayanan<sup>1</sup>  
**Institution(s):** 1. Haverford College, 2. Universidad de Concepción, 3. University of Arizona

### 342.02 – Comparing Simulations of Galaxy Halos

There are still many uncertainties in our understanding of galaxy formation and evolution. One way of making progress in our

understanding is the use of hydrodynamical simulations, but there still remain many uncertainties in their use, particularly below a simulation's resolution. The goal of this project is to compare the results from five different hydrodynamical simulations of the progenitor of a Milky Way mass halo at  $z=3$ . We characterize these simulations by analyzing the relationship between total halo, star, and gas mass in dark matter halos. We also compare these relationships with trends inferred from observational data.

**Author(s):** Francisco Holguin<sup>2</sup>, Ariyeh Maller<sup>1</sup>  
**Institution(s):** 1. AMNH, 2. MIT

### 342.03 – A Semi-Analytic Study of Feedback Processes and Metallicity Profiles in Disc Galaxies

The metallicity gradients of disc galaxies contain valuable information about the physics governing their formation and evolution. The observed metallicity profiles have negative gradients that are steeper at high redshifts, indicating an inside-out formation of disc galaxies. We improve on our semi-analytic galaxy formation model (*Lu, Mo & Wechsler 2015*) by incorporating the radial distribution of metals into the model. With the improved model, we explore how feedback scenarios affect metallicity gradients. The model features 3 feedback scenarios: An Ejective (EJ) model, which includes ejective supernova (SN) feedback, a Pre-Heating (PR) model, which assumes that the intergalactic medium is preheated, preventing it from collapsing onto galaxies, and a Re-Incorporation (RI) model, which also includes strong outflows but allows ejected gas to re-accrete onto the galaxies. We compare the models with observations from *Ho et al. (2015)* and find that while all models struggle to match the observed metallicity gradient-stellar mass relationship, the PR model predicts metallicity gradients that best match observations. We also find that the RI model predicts a flat gradient because its outflow and re-accretion replenish the disc uniformly with newly accreted enriched gas, erasing the mark of inside-out formation. Our findings suggest feedback plays a key role in shaping the metallicity gradients of disc galaxies and require more detailed theoretical modeling to understand them.

**Author(s):** Nathan Ross Sandford<sup>1</sup>, Yu Lu<sup>2</sup>  
**Institution(s):** 1. Pomona College, 2. The Observatories, The Carnegie Institution for Science

### 342.04 – Matching High- $z$ Observations of Damped Ly- $\alpha$ Absorption Systems

Damped Lyman Alpha Absorption systems, the highest column density quasar absorption systems, can place tight constraints on models of galaxy formation. While many current models can match the properties of these objects at  $z \sim 2-3$ , all current models severely underestimate their abundances at  $z \sim 5$ . We study the ability of a semi-analytic model to match the line density of damped systems and find that serious changes to the model must be made. If gas disks give rise to these systems, then more baryons must be in HI than is currently assumed in the model, either because fewer stars are formed or less gas is ejected by supernova. In addition, the disks must be much larger than assumed in the model. Alternatively, gas outflows could account for much of the cross section, placing constraints on the physics of supernova feedback.

**Author(s):** Jacob Hamer<sup>1</sup>, Ariyeh Maller<sup>2</sup>, Rachel S. Somerville<sup>3</sup>  
**Institution(s):** 1. CUNY Macaulay Honors College at Hunter College, 2. CUNY New York City College of Technology, 3. Rutgers University

### 342.05 – Machine Learning and Cosmological Simulations

We explore the application of machine learning (ML) to the problem of galaxy formation and evolution in a hierarchical universe. Our motivations are two-fold: (1) presenting a new, promising technique to study galaxy formation, and (2) quantitatively evaluating the extent of the influence of dark matter halo properties on small-scale structure formation. For our analyses, we use both semi-analytical models (Millennium simulation) and N-body + hydrodynamical simulations (Illustris simulation). The ML algorithms are trained on important dark matter halo properties (inputs) and galaxy properties

(outputs). The trained models are able to robustly predict the gas mass, stellar mass, black hole mass, star formation rate,  $g-r$  color, and stellar metallicity. Moreover, the ML simulated galaxies obey fundamental observational constraints implying that the population of ML predicted galaxies is physically and statistically robust. Next, ML algorithms are trained on an N-body + hydrodynamical simulation and applied to an N-body only simulation (Dark Sky simulation, Illustris Dark), populating this new simulation with galaxies. We can examine how structure formation changes with different cosmological parameters and are able to mimic a full-blown hydrodynamical simulation in a computation time that is orders of magnitude smaller. We find that the set of ML simulated galaxies in Dark Sky obey the same observational constraints, further solidifying ML's place as an intriguing and promising technique in future galaxy formation studies and rapid mock galaxy catalog creation.

**Author(s):** Harshil Kamdar<sup>1</sup>, Matthew Turk<sup>1</sup>, Robert Brunner<sup>1</sup>  
**Institution(s):** 1. University of Illinois at Urbana-Champaign

### 342.06 – Constraining the Satellite Quenching Timescale at $z < 1.5$

Despite remarkable success at modeling the evolution of massive galaxies over cosmic time, modern hydrodynamic and semi-analytic models of galaxy formation generally fail to reproduce the properties of low-mass galaxies. This shortcoming in our theoretical picture is largely driven by an inability to understand the physics of satellite (or “environmental”) quenching. Using abundance matching prescriptions to populate large dissipationless N-body simulations, including the Bolshoi Simulation, we study the dependence of satellite properties on cluster-centric distance within massive host halos at  $z < 1.5$ , focusing on the potential physical mechanisms that may be at play in suppressing star formation in the satellite population. Our results illustrate the potential power of ongoing cluster surveys, such as the multi-year GOGREEN Survey at Gemini Observatories, to constrain the quenching timescale over more than half of cosmic time.

**Author(s):** M. Katy Rodriguez Wimberly<sup>1</sup>, Michael Cooper<sup>2</sup>  
**Institution(s):** 1. California University State, Long Beach, 2. University of California, Irvine

### 342.07 – SurveySim: a new MCMC code to explore the evolution of the IR luminosity function

The Herschel and Spitzer space telescopes have been crucial in furthering our understanding of the formation and evolution of galaxies. However key questions, such as the role of SF and AGN in powering the IR output of galaxies remain unanswered. The large numbers of high redshift galaxies detected by recent IR surveys make individual spectroscopic follow-up impractical. However statistical trends in SED and luminosity function evolution in an entire population can be realized. We present a new open source Markov-Chain Monte Carlo code, SurveySim. It is built to constrain the spectral energy distribution and luminosity function evolution required to produce a given multi-wavelength survey. Its very general design allow us to use a wide range of different dusty galaxy populations (including SFGs, AGNs and Composites), luminosity function forms and SED templates. The code employs a multidimensional color-color diagnostic to determine goodness of fit. It simulates observational errors and takes into account incompleteness. Here, dusty high- $z$  galaxies at different parts of the IR SED have been considered to analyze the relative selection biases.

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**Institution(s):** 1. California Institute of Technology, 2. Stanford University, 3. Tufts University, 4. University of Massachusetts Amherst

### 342.08 – Galaxy Transformation from Flyby Encounters

Galaxy flybys are transient encounters where two halos interpenetrate and later detach forever. Although these encounters are surprisingly common—even outnumbering galaxy mergers for massive halos at the present epoch—their dynamical effects have

been largely ignored. Using idealized collisionless N-body simulations of flyby encounters, it has been shown that a galaxy flyby can excite a bar and spin up the halo. Here, we compare the structural properties of recent flybys to that of recent mergers and isolated systems within the Illustris Simulation.

**Author(s):** Christina E Davis<sup>1</sup>, Kelly Holley-Bockelmann<sup>1</sup>  
**Institution(s):** 1. Vanderbilt University

### 342.09 – Ram Pressure Stripping: The Long Goodbye

What turns off star formation in satellite galaxies? Ram pressure stripping, the removal of a galaxy's gas through direct interaction with the gas halo in which it orbits, is an attractive quenching mechanism, particularly in the Milky Way halo where the radial distribution of quenching is dramatic. However, many implementations of this process in semi-analytic models result in overly-rapid gas removal when compared with observations. We use high resolution hydrodynamical simulations run with Enzo to parameterize the stripping of disk and halo gas from an orbiting satellite galaxy for use in the semi-analytic modeling code Galacticus. We find that using the instantaneous ram pressure overestimates the amount of gas that is stripped, and present a physically-motivated module for including ram pressure stripping in semi-analytic models that uses the integral of the ram pressure experienced by a satellite galaxy. We will compare our results to observations of the Milky Way satellites.

**Author(s):** Stephanie Tonnesen<sup>1</sup>, Yu Lu<sup>1</sup>, Andrew Benson<sup>1</sup>, Annika Peter<sup>2</sup>, Michael Boylan-Kolchin<sup>3</sup>, Andrew R. Wetzel<sup>1</sup>, Daniel R. Weisz<sup>4</sup>

**Institution(s):** 1. Carnegie Observatories, 2. Ohio State University, 3. University of Texas at Austin, 4. University of Washington

### 342.10 – Galactic Bridges in Pairs

We employ a suite of 75 simulations of galaxies in idealized major mergers to investigate the bridges formed by interactions. These simulations are based on the Feedback in Realistic Environments (FIRE) model (Hopkins et al. 2011). Moreover, unlike past work, we have both the resolution and diversity in merging orbits to make statistically meaningful predictions. We find that very dense, star forming bridges can be characterized as strong bridges. In particular, prograde mergers with high eccentricities and high impact parameters produce the most mass of stars in the bridge.

**Author(s):** Brianna Thierjung<sup>1</sup>

**Institution(s):** 1. Cal Poly Pomona

**Contributing team(s):** Jorge Moreno, Paul Torrey, Phil Hopkins

### 342.11 – Interaction Induced Size Evolution in Galaxies

We utilize a suite of 75 different simulations of major mergers based on the “Feedback in Realistic Environments” FIRE model (Hopkins et al. 2014). The suite consists of mergers of disk galaxies with mass ratio of 2.5:1, set at various eccentricities, impact parameters and relative spin-orbit orientations. This work focuses on the evolution of the size of the stellar, gaseous and star-forming components. We find that, whilst older models (based on Springel & Hernquist 2003) predict dramatic size evolution - this effect is mild for the newer FIRE simulations. We believe this is due to the fact that newer simulations produce weaker gravitational tidal torques.

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**Institution(s):** 1. Cal Poly Pomona

**Contributing team(s):** Jorge Moreno, Paul Torrey, Phil Hopkins

### 342.12 – Source of the Stellar Age-Velocity Dispersion Relation in Simulated Galaxies

We investigated the source of the stellar age-velocity dispersion relation using six high-resolution simulated galaxies. Observations show that velocity dispersion increases with stellar age. This trend is thought to be due to a combination of the evolution of the velocity dispersion of the interstellar media (ISM), interactions within the disk, and galactic mergers. Our simulated galaxies show redshift zero

age-velocity dispersion relations consistent with those of observed galaxies. In order to determine how the velocity dispersion of stars evolves after their formation, we calculated the velocity dispersion versus the age of the stars at both redshift zero and at their time of formation. We found that while the ISM velocity dispersion evolves, it cannot be the sole source of the relation. Additionally, dwarf galaxies display a greater relative change in their velocity dispersion than more massive galaxies. Furthermore, we show that major mergers markedly increase the velocity dispersion of stars.

**Author(s):** Drew Wills<sup>1</sup>, Charlotte Christensen<sup>1</sup>

**Institution(s):** 1. Grinnell College

### 342.13 – Target Selection for the Arecibo Pisces-Perseus Supercluster Survey (APPSS)

The Arecibo Pisces-Perseus Supercluster Survey (APPSS) is a new large targeted HI survey now underway using Arecibo's L-band Wide receiver system. A major goal is to constrain models of the Pisces Perseus infall, producing 5- $\sigma$  detections of infall motions  $\sim 500$  km s<sup>-1</sup>. We are targeting sources that are likely to be at the PPS distance, but that are just below the HI mass detection threshold of the ALFALFA survey. We expect to identify  $\sim 800$  objects of mass  $\sim 10^8 - 9 M_{\odot}$  which will allow us to constrain the lower mass end of the HI mass function in this infall environment.

We have pursued a multi-pronged approach to target selection for this survey. Sources from ALFALFA, SDSS, and the GALEX GCAT single source catalogs were matched and intercompared via multi-band color photometry, surface brightnesses, and appearance in SDSS images. Final target selection based on visual inspection of SDSS images was found to correlate well with a color-selection technique based on GALEX/NUV - SDSS/r. Along with the details of the source selection we will discuss the facilitation and implementation of this process via a multi-institution collaborative website, and early results from the APPSS survey.

This work has been supported by NSF grant AST-1211005.

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**Institution(s):** 1. Cornell University, 2. George Mason University, 3. St. Lawrence University, 4. Union College, 5. University of San Francisco, 6. West Texas A&M University

**Contributing team(s):** Undergraduate ALFALFA Team

### 342.14 – Cleaning HI Spectra Contaminated by GPS RFI

The NUDET systems aboard GPS satellites utilize radio waves to communicate information regarding surface nuclear events. The system tests appear in spectra as RFI (radio frequency interference) at 1381MHz, which contaminates observations of extragalactic HI (atomic hydrogen) signals at 50-150 Mpc. Test durations last roughly 20-120 seconds and can occur upwards of 30 times during a single night of observing. The disruption essentially renders the corresponding HI spectra useless.

We present a method that automatically removes RFI in HI spectra caused by these tests. By capitalizing on the GPS system's short test durations and predictable frequency appearance we are able to devise a method of identifying times containing compromised data records. By reevaluating the remaining data, we are able to recover clean spectra while sacrificing little in terms of sensitivity to extragalactic signals. This method has been tested on 500+ spectra taken by the Undergraduate ALFALFA Team (UAT), in which it successfully identified and removed all sources of GPS RFI. It will also be used to eliminate RFI in the upcoming Arecibo Pisces-Perseus Supercluster Survey (APPSS).

This work has been supported by NSF grant AST-1211005.

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**Institution(s):** 1. Union College

**Contributing team(s):** the Undergraduate ALFALFA Team

### 342.15 – Extending ALFALFA: Reducing L-Band Wide

## Observations of Optically Selected Galaxies

Observations of galaxies in the Virgo Cluster were completed at the Arecibo Observatory in the spring and summer of 2015. 161 targets were observed, selected by photometry criteria such as magnitude and shape from the Sloan Digital Sky Survey. The targets, some too dim to be detected by Arecibo's ALFA drift scanner, were observed with the L-Band Wide detector. Once reductions in an IDL environment were done, these data were matched to the targets from the Sloan Digital Sky Survey and the GALEX/MAST catalog. 115 of the 161 targets observed had positive detections, a 71% success rate. Comparing the galaxies that were detected against the galaxies that were not detected (by the L-Band Wide receiver) will allow us to refine our method of using photometric data to select HI-rich galaxies in the 2000 km/s to 9000 km/s range to refine our selection for the Arecibo Pisces-Perseus Supercluster Survey (APPSS), which uses the same method of target selection.

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**Contributing team(s):** Undergraduate ALFALFA Team

## 342.16 – HI Gas in Large-Scale Filaments as Measured by ALFALFA

We assess the relationship between galaxy environment and HI content as measured by ALFALFA. In particular, we consider membership in large-scale filaments in order to provide clues to how star formation in galaxies is quenched in different environments. We use data from the Sloan Digital Sky Survey to define galaxy environments in terms of clusters, filaments, and voids for a sample of galaxies with  $z < 0.05$ , using both a friends-of-friends algorithm and a more refined approach similar to that used for the Galaxy and Mass Assembly (GAMA) survey, where a minimal spanning tree is constructed from group centers, and galaxies near branches are associated with filaments. We compare the HI content in these environments using statistics that include both HI detections and the upper limits on detections from ALFALFA. This work is supported by NSF grant AST-1211005.

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**Institution(s):** 1. Skidmore College

**Contributing team(s):** ALFALFA Team

## 342.17 – HI Gas in Early Type Galaxies as Measured by ALFALFA

We present the HI content of 1580 early type galaxies (ETGs) in a total sample of 7747 galaxies that have HI measurements or upper limits from the ALFALFA survey. We find a significant correlation between HI content and local density, with HI detections almost exclusively in low-density environments. Using optical line ratios, we split the population into galaxies with spectral lines dominated by active galactic nuclei (AGN) and dominated by star forming regions. Compared with HI-rich star forming ETGs, HI-rich ETGs with AGN tend to be brighter and redder and to exhibit a stronger correlation between stellar mass and HI mass. This work is supported by NSF grant AST-1211005.

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**Contributing team(s):** ALFALFA Team

## 342.18 – Surface Brightness Profiles and Star Formation Rates of Galaxies in NRGb054

We present new optical R and H-alpha images of the galaxy group NRGb054, obtained with the WIYN 0.9m telescope at KPNO using the MOSAIC camera. This group was studied as part of the larger Undergraduate ALFALFA Team project investigating the effects of a group environment on star formation. The stacked H-alpha image was continuum subtracted by the removal of a scaled and stacked R

image. Surface photometry was performed on R and continuum-subtracted H-alpha cutouts of 20 covered galaxies to determine the surface brightness as a function of radius. Integrating the continuum-subtracted H-alpha surface brightness profile provides the total star formation within that galaxy, while the shape of the profile illustrates how star formation is spread throughout the galaxy. We provide a catalog of surface brightness profiles and integrated star formation rates for NRGb054. We consider star formation as a function of galaxy-galaxy separation and galaxy location within the group, and discuss our findings in the context of the wider study. This work has been supported by NSF grant AST-1211005.

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## 342.19 – H-alpha Observations of MKW10

As part of the Undergraduate ALFALFA Team project looking at clusters and groups of galaxies to investigate the effects of environment on star formation, we analyzed H-alpha and R-band observations of the group MKW10 from the WIYN 0.9-m telescope with MOSAIC camera at Kitt Peak. We continuum-subtract the H-alpha images by scaling and subtracting the broadband R images. This process includes: determining the seeing of each image by calculating the FWHM values of several stars in the image; convolving all images to the worst seeing; stacking images for each filter; subtracting sky background; scaling the R image to H-alpha; and subtracting the scaled R from H-alpha. We then use the H-alpha-continuum-subtracted image to perform surface photometry of individual galaxies in MKW10. The data will be used to determine star formation rates and distributions of galaxies in this group environment and will be compared to results for galaxies in other UAT group and cluster environments. Analysis is ongoing.

This work has been supported by NSF grant AST-1211005 and the Illinois Space Grant Consortium.

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**Contributing team(s):** Undergraduate ALFALFA Team

## 342.20 – The Power of Wide Field HI Surveys: ALFALFA Imaging of Massive Tidal Features in the Leo Cloud of Galaxies

Tidal interactions are well known to play an important role in galactic evolution in group environments, but the extent of these interactions, and their relative impact on the morphology-density relation is still unclear. Neutral hydrogen (HI) mapping can reveal the recent interaction history of group galaxies, but is difficult to execute due to the need for high sensitivity over wide fields. The Arecibo Legacy Fast ALFA survey (ALFALFA; Giovanelli et al. 2005; Haynes et al. 2011) provides high sensitivity, unbiased, wide field maps of HI in the local volume; here we will present a 50 deg<sup>2</sup> ALFALFA map of a well studied region of the Leo Cloud of galaxies, which includes the NGC3226/7 group and HCG44. These observations reveal HI tails and plumes with extents exceeding 1.4 deg (~600 kpc), well beyond the primary beams of previous observations. These tails constitute a significant fraction of the total HI mass in NGC3226/7 (Arp 94) and HCG44. We will also present WSRT maps of the extended emission near Arp 94, which show tail morphologies inconsistent with 2 body interactions. These observations demonstrate that large scale group interactions will be an important science outcome for future sensitive, wide field HI surveys.

This work is supported by NSF grants AST-0607007 and AST-1107390 and by grants from the Brinson Foundation.

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**Contributing team(s):** The ALFALFA Almost Darks Team

### 342.21 – Studying the Structure and Dynamics of the Subcomponents of the Milky Way

The Milky Way (MW) galaxy is the only large galaxy besides the Andromeda (M31) galaxy that is nearby enough to be dissected star by star, making it an excellent candidate for studying galaxy formation and evolution. A galaxy's evolutionary path is determined by factors such as its dark matter distribution, gas content, energy injection by supernovae and active nucleus, merger history, etc.. To constrain these physical processes, we studied the structure and dynamics of the MW galaxy using very accurate proper motion (PM) measurements and exquisite photometry from three M31 fields. After defining our MW sample using color-magnitude and PM cuts, we analyzed each MW sample alongside the Besançon model. We found a break in the MW stellar density profile, thereby providing input and incentive for refining the model. Our pilot study highlights the importance of PM measurements in constraining the structure and dynamics of the MW galaxy, and it uses methods applicable to future surveys with even more precise PM measurements for faint stars over larger areas of sky. Our results allow us to constrain the MW halo density profile, significantly enhancing the current understanding of the dark matter contents and formation of the MW.

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**Contributing team(s):** HSTPROMO collaboration, HALO7D collaboration, SPLASH collaboration

### 342.22 – Studying the Structure and Dynamics of the Subcomponents of the Andromeda Galaxy

The Andromeda (M31) galaxy is the only large galaxy besides the Milky Way (MW) that is nearby enough to be dissected star by star, making it an excellent candidate for studying galaxy formation and evolution. A galaxy's evolutionary path is determined by factors such as its dark matter distribution, gas content, energy injection by supernovae and active nucleus, merger history, etc.. To constrain these physical processes, we studied the structure and dynamics M31 using very accurate proper motion (PM) measurements and exquisite photometry from three Hubble Space Telescope fields in the direction of the M31 galaxy. In order to exclude the MW contaminants from our data set, we used PM and photometric data to cuts define our M31 sample. We used this sample to analyze the motion of the subcomponents of M31 in the context of the state-of-the-art M31 model presented in van der Marel et al. 2012. We observed the relative PMs of three M31 subcomponents to gain unprecedented insight into the internal kinematics of M31. The PM differences we found were compared to a M31 model and provide input for refining the model. Our results serve as constraints for any dynamical formation model of the subcomponents of M31 and for any other large galaxy, allowing for better study and understanding of the dark matter contents and formation of the M31 galaxy.

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**Contributing team(s):** HSTPROMO, HALO7D, SPLASH

### 342.23 – Discovery of Remote Globular Cluster Satellites of M87

We present the discovery of several tens of globular clusters (GCs) in the outer regions of the giant elliptical M87, the brightest galaxy in the Virgo Cluster. These M87 GC satellites were discovered in the course of Keck/DEIMOS spectroscopic follow up of GC candidates that were identified in the Next Generation Virgo cluster Survey

(NGVS). Specifically, the primary targets of this Keck spectroscopic campaign were GC satellites of early-type dwarf (dE) galaxies. However, we found that our sample contained a subset of GCs for which M87 is the most likely host. This subset is consistent with having an  $r^{-1}$  power-law surface density distribution and a radial velocity distribution both centered on M87. The remote M87 GC satellites span the radial range 140 to 900 kpc, out to about a third of the Virgo Cluster's virial radius (for comparison, M87's effective radius is only 8 kpc). These M87 GC satellites are probably former satellites of other Virgo Cluster galaxies that have subsequently been cannibalized by M87.

This research was supported by the National Science Foundation and the UC Santa Cruz Science Internship Program.

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**Contributing team(s):** NGVS Collaboration

### 342.24 – Predicting Intrinsic mid-IR to optical flux ratios for galaxies of different types using Spectral Synthesis Models of Composite Stellar Populations

We analyze the intrinsic flux ratios of simple and composite stellar populations for various visible--near-infrared filters with respect to  $\sim 3.5\mu\text{m}$  (L-band), and their dependence on metallicity, star-formation history, and effective mean age. This study is motivated by the fact that light from galaxies is reddened and attenuated by dust via scattering and absorption, where different sightlines across the face of a galaxy suffer various amounts of extinction. Ignoring the effects of this extinction could lead one to infer lower stellar mass, and SFR, or higher metallicity. Tamura et al. (2009) developed an approximate method, dubbed the " $\beta_V$ " method, which corrects for dust-extinction on a pixel-by-pixel basis, by comparing the observed flux ratio and empirical estimate of the intrinsic flux ratio of optical and  $\sim 3.5\mu\text{m}$  broadband data. Here, we aim to validate and test the limits of the  $\beta_V$  method for various filters spanning the visible through near-infrared wavelength range. Through extensive modeling, we test their assumptions for the intrinsic flux ratios for a wide variety of simple and composite stellar populations. We build spectral energy distributions (SEDs) of simple stellar populations (SSPs), by adopting Starburst99 and BC03 models for young ( $< 9\text{Myr}$ ) and old ( $> 100\text{Myr}$ ) stellar populations, respectively, and linear combinations of these for intermediate ages. We then construct composite stellar population (CSP) SEDs by combining SSP SEDs for various realistic star-formation histories (SFHs). We convolve filter response curves of visible--near-infrared filters for HST imaging surveys and mid-infrared filters in current (WISE, Spitzer/IRAC) and near-future use (JWST/NIRCam) with each model SED, to obtain intrinsic flux ratios ( $\beta_{\lambda,0}$ ). We find that  $\beta_{\text{NIR},0}$  is only varying slightly as a function of metallicity but is insensitive to SFH or redshift ( $z \leq 2$ ). We also find a narrow range of  $\beta_{V,0}$  ( $0.7^{+0.05}_{-0.08}$ ) for early Hubble type galaxies (E and So) using SEDs of randomly generated multi-burst SFHs together with age and metallicity profiles of nearby galaxies from the literature.

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### 342.25 – Ultraviolet to Infrared SED (Spectral Energy Distribution) Analysis of Nearby Late-Stage Merging Galaxies Using CIGALE

We present an analysis of the fundamental properties of nearby merging galaxies based on in-depth analysis of their spectral energy distributions. Our new sample, which is based on the catalog of nearby merging galaxies from the SIGS sample (Spitzer Interacting Galaxy Sample; Lanz et al. 2013, 2014), cross-correlates the Revised IRAC-FSC Redshift Catalogue (Wang et al. 2014) with Galaxy Zoo, which builds on and extends the previous investigation by Lanz et al. in two ways. First it enlarges the sample considerably, increasing the

statistical power of the analysis significantly. Second, it includes galaxies in the most advanced merger stage, filling a potential gap in the Lanz et al. sample. The cross-correlation gave 453 possible mergers, between 400 and 453 of which are interacting on some level. After more clearly defining the evolutionary stages of the merging process, these galaxies' stages were identified morphologically, and selected according to brightness () and stage (late stages 4-6), more than tripling the total late-stage sample to about 40 or 50 systems, 16 of which have sufficient observational data for a full SED analysis. These, along with the late-stage mergers found in the SIGS sample, have been photometered from the ultraviolet (UV) to the far-infrared (FIR) and subsequently fit and analyzed by the newly revised and updated CIGALE (Code Investigating Galaxy Emission; Burgarella et al. 2005) in order to retrieve key physical properties of the galaxies including star-formation rate (SFR), AGN fraction, and stellar and dust mass, as well as identify any trends in terms of shape and physical properties of spectra within the evolutionary range of late-stage mergers.

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### 342.26 – CSS Object Found in Galaxy Merger 1015+364 at 2.3 and 8.5 Hz

We investigated the ongoing galaxy merger 1015+364 at 2.3 and 8.5 Hz with the Very Long Baseline Array to determine the state of evolution of the merger's resident supermassive black holes. During the merger of two massive galaxies, we expect that the two supermassive black holes will form a binary and eventually coalesce. In our observations we detected a highly compact radio source with an extent of 21.14 parsecs. For each of two detected radio components, we measured their flux density and spectral index. By looking at their spectra, we concluded our radio detection to be a Compact Steep-Spectrum object (CSS), indicating a young radio object less than a few thousand years in age. This result hints at a connection between the recent merger and the ignition of the central radio source.

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**Institution(s):** 1. *National Radio Astronomy Observatory*

**Contributing team(s):** Other people involved

### 342.27 – Low-level supermassive black hole activity and star formation in isolated ellipticals

We present and discuss Chandra ACIS-S X-ray observations of six early-type galaxies located within cosmic voids. The targeted galaxies have comparable stellar masses of 6-9e10 solar but span a wide range of star formation rates, from 0.03 to 6.5 solar masses per year. These data permit clean investigation of the link, if any, between star formation and low-level supermassive black hole activity. We isolate the nuclear X-ray emission associated with SMBH activity through analyzing the X-ray surface brightness profiles and calculating the predicted X-ray binary contamination within the extraction aperture. The galaxies with higher star formation rates also tend to have greater SMBH-associated X-ray luminosities, perhaps suggestive of a mutual dependence on cold gas. We also compare our void galaxies to cluster early-type galaxies of similar stellar mass, finding that the void galaxies have, on average, more compact optical surface brightness profiles along with greater X-ray luminosities.

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**Institution(s):** 1. *Macalester College*, 2. *University of Michigan*

### 342.28 – Bivariate mass-size relation as a function of morphology as determined by Galaxy Zoo 2 crowdsourced visual classifications

It is well known that the mass-size distribution evolves as a function of cosmic time and that this evolution is different between passive and star-forming galaxy populations. However, the devil is in the

details and the precise evolution is still a matter of debate since this requires careful comparison between similar galaxy populations over cosmic time while simultaneously taking into account changes in image resolution, rest-frame wavelength, and surface brightness dimming in addition to properly selecting representative morphological samples.

Here we present the first step in an ambitious undertaking to calculate the bivariate mass-size distribution as a function of time and morphology. We begin with a large sample ( $\sim 3 \times 10^5$ ) of SDSS galaxies at  $z \sim 0.1$ . Morphologies for this sample have been determined by Galaxy Zoo crowdsourced visual classifications and we split the sample not only by disk- and bulge-dominated galaxies but also in finer morphology bins such as bulge strength. Bivariate distribution functions are the only way to properly account for biases and selection effects. In particular, we quantify the mass-size distribution with a version of the parametric Maximum Likelihood estimator which has been modified to account for measurement errors as well as upper limits on galaxy sizes.

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**Institution(s):** 1. *University of Minnesota*

### 342.29 – Inside-Out or Outside-In? Metallicity Gradients in Low Surface Brightness Galaxies in the MUSCEL Program

We present the metallicity profiles of three low surface brightness (LSB) galaxies as clues to the formation of these galaxies. This easily overlooked class of galaxy comprises up to half of the galaxy population with masses spanning that of the Milky Way, making them cosmologically significant baryon repositories. LSB galaxies are also very different from the more familiar archetypal galaxies in that they have unusually high gas fractions, up to 95%. Yet, they do not represent a distinct class of galaxy, but are simply on the low surface brightness end of a continuum.

We have observed a sample of low surface brightness galaxies with the VIRUS-P integral field spectrograph as part of the MUSCEL program (Multiwavelength observations of the Structure, Chemistry, and Evolution of LSB galaxies). Our program aims to fully characterize the formation histories of these galaxies by using these data in tandem with Spitzer, Galex, and Swift observations.

Optical emission lines contained within the VIRUS-P spectra have allowed us to determined the metallicities of HII regions within these galaxies via emission-line ratio diagnostics. Because ISM metallicities are directly linked to the competing effects of star formation and gas accretion, the distribution of metals is a significant clue to the formation of these galaxies.

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### 342.30 – Large-scale environmental dependence of gas-phase metallicity in dwarf galaxies

We study how the cosmic environment affects galaxy evolution in the Universe by comparing the metallicities of dwarf galaxies in voids with dwarf galaxies in more dense regions. Ratios of the fluxes of emission lines, particularly those of the forbidden [O III] and [S II] transitions, provide estimates of a region's electron temperature and number density. From these two quantities and the emission line fluxes [O II]  $\lambda 3727$ , [O III]  $\lambda 4363$ , and [O III]  $\lambda \lambda 4959, 5007$ , we estimate the abundance of oxygen with the Direct  $T_e$  method. We estimate the metallicity of 37 void dwarf galaxies and 71 dwarf galaxies in more dense regions using spectroscopic observations from the Sloan Digital Sky Survey Data Release 7, as re-processed in the MPA-JHU value-added catalog. We find very little difference between the two sets of galaxies, indicating little influence from the large-scale environment on their stellar evolution. Of particular interest are a number of extremely metal-poor dwarf galaxies that are equally abundant in both voids and denser regions.

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### 342.31 – A Direct Comparison of HI and Ly $\alpha$ Morphologies in Two LARS Galaxies

The Lyman-Alpha Reference Sample (LARS) and its extension (eLARS) represent an exhaustive campaign to reverse-engineer galaxies. The main goal is to understand how Ly $\alpha$  is transported within galaxies: what fraction of it escapes, and what physical properties affect Ly $\alpha$  morphology and radiative transport (e.g. dust and gas content, metallicity, kinematics, properties of the stellar population). Neutral hydrogen emission, which can be used to determine a galaxy's structure and kinematics, was observed using the B and C configurations of the Very Large Array in two galaxies from the sample: LARS02 and LARS09. Images of the HI mass surface density and of the intensity weighted HI velocity field were created at angular scales of  $\sim 8$  arcseconds. Extended HI gas is detected at high significance up to  $\sim 30$  kpc from the optical body of LARS02. LARS09 has a severely disturbed optical morphology; our new HI observations reveal that LARS09 is interacting with the nearby field galaxy SDSS J082353.65+280622.2. In combination with direct imaging of the Ly $\alpha$  morphology from the Hubble Space Telescope, this program has produced the first direct comparison of Ly $\alpha$  and HI morphologies. These observations demonstrate concept for a significant observational campaign that will produce similar comparisons in the remaining 40 LARS+eLARS galaxies.

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**Contributing team(s):** LARS Team

### 342.32 – Understanding the Physical Conditions in Local Analogs of High-Redshift Starburst Galaxies

Observations of strong nebular emission lines in high-redshift galaxies ( $z \sim 2$ ) can be illuminated through the use of analogous local galaxies ( $z < 0.4$ ), for which many more emission lines can be measured. The observed offset in the “BPT” ([N II] $\lambda 6584$ /H $\alpha$  vs. [O III] $\lambda 5007$ /H $\beta$ ) nebular diagnostic diagram between the locus of high redshift galaxies and that of typical local galaxies indicates a change in the physical conditions of the galaxies with redshift; the cause of this offset is unknown, but it may be associated with the ionization parameter, the hardness of the ionizing spectrum, or the N/O abundance ratio. To study the offset, we have selected a sample of local galaxies from the Sloan Digital Sky Survey III Baryon Oscillation Spectroscopic Survey Data Release 12 (SDSS-III/BOSS DR12), which occupies the same space in the [N II] $\lambda 6584$ /H $\alpha$  vs. [O III] $\lambda 5007$ /H $\beta$  diagnostic diagram as the  $z \sim 2$  sample. Using a suite of  $> 50$  different emission lines, most of which are unavailable in analyses of higher redshift galaxies, and a novel method of improving the spectrophotometric calibration of BOSS data, we investigate the metallicity, ionization state, and abundance ratios of this offset sample in order to shed light on the physical conditions in galaxies in the early universe.

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### 342.33 – Environmentally driven star formation during a super galaxy group merger

We find evidence for outside-in growth of galaxies within a merging super galaxy group at a redshift of  $z \sim 0.37$ . We utilize Hubble Space Telescope imaging in rest-frame UV and visual to measure color gradients across the super group and internally within 138 individual galaxies that are spectroscopically confirmed members. The group members show enhanced star formation at intermediate environmental densities. The high resolution imaging shows that the group galaxies have bluer disks, i.e. most of the new stars are forming in the disk which supports outside-in growth. These

disk-dominated galaxies will likely fade to become So members.

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### 342.34 – Emission Line Science in the Faint Infrared Grism Survey (FIGS) Sample

Emission lines can reveal a bounty of information about the processes occurring within a galaxy. Physical properties such as star formation rate and metallicity can be determined from ratios of emission line fluxes. The study of emission line galaxies (ELGs) through cosmic time gives insight into the processes by which galaxies evolve. Extreme emission line galaxies (EELGs), typified by strong nebular emission lines which dominate their spectra, are of interest because they are well known to be galaxies undergoing periods of intense star formation. Slitless grism spectroscopy offers a significant advantage to the study of ELGs and EELGs, allowing for measurement of the spectra of a large number of galaxies within a field. This allows for detection of ELGs and EELGs with few selection biases. Optical follow-up of FIGS-selected sources allows for analysis of star formation rate (SFR) through H-alpha measurements over the redshift range  $0.3 < z < 0.75$  and analysis of mass-metallicity relations, using the gas phase oxygen abundance found with [OII], [OIII], and H-beta fluxes to infer metallicity, over the range  $0.3 < z < 1.3$ .

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**Institution(s):** 1. Arizona State University  
**Contributing team(s):** The FIGS Team

### 342.35 – Galaxies Unveiled: Rest-frame UV Clumps at $0.5 \leq z \leq 1.5$

We present an investigation of clumpy galaxies in the Hubble Ultra Deep Field at  $0.5 \leq z \leq 1.5$  in their rest-frame FUV using 3 ultra-deep UV mosaics in the F225W, F275W, and F336W filters taken with Wide Field Camera 3 UVIS detector. An analysis of all clumpy galaxies in our redshift range yields 209 galaxies that host 403 clumps detected at rest-frame  $1500\text{\AA}$ . These host galaxies appear to be typical star-forming main sequence galaxies, with a diversity of clump number, ranging from a single clump to galaxies with several clumps. We measure the photometry of the clumps and determine the mass, age, and star formation rates of a subsample of 100 clumps utilizing FAST (Fitting and Assessment of Synthetic Templates). We find that clumps contribute an average of 19% of the total rest-frame FUV flux of the host galaxy, comprise only a small fraction of the total star formation rate of their host galaxy, and individually contribute a median of  $\sim 1\%$  of the host galaxy mass, with an average total clump mass contribution of 4%. We discuss clump properties in the context of the overall properties of their host galaxies to determine the role they play in galaxy evolution.

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### 342.36 – Emission line galaxy pairs up to $z=1.5$ from the WISP survey

We present a sample of spectroscopically identified emission line galaxy pairs up to  $z=1.5$  from WISPs (WFC3 Infrared Spectroscopic Parallel survey) using high resolution direct and grism images from HST. We searched  $\sim 150$  fields with a covered area of  $\sim 600$  arcmin<sup>2</sup>, and a comoving volume of  $> 400$  Gpc<sup>3</sup> at  $z=1-2$ , and found  $\sim 80$  very close physical pairs (projected separation  $D_p < 50$  h<sup>-1</sup>kpc, relative velocity  $d_v < 500$  kms<sup>-1</sup>), and  $\sim 100$  close physical pairs ( $50 < D_p < 100$  h<sup>-1</sup>kpc,  $d_v < 1000$  kms<sup>-1</sup>) of emission line galaxies, including two dozen triplets and quadruples. In this poster we present the multi-wavelength data, star formation rate (SFR), mass ratio, and study the merger rate evolution with this

special galaxy pair sample.

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**Contributing team(s):** WISPs Team

### 342.37 – AGN contribution to the total IR luminosity in Herschel selected galaxies out to $z \sim 1.5$

In the past decade, a growing amount of evidence suggests a tight link between the growth of Active Galactic Nuclei (AGN) and that of their host galaxies. X-ray studies on the Super Massive Black Holes (SMBHs) activity indicate the existence of a Black Hole Accretion Rate (BHAR) “main sequence”, similar to the “main sequence” observed in star-forming galaxies, between the star-formation rate (SFR) and stellar mass ( $M^*$ ). We use the multi wavelength data from the SIMES survey to study the optical to sub-mm spectral energy distribution (SED) of galaxies identified at 250  $\mu\text{m}$  by the Herschel Space Observatory. In particular, for galaxies in the 0.2–1.5 redshift range, we explore the relations among galaxy’s stellar mass, SFR, and SMBH accretion rate. The deep Spitzer-IRAC/MIPS (3.6, 4.5 and 24  $\mu\text{m}$ ) together with the deep AKARI-IRC observations (7, 11 and 15  $\mu\text{m}$ ) allow us to constrain the critical spectral region where the dusty torus emission of AGNs is more prominent. Thanks to the Herschel-SPIRE observations, we can also precisely measure the SFR from the bolometric (i.e. 8-1000  $\mu\text{m}$ ) far-IR emission. Using this multi-wavelength approach we confirm the existence, at  $z < 0.5$ , of the  $M^*$ -BHAR “main sequence”. The measured average ratio between BHAR and SFR is close to the value required to maintain the SMBH-to- $M^*$  ratio of  $\sim 10^3$  and decreases at higher specific SFRs ( $\text{SSFR} = \text{SFR}/M^*$ ). Finally, combining our observations with literature results, we show that the slope of the BHAR main sequence is evolving with redshift between  $z \sim 0$  and  $z \sim 2$ .

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### 342.38 – The Mass-Size Relation of Quenched, Quiescent Galaxies in the WISP Survey

The relation between the stellar mass and size, if measured for galaxies of similar types, can be a useful tool for studying galactic evolution. We study the mass-size relation of quenched, quiescent galaxies to determine the effect of star-formation history on the growth of these objects over time. The WFC3 Infrared Spectroscopic Parallels (WISP) survey is a large HST IR grism survey of over 385 fields of  $\sim 4$  arcmin<sup>2</sup> each, and it is ideal for studying the star-formation rate with its broad spectral coverage. Using a subset of these fields with deep IR data and measurements across both filters (28 fields), we perform a color selection and identify 83 quenched galaxies with a median  $z \sim 1.6$ . With GALFIT, we measure their effective radius and sersic index on the 2-D surface brightness distribution in the F110W band. We perform fitting of grism spectra of the observed galaxies to derive redshift, stellar mass and age for all galaxies. We combine the size, stellar mass, and stellar age determinations to investigate whether the evolution of the mass-size relation over time is primarily driven by the entrance of newly quenched galaxies or by processes affecting the individual quenched galaxies.

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### 342.39 – Galaxy Classification: Citizen Scientists versus Experts

We present the differences of morphological galaxy classification between non-experts and experts. The non-experts are represented by college students and a retired adult community, who use an online application to visually classify galaxies selected from a galaxy morphology catalog. We find that the non-expert group lags the expert classification by one Hubble type behind, for instance, the non-experts classify a set of galaxies with Sb, while the experts classify the same set as Sc. We believe the reason is because the Hubble sequence is increasing the asymmetric structures towards later types. Our results show that the experts have the ability to identify more detailed structures, which the laymen commonly do not recognize.

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### 342.40 – Galaxy Zoo Hubble: First results of the redshift evolution of disk fraction in the red sequence

The transition of galaxies from the blue cloud to the red sequence is commonly linked to a morphological transformation from disk to elliptical structure. However, the correlation between color and morphology is not one-to-one, as evidenced by the existence of a significant population of red disks. As this stage in a galaxy’s evolution is likely to be transitory, the mechanism by which red disks are formed offers insight to the processes that trigger quenching of star formation and the galaxy’s position on the star-forming sequence. To study the population of disk galaxies in the red sequence as a function of cosmic time, we utilize data from the Galaxy Zoo: Hubble project, which uses crowdsourced visual classifications of images of galaxies selected from the AEGIS, COSMOS, GEMS, and GOODS surveys. We construct a large sample of over 10,000 disk galaxies spanning a wide ( $0 < z < 1.0$ ) redshift range. We use this sample to examine the change in the fraction of disks in the red sequence with respect to all disks from  $z_{\text{sim}}$  to the present day. Preliminary results confirm that the fraction of disks in the red sequence decreases as the Universe evolves. We discuss the quenching processes which may explain this trend, and which morphological transformations are most affected by it.

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**342.41 – Galaxy Zoo Hubble: Crowdsourced Morphologies for 169,944 Galaxies at  $0 < z < 2.5$**   
The Galaxy Zoo project uses crowdsourced visual classifications to create large and statistically robust catalogs of detailed galaxy morphology. We present initial results for the Galaxy Zoo: Hubble dataset, which includes 169,944 images of galaxies selected from the AEGIS, COSMOS, GEMS, and GOODS surveys. The galaxies span a redshift range of  $0 < z < 2.5$ , with a median of  $z \approx 0.7$ . The classification scheme distinguishes between bulge-dominated and disk-dominated galaxies, as well as identifying kpc-scale features including galactic bars, spiral arms, irregular structure, and mergers. In addition, we also measure the geometry and relative positions of clumpy structures that are unique to high-redshift star-forming galaxies. Visual classifications are calibrated using a set of  $z \approx 0.05$  SDSS images that are processed to appear as they

would at a variety of simulated redshifts using Hubble; this measures the morphological bias for galaxies as a function of changing the apparent size and brightness, without overcorrecting for effects such as an evolving  $L_{\text{star}}$ . We present a new technique for debiasing the morphologies based on a simple parametric model of surface brightness and distance, which adjusts the threshold for detecting feature or disk-dominated galaxies in fainter galaxies and at higher redshifts. We demonstrate the effectiveness of this technique for bulge/disk separation, and discuss its applications and limitations for smaller physical sub-structures. We also present preliminary results analyzing the evolution of disk sub-structure as a function of cosmic time. All the above data will be included in the upcoming release of the full Galaxy Zoo: Hubble catalog.

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**Contributing team(s):** Galaxy Zoo volunteers

### 342.42 – Galaxy Zoo CANDELS Data Release I: Morphologies of ~50,000 Galaxies With $z \leq 3$ in Deep Hubble Legacy Fields

We present quantified visual morphologies of approximately 48,000 galaxies in rest-frame optical to  $z \sim 3$ , using galaxies observed in three Hubble Space Telescope legacy fields by the Cosmic And Near-infrared Deep Extragalactic Legacy Survey (CANDELS) and classified by participants in the Galaxy Zoo project. Each galaxy received an average of 43 independent classifications, which we combine into detailed morphological information on galaxy features such as clumpiness, bar instabilities, spiral structure, and merger and tidal signatures. We apply a consensus-based classifier weighting method that preserves classifier independence while effectively down-weighting significantly errant classifications. Comparing the Galaxy Zoo classifications to previous human and machine classifications of the same galaxies shows very good agreement; in some cases the high number of independent classifications provided by Galaxy Zoo provides an advantage in selecting galaxies with a particular morphological profile, while in others the combination of Galaxy Zoo with other classifications is a more promising approach than using any one method alone. We combine the Galaxy Zoo classifications of "smooth" galaxies with parametric morphologies to select a sample of featureless disks at  $1 \leq z \leq 2$ , which may represent a dynamically warmer progenitor population to the settled disk galaxies seen at later epochs.

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**Contributing team(s):** Galaxy Zoo Team, CANDELS Team

### 342.43 – AGN in Infrared Galaxies and the Evolving BPT Diagram: Results from the FMOS-COSMOS Survey

We are undertaking an observational campaign to obtain near-infrared spectroscopy for distant galaxies in the COSMOS field using FMOS on Subaru. With this spectroscopy we can detect key rest-frame optical emission lines for galaxies out to  $z \sim 1.7$ . In this talk, I will focus on the subset of 123 galaxies selected in the far-infrared with Herschel. These galaxies are highly obscured and known to have a high AGN fraction based on detections at other wavelengths. This is the largest sample of infrared galaxies with near-infrared spectroscopy at these redshifts. The far-infrared selection results in a sample of galaxies that are massive systems that span a range of metallicities in comparison with previous optically selected surveys,

and thus has a higher AGN fraction and better samples the AGN branch. Using this sample, and other optically selected samples, we investigate how the BPT diagram evolves over time and how this evolution agrees with the prediction of the models of Kewley et al. 2013. We find that a large fraction of our IR-selected sample are BPT-selected AGN using their new, redshift dependent classification line and find large agreement with other methods of identifying AGN. Additionally, we identify new, likely obscured AGN that were not identified at other wavelengths and discuss the properties of these objects in detail.

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**Contributing team(s):** COSMOS

### 342.44 – Co-evolution of Extreme Star Formation and Quasar: hints from *Herschel* and the Sloan Digital Sky Survey

Using the public data from the *Herschel* wide field surveys, we study the far-infrared properties of optical-selected quasars from the Sloan Digital Sky Survey. Within the common area of  $\sim 172 \text{ deg}^2$  we have identified the far-infrared counterparts for 354 quasars, among which 134 are highly secure detections in the *Herschel* 250  $\mu\text{m}$  band (signal-to-noise ratios  $\geq 5$ ). This sample is the largest far-infrared quasar sample of its kind, and spans a wide redshift range of  $0.14 \leq z \leq 4.7$ . Their far-infrared spectral energy distributions, which are due to the cold dust components within the host galaxies, are consistent with being heated by active star formation. In most cases ( $> 80\%$ ), their total infrared luminosities as inferred from only their far-infrared emissions ( $L_{\text{IR}}^{(\text{cd})}$ ) already exceed  $10^{12} L_{\text{sun}}$ , and thus these objects qualify as ultra-luminous infrared galaxies. There is no correlation between  $L_{\text{IR}}^{(\text{cd})}$  and the absolute magnitudes, the black hole masses or the X-ray luminosities of the quasars, which further support that their far-infrared emissions are not due to their active galactic nuclei. A large fraction of these objects ( $> 50\text{--}60\%$ ) have star formation rates  $> \sim 300 M_{\text{sun}}/\text{yr}$ . Such extreme starbursts among optical quasars, however, is only a few per cent. This fraction varies with redshift, and peaks at around  $z \sim 2$ . Among the entire sample, 136 objects have secure estimates of their cold-dust temperatures ( $T$ ), and we find that there is a dramatic increasing trend of  $T$  with increasing  $L_{\text{IR}}^{(\text{cd})}$ . We interpret this trend as the envelope of the general distribution of infrared galaxies on the ( $T$ ,  $L_{\text{IR}}^{(\text{cd})}$ ) plane.

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### 342.45 – Interpreting the IR SED of $z \sim 0.3\text{--}2.8$ IR-Luminous Galaxies and AGN Using Hydrodynamic Simulations

We use three-dimensional hydrodynamical galaxy merger simulations to further investigate the nature of a sample of 342  $\mu\text{m}$ -selected (ultra) luminous infrared galaxies at  $z \sim 0.3\text{--}2.8$ . All of our sources have low-resolution *Spitzer*/IRS spectra -- the largest such sample outside the local universe. These spectra allow us to determine that our sample consists of a mixture of star forming galaxies (SFGs), AGN, and composites. We address the question of how well do empirical IR AGN fraction estimates trace the intrinsic AGN fraction (i.e. the AGN-to-total power in the galaxy prior to dust re-processing), including how they relate to galaxy properties such as merger stage, dust/gas content, and star formation rates. We do this by fitting the observed SEDs of our sample with theoretical SEDs based on GADGET hydrodynamic merger simulations additionally processed through the SUNRISE radiative transfer code. We additionally investigate systematic uncertainties associated with these quantities using the goodness of fits to our model library. The key findings are: 1) our simulation-based fits are in broad agreement with the empirical model-based fits, 2) much of the AGN fraction of  $L_{\text{IR}}$  is missed if the AGN's contribution to heating the host galaxy dust is not accounted for, and 3) the IR AGN fraction traces the intrinsic AGN fraction up to the coalescence stage, however may underestimate the intrinsic AGN fraction post coalescence.

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### 342.46 – The faint end slope of the UV LF at $z \sim 2$ from the Hubble UV Ultra Deep Field

We present the  $z \sim 2$  UV luminosity function (LF) at 1500Å derived using UV imaging data obtained as part of the Hubble Ultra-Violet Ultra Deep Field (UVUDF) program (Teplitz et al. 2013). We apply the Lyman break dropout selection to isolate a sample of  $z \sim 2$  Lyman-break galaxy (LBG) candidates. We perform simulations to quantify the survey incompleteness for UVUDF, as a function of magnitude and size, and also compute the selection function for our dropout selection criteria. Our simulations indicate that we are 50% complete at  $M_{1500} = -17.5$  (AB). We used the modified maximum likelihood estimator introduced in Mehta et al. (2015) to derive the best fit parameters of the Schechter luminosity function. The faint end slope value for the  $z \sim 2$  UV LF in recent literature ranges from very steep ( $\alpha = -1.74$ ) to considerably shallow ( $\alpha = -1.17$ ) values. We find a faint end slope value that lies in between these extremes.

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### 342.48 – A Catalog of $z=3.1$ Lyman Alpha Emitting Galaxies Discovered in Narrow-band Imaging of MUSYC 1030+05

We present a catalog of  $\sim 200$  Lyman Alpha Emitting galaxies (LAEs) at redshift  $z=3.1$  found in a 5015 Å narrow-band image of the MUSYC 1030+05 field. We reduced raw optical images taken with the MOSAIC II CCD camera at the CTIO 4m telescope with the IRAF MSCRED package. The reduction included the crucial steps of bias subtraction, flat-field correction, cosmic ray and satellite trail rejection, astrometric calibration, tangent plane projection, weighted stacking, and sky background removal. Our initial catalog of sources detected in the narrow-band filter contains  $\sim 20,000$  sources. We used additional photometric measurements in the MUSYC broad-band filters to identify LAEs via their flux density excess in the narrow-band. This catalog of LAEs will undergo further analysis to characterize how the number density, clustering, colors, and star formation rates of LAEs vary with position and evolve with redshift. We gratefully acknowledge support from NSF grants AST-1055919 & PHY-1263280.

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**Contributing team(s):** MUSYC Collaboration

### 342.49 – Gas Content and Star Formation Efficiency of Massive Main Sequence Galaxies at $z \sim 3-4$

Recent observations have shown that the neutral gas content and star formation efficiency of massive (with  $\log(\text{stellar masses}) > 10$ ), normal star forming galaxies, i.e. they reside on the main sequence of star forming galaxies, are steadily decreasing from the peak of star formation activity (at redshifts of  $z \sim 2$ ) till today. This decrease is coincident with the observed decline in the cosmic star formation rate density over this time range. However, only few observations have probed the evolution of the gas content and star formation efficiency beyond this peak epoch when the cosmic star formation rate density has been increasing, i.e. at redshifts of  $z \sim 3-4$ .

We will present new ALMA rest-frame 250 $\mu\text{m}$  continuum detections of 45 massive, normal star forming galaxies in this critical redshift interval selected in the COSMOS deep field. Using the sub-mm continuum as proxy for the cold neutral gas content, we find gas

mass fractions and depletions similar to those reported during the peak epoch of star formation. We will discuss our findings in the context of results from lower redshift observations and model expectations.

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### 342.50 – Evidence for the Suppression of Star-Formation in the Centers of Massive Galaxies at $z=4$

We perform the first spatially-resolved stellar population study of galaxies over the GOODS-S field in the early universe ( $z = 3.5-6.5$ ), utilizing the Hubble Space Telescope Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS) imaging dataset. We select a sample of  $\sim 550$  bright and extended galaxies at  $z = 3.5-6.5$ , from a parent sample of  $\sim 8000$  photometric-redshift selected galaxies at  $z = 3.5-8.5$  (Finkelstein et al. 2015). We separate each galaxy into several concentric rings with various radial distances to the galactic center, and perform aperture photometry to calculate the fluxes from each annulus. We derive the radial dependence of the galaxy properties such as stellar mass, star formation rate, and dust content via spectral energy distribution fitting based on a Markov Chain Monte Carlo algorithm. We find that in our highest two redshift bins ( $z \sim 5$  and 6), our sample of galaxies show specific star formation rates (sSFRs) which are generally independent of the radial distance from the center of the galaxies, indicating that stars are formed uniformly at all radii, contrary to massive galaxies at  $z \leq 2$ . However, in our lowest redshift bin of  $z \sim 4$ , the majority of galaxies with the highest central mass densities ( $\log M/M_{\odot} > 9 \text{ kpc}^{-2}$ ) show evidence for a preferentially lower sSFR in their centers than in their outer regions, indicative of the suppression of star formation in their central regions, possibly leading to the formation of bulges.

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**Institution(s):** 1. University of Texas at Austin

**Contributing team(s):** CANDELS team

### 342.51 – A Systematic Investigation of Cold Gas and Dust in "Normal" Star-Forming Galaxies and Starbursts at Redshifts 5-6

Cold molecular and atomic gas plays a central role in our understanding of early galaxy formation and evolution. It represents the material that stars form out of, and its mass, distribution, excitation, and dynamics provide crucial insight into the physical processes that support the ongoing star formation and stellar mass buildup. We present some of the most recent progress in studies of gas-rich galaxies out to the highest redshifts through detailed investigations of the cold gas and dust with the most powerful facilities, i.e., the Karl G. Jansky Very Large Array (VLA), the Northern Extended Millimeter Array (NOEMA) and the Atacama Large (sub-) Millimeter Array (ALMA). Facilitating the impressive sensitivity of ALMA, this investigation encompasses a systematic study of the star-forming interstellar medium, gas dynamics, and dust obscuration in massive dusty starbursts and (much less luminous and massive) "typical" galaxies at such early epochs. These new results show that "typical"  $z > 5$  galaxies are significantly metal-enriched, but not heavily dust-obscured, consistent with a decreasing contribution of dust-obscured star formation to the star formation history of the universe towards the earliest cosmic epochs.

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**Contributing team(s):** COSMOS, HerMES

### 342.52 – A Search for $z > 6.5$ Lyman-alpha Emitting Galaxies with WISP

The observed number density of Lyman-alpha emitting galaxies at

$z > 6$  provides an important probe of the reionization history of the universe. Because Lyman-alpha photons are very sensitive to the presence of neutral hydrogen, the evolution of the galaxy number density above redshift 6 can be used as a measurement on the progress of reionization. However, the Lyman-alpha luminosity function is currently poorly constrained at high- $z$ . We present the results of a systematic search for Lyman-alpha emitters (LAEs) at redshifts of  $\sim 6.5$  to  $7.5$  using the HST WFC3 Infrared Spectroscopic Parallels (WISP) survey. WISP's uncorrelated fields are well-suited to the study of bright LAEs, minimizing the effects of clustering introduced by a patchy reionization. From the 30 deepest WISP fields, we compile a sample of single-line emitters, confirm redshifts with broadband colors, and identify LAE candidates that have "dropped out" (are undetected at the 1 sigma level) of the WFC3 UVIS filters. By combining our results with other  $z \sim 7$  studies, we determine whether the number density of LAEs evolves past  $z \sim 6.5$ .

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**Contributing team(s):** The WISP Team

### 342.53 – A Sneak Peek at the JWST Era: Observing Galaxies Below the Hubble Limit with Gravitational Lensing

The installation of WFC3 on the Hubble Space Telescope pushed the frontier of high-redshift galaxy studies to only 500 Myr after the Big Bang. However, observations in this epoch remain challenging and are limited to the brightest galaxies; the fainter sources believed to be responsible for reionizing the Universe remain beyond the grasp of Hubble. With gravitational lensing, however, we can benefit from the magnification of faint sources, which brings them within reach of today's telescopes. The Hubble Frontier Fields program is a deep survey of strongly lensing clusters observed in the optical and near-infrared. Unfortunately, detecting highly magnified, intrinsically faint galaxies in these fields has proved challenging due to the bright foreground cluster galaxies and intracluster light. We have developed a technique using wavelet decomposition to overcome these difficulties and detect galaxies at  $z \sim 7$  with intrinsic UV magnitudes as faint as  $M_{UV} = -13$ . We present this method and the resulting luminosity functions, which support a steep faint-end slope extending out to the observational limits. Our method has uncovered hundreds of galaxies at  $z > 6$  fainter than any that have been seen before, providing our first insight into the small galaxy population during the epoch of reionization and a preview of the capabilities of JWST.

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### 342.54 – Exploring the Escape of Hydrogen Ionizing Photons from Local Galaxies

Low-mass galaxies dominate the universe by number and many of these systems have large star formation rates per unit mass. Measurements of the escape fraction of ionizing radiation from dwarf galaxies are an important input to cosmological simulations and theoretical studies but are largely unconstrained by observations. As a result, the role of low-mass galaxies in cosmological reionization and the ionization state of the intergalactic medium (IGM) at high and low redshifts remains poorly understood. Here we study a sample of 18 star-forming galaxies (12 from the Lyman-Alpha Reference Sample, Rivera-Thorsen et al. 2015; 6 from the KISS sample, Salzer et al. 2001), some of which are low-mass systems (10 with  $M_{\text{star}} < 5 \times 10^9 M_{\text{sun}}$ ). All of the sample galaxies were observed in the FUV with the HST/COS spectrograph and these measurements were used to derive limits on their escaping Lyman-alpha radiation (Rivera-Thorsen et al. 2015, Wofford et al. 2013). Using the numerical radiative transfer simulations of Yajima et al. 2014, we relate the escape of Lyman-alpha radiation to limits

on the fraction of escaping H-ionizing radiation from these galaxies. This correlation is stronger for low-redshift galaxies (Yajima et al. 2014) and these galaxies are more accessible observationally for these studies. Although the Yajima et al. (2014) study focuses on high-mass galaxies, we derive tentative limits on the escape fraction for H-ionizing radiation for all of the galaxies in this sample. From our analysis, we find escape fractions of less than 5% in all but two extreme cases where the escape fractions are greater than 14%. Our sample averaged escape fraction is insufficient for what reionization requires, although our values are likely to be lower limits and the two outliers are two of the lowest mass systems from the LARS sample. We discuss future directions, including further modeling of the radiative transfer and the galaxy's physical conditions, to better understand the role of dwarf galaxies in the ionization of the local IGM and cosmic reionization.

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## 343 – Circumstellar and Debris Disks Poster Session

### 343.01 – Investigations of the Circumstellar Disk Fraction as a Function of Mass in Young Embedded Clusters in Orion B

In the current paradigm of star formation, all stars form with circumstellar disks. However, recent studies of the young NGC 2264 clusters (age  $\sim 2$  Myr, Marinas et al 2013; 2015) have unexpectedly revealed that stars with masses less than 0.3 solar masses exhibit a lower circumstellar disk fraction than more massive stars in the clusters. Is it possible that a significant number of very low mass stars form without a disk? To answer this, we are studying three very young embedded clusters (age  $< 1$  Myr) in the Orion B Molecular Cloud. For these clusters, we are determining the disk fraction as a function of spectral type and inferred mass. Since the clusters are very young, the disk fractions should represent the initial frequency distribution of disks in these clusters. We are using FLAMINGOS NIR spectroscopy (Levine PhD UF 2006) and photometry to estimate the masses of the stars and FLAMINGOS JHK and Spitzer photometry to estimate the disk frequency of our spectroscopic sample. Our work should provide valuable insights toward understanding the formation and early evolution of circumstellar disks around low mass stars in embedded clusters.

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### 343.02 – PRISM Polarimetry of Massive Stars

We present the early results from our long-term, multi-epoch filter polarization survey of massive stars in and around young Galactic clusters. These BVRI polarization data were obtained using the PRISM instrument mounted on the 1.8m Perkins Telescope at Lowell Observatory. We first detail the creation of our new semi-automated polarization data reduction pipeline that we developed to process these data. Next, we present our analysis of the instrumental polarization properties of the PRISM instrument, via observations of polarized and unpolarized standard stars. Finally, we present early results on the total and intrinsic polarization behavior of several isolated, previously suggested classical Be stars, and discuss these results in the context of the larger project.

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### 343.03 – Time Monitoring Variability of Classical Be Stars

Classical Be stars are B type stars that show hydrogen emission in their spectra, and exhibit variability across the electromagnetic spectrum, including visible and infrared wavelengths. While spectroscopic variability in the optical range has been studied previously, the near infrared region has not been investigated as thoroughly. We present multiple epochs of near infrared spectroscopy for a sample of eight Classical Be stars. Our observations were taken using the FSPEC instrument on the 90-inch Bok reflector telescope at Kitt Peak during the months of May and June of 2010 and 2011. We targeted the Brackett Gamma emission line of hydrogen with a resolution of  $\approx 3500$ . Using Python we developed tools to analyze the reduced and calibrated spectra, as well as compute equivalent widths. Time-series spectra indicate that a majority of the systems exhibit spectroscopic variability. By monitoring the strengths of the emission feature over time we aim to constrain the physical properties of these systems.

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### 343.04 – Searching for Disk Truncation in the Be Star Gamma Cassiopeiae

Gamma Cassiopeiae is a rapidly rotating Be star that has a circumstellar disk. In addition there is evidence that Gamma Cas has a binary companion which may influence its disk. In this work, we search for evidence that the binary companion truncates the disk. To do so, we construct the full spectral energy distribution (SED) of Gamma Cas using radio data from the Karl G. Jansky Very Large Array at 0.6, 1.3, 3.5, and 6 cm, along with multi-wavelength archival data. The archival data include UV, optical, and IR flux calibrated spectra, optical UBVR photometry, IR photometry, and millimeter to centimeter radio flux measurements. To model this SED, we employ the 3-D NLTE Monte Carlo radiative transfer code HDUST to calculate the emergent continuum flux for a rapidly rotating (oblate), gravity darkened Be star with a steady state viscous decretion disk. The stellar parameters are constrained using the UV portion of the spectrum. The disk inclination is determined from CHARA K-band interferometry, while the IR data determine the disk mass-loss rate. Finally, since the radio flux is determined by the disk density at large radii, the possibility of disk truncation is best probed by long wavelength data. We find that the steady state HDUST model overestimates the flux in the millimeter and submillimeter range by a factor of 5, suggesting that the disk is truncated.

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### 343.05 – ALMA Early Science Observations of Outbursting Stellar Systems: Disk Masses for FU Ori and EXor Objects

It is believed that low-mass stars build a significant fraction of their total mass during short outbursts of enhanced accretion (up to  $10E-4 M_{\text{SOLAR}}/\text{yr}$ ). The most dramatic episodic accretion events known in Young Stellar Objects (YSOs) are FU Ori and EXor outbursts. FU Ori objects are characterized by a sudden brightening of 5 magnitudes or more within one year and remain bright for decades. EXor objects have lower amplitude outbursts on shorter timescales (months to years). Here we present an ALMA 230 GHz (1.3 mm / band-6) mini-survey of 8 outbursting sources (three FU Ori and five EXor objects) in Orion with 1" (450 AU) resolution. We present

continuum, 12CO, 13CO, and C18O line images and derive dust and (when possible) gas disk masses. The disk masses derived from the line observations are systematically lower (by factors of 3-5) than those calculated from the continuum and adopting the standard gas-to-dust ratio of 100, which agrees with results on T Tauri disks in Taurus. After beam deconvolution, we find that the disks are remarkably compact ( $r = 70-150$  AU). The 1.3 mm fluxes of the outbursting sources span over three orders of magnitude, but the FU Ori objects are significantly brighter than the EXor objects. The inferred disk masses for the brightest objects are  $> 0.1 M_{\text{SOLAR}}$ , rendering gravitational instability a likely outburst mechanism. On the other hand, the inferred disk masses for the faintest targets are  $\sim 1-5 M_{\text{JUP}}$ , and thus an alternative mechanism must be responsible for their outbursts.

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### 343.06 – Numerical 3D Hydrodynamics Study of Gravitational Instabilities in a Circumbinary Disk

We present a 3D hydrodynamical study of gravitational instabilities (GIs) in a circumbinary protoplanetary disk around a Solar mass star and a brown dwarf companion ( $0.02 M_{\odot}$ ). GIs can play an important, and at times dominant, role in driving the structural evolution of protoplanetary disks. The reported simulations were performed employing CHYMERA, a radiative 3D hydrodynamics code developed by the Indiana University Hydrodynamics Group. The simulations include disk self-gravity and radiative cooling governed by realistic dust opacities. We examine the role of GIs in modulating the thermodynamic state of the disks, and determine the strengths of GI-induced density waves, non-axisymmetric density structures, radial mass transport, and gravitational torques. The principal goal of this study is to determine how the presence of the companion affects the nature and strength of GIs. Results are compared with a parallel simulation of a protoplanetary disk without the presence of the brown dwarf binary companion. We detect no fragmentation in either disk. A persistent vortex forms in the inner region of both disks. The vortex seems to be stabilized by the presence of the binary companion.

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### 343.07 – Constraining magnetic fields morphologies using mid-IR polarization: observations and modeling

Polarization arises from aligned dust grains in magnetic fields, and thus the direction of polarization can trace the direction of **B** fields. We present the mid-IR imaging and spectropolarimetry observations made with the GTC's *CanariCam* of the Herbig Ae star WL 16. WL 16 is embedded in/behind the  $\rho$  Ophiuchus molecular cloud with visual extinction of  $\sim 31$  mag. It exhibits large and extended ( $\sim 900$  AU) emission, which is believed to come from the emission of PAHs and very small dust grains. Uniform polarization vectors from imaging polarization and the absorption-dominated polarization profile from spectropolarimetry consistently indicate a uniform foreground magnetic field oriented at about 30 deg from the North. We also model the predicted polarization patterns expected to arise from different magnetic field morphologies, which can be distinguished by high-resolution observations. As an example, we present the mid-IR polarization modeling of AB Aur, a well-studied Herbig Ae star. We incorporate polarization from dichroic absorption, emission and scattering in the modeling. The observed polarization structures are well reproduced by two components: emissive polarization arising from a poloidal **B** field and scattering polarization by  $0.01-1 \mu\text{m}$  dust grains.

**Author(s):** Han Zhang<sup>2</sup>, Dan Li<sup>2</sup>, Eric Pantin<sup>1</sup>, Charles M. Telesco<sup>2</sup>

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### 343.08 – Modeling Observable Signatures of Protoplanetary Disks: Combining Hydrodynamic Simulations with Radiative Transfer Methods

New high resolution images of protoplanetary disks from facilities like ALMA are revealing complex disk structures, possibly due to interactions between the disk and newly forming planets within that disk. Analysis of what the structures in these images reveal about the evolution of protoplanetary disks requires detailed models of disk/planet interaction combined with radiative transfer techniques to calculate observable signatures of these disks. We model this disk-planet interaction as hydrodynamic and magnetohydrodynamic numerical simulations using the PLUTO code. We then apply a modified version of the radiative transfer code PaRTY (Parallel Radiative Transfer in YSOs) to these HD/MHD simulations to calculate the observed intensity of these disks via thermal emission and scattering from the host star. Using a wide variety of stellar properties, disk structures, and planet masses, our goal is to produce a robust set of models that will be essential in analyzing the images taken with this new generation of telescopes.

**Author(s):** Dylan Kloster<sup>1</sup>, Hannah Jang-Condell<sup>1</sup>, David Kasper<sup>1</sup>

**Institution(s):** 1. *University of Wyoming*

### 343.09 – Radiative Transfer Modeling in Protoplanetary Disks

Young Stellar Objects (YSOs) are rich astronomical research environments. Planets form in circumstellar disks of gas and dust around YSOs. With ever increasing capabilities of the observational instruments designed to look at these proto-planetary disks, most notably GPI, SPHERE, and ALMA, more accurate interfaces must be made to connect modeling of the disks with observation. PaRTY (Parallel Radiative Transfer in YSOs) is a code developed previously to model the observable density and temperature structure of such a disk by self-consistently calculating the structure of the disk based on radiative transfer physics. We present upgrades we are implementing to the PaRTY code to improve its accuracy and flexibility. These upgrades include: creating a two-sided disk model, implementing a spherical coordinate system, and implementing wavelength-dependent opacities. These upgrades will address problems in the PaRTY code of infinite optical thickness, calculation under/over-resolution, and wavelength-independent photon penetration depths, respectively. The upgraded code will be used to better model disk perturbations resulting from planet formation.

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### 343.10 – Decoding Debris System Substructures: Imprints of Planets/Planetesimals and Signatures of Extrinsic Influences on Material in Ring-Like Disks

How do circumstellar (CS) disks evolve and form planetary systems? Is our solar system's two-component debris disk (DD) typical? Are planets implicated by evidence of dynamical stirring in disks? Are DD architectures correlated with stellar mass? To address these highly-compelling questions of fundamental astrophysical import, we obtained deep follow-up HST/STIS coronagraphic imagery of five intermediate-inclination ring-like DDs. By combining data from two coronagraphic apertures we obtain images with unprecedented clarity, sensitivity, and photometric efficacy. We discover a scattered light counterpart to the dust disk previously seen in the mid-IR only in HD 141569 A interior to the 2 rings previously imaged in scattered light. We also place refined optical limits on planets in that system. For HR 4796 A we detect outer nebulosity extending as far as 10 arc seconds from the star, and compare it with other systems with distant dust. We report on early stages of analysis for our other 3 program stars.

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### 343.11 – Millimeter Resolved Observations of the HD 181327 Debris Disk

The presence of debris disks around young main sequence stars hints at the structure of hidden planetary systems, with any deviations from axisymmetry pointing toward interactions among planetesimals. HD 181327 is a ~24 Myr old F5.5 member of the Beta Pic Moving Group that hosts an extremely bright debris disk ( $L_{\text{IR}}/L_{\text{star}} = 0.25\%$ ) of dust continuously generated through the collisional erosion of a circumstellar ring of planetesimals at 90 AU. An HST STIS observation of the HD 181327 disk provided tentative evidence for the recent collisional destruction of a Pluto mass object. Spatially resolved millimeter wavelength observations are crucial to investigate this scenario, characterize the structure of the dust disk, and characterize the gravitationally interacting grains. We present ALMA observations at ~1 arcsec resolution and investigate the azimuthal variations in the HD 181327 debris disk at 1.25 mm.

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### 343.12 – Analyzing the Distribution and Chemical Evolution of Major Nitrogen Carriers within Protoplanetary Disks

Nitrogen is an important component in many of the world's known organic and inorganic compounds, and its presence is crucial for the existence and survival of life as we know it on Earth today. And yet, in comparison to the total amount of nitrogen available, nitrogen exists as a depleted resource throughout the Solar System, with Earth and unearthed meteorites featuring nitrogen levels depleted from 1 to 5 orders of magnitude relative to the Sun. Additionally, comets have been discovered that contain depleted levels of N<sub>2</sub> in comparison to CO, despite the similar binding strengths of both N<sub>2</sub> and CO to ices, with ices functioning as the main component in comets.

Mechanisms that are likely to play a major part in the distribution of nitrogen throughout the Solar System, and other extra-solar systems, are condensation fronts, such as snowlines and snowsurfaces. Here, condensation fronts refer to the locations at which 50% of a given volatile is contained in gaseous form, while the other 50% is contained within grain form. During formation, astronomical bodies will accumulate different chemical compositions, depending upon where they form with respect to the locations of the condensation fronts within the system. In addition, a system's initial chemistry, as well as how that chemistry evolves, will ultimately alter how the volatiles in the system are distributed over time.

Thus, the locations of these condensation fronts, coupled with a protoplanetary disk's initial chemistry and chemical evolution, are mechanisms that affect the eventual distribution and evolution of the disk's volatiles. In this project, we characterize and interpret these mechanisms within disk models. We vary the disk's time dependence and initial chemical conditions, and then analyze the effects of those variations upon the main carriers of nitrogen in both gaseous and grain form. From observed patterns and characteristics of these varied models, we evolve our understanding of curious nitrogen depletions found within the Solar System, of the acquisition of nitrogen by astronomical bodies of the Solar System and other extra-solar systems, and of the chemistry and distribution of nitrogen during planet formation overall.

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### 343.14 – Does Fomalhaut A Have an Asteroid-belt Analog?

Fomalhaut plays an important role in the study of debris disks and small bodies in other planetary systems. The proximity and luminosity of the star make key features of its debris like the water ice-line easily accessible. Here we present ALMA cycle 1, 870  $\mu\text{m}$  (345 GHz) observation targeted at the inner part of the Fomalhaut system with a synthesized beam of  $0.45'' \times 0.37''$  ( $\sim 3$  AU linear resolution at the distance of Fomalhaut) and a rms of 26  $\mu\text{Jy}$  per beam. The high angular resolution and sensitivity of the ALMA data enable us to place strong constraints on the nature of the warm excess revealed by Spitzer and Herschel observations. We detect a point source at the star position with a total flux consistent with thermal emission from the stellar photosphere. No structures that are brighter than  $3\sigma$  are detected in the central 15 AU  $\times$  15 AU region. Modeling the spectral energy distribution using parameters expected for a dust-producing planetesimal belt indicates a radial location in the range  $\sim 8$ –15 AU. This is consistent with the location where ice sublimates in Fomalhaut, i.e., an asteroid-belt analog. We also provide a new interpretation for the emission structure in the inner 10 AU region revealed by interferometric measurements at 2 and 8–13  $\mu\text{m}$  as dust naturally connected to this proposed asteroid belt by Poynting-Robertson drag, dust sublimation, and magnetically trapped nano grains.

**Author(s):** Kate Y.L. Su<sup>4</sup>, George Rieke<sup>4</sup>, Denis Defrere<sup>4</sup>, Kuo-Song Wang<sup>1</sup>, Shih-Ping Lai<sup>3</sup>, David J. Wilner<sup>2</sup>, Rik van Lieshout<sup>5</sup>, Chin-Fei Lee<sup>1</sup>

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### 343.15 – Tracing neutral FeI gas evaporating from exocomets in the beta Pictoris disk

Absorption variability due to the evaporating gas from comet-like bodies on their grazing approach towards a parent star has now been observed in over a dozen A-type stellar systems. Ground based observations of the resultant replenished gas have routinely been performed using high resolution spectroscopy of the CaII-K (3933Å) and NaI (5890Å) circumstellar absorption lines, especially towards the well-known exoplanet bearing Beta Pictoris stellar system.

Here we present a preliminary study of the neutral FeI (3860Å) circumstellar absorption line observed towards Beta Pictoris using data in the ESO Data Archive obtained over the 2003 to 2014 timeframe. This spectral line samples neutral gas with an ionization potential  $< 7.9\text{eV}$  and from a sample of 15 observations we show 5 examples in which high velocity absorption features ( $V_{\text{helio}} > +35 \text{ km s}^{-1}$ ) have, for the first time, been simultaneously detected in both the FeI and CaII line profiles. Such absorption features can be associated with liberated exocomet gas which seems to be preferentially observed at circumstellar disk velocities of  $+35$  to  $+45 \text{ km s}^{-1}$ . Additional absorption features with velocities  $> 100 \text{ km s}^{-1}$  in the FeI line profile have also been observed on two occasions.

Our data supports the recent findings of Kiefer et al (2014) in which at least two families of exocomets exist with distinctly different circumstellar gas disk velocities, both residing within  $\sim 1$  AU from the central star.

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## 344 – Binary Stellar Systems, X-ray Binaries Poster Session

### 344.01 – Characteristics of the Eclipsing Triple System EPIC 202062176

Time series photometry from the Kepler K2 mission has led to the discovery of a number of particularly interesting eclipsing binary systems. One of these is EPIC 202062176, a young, eccentric binary found in the star forming region NGC 2175. Our analysis of the light

curve from K2 Campaign 0 and spectra from the CHIRON spectrograph and CTIO's 1.5m telescope indicates that EPIC 202062176 is actually a triple system composed of a hot B-type star and a distant pair of less massive stars. We determined the pulsation frequency of the hot star with Period04, removed this signal from the light curve, and then modeled the eclipses of the companion binary with the Eclipsing Light Curve (ELC) program. We estimated the effective temperature and flux contribution for the hot star by comparison with TLUSTY model spectra, and we completed a radial velocity analysis of the hot star using cross-correlation methods. We present the characteristics of the triple system, including the stellar parameters of the primary BoV star and the orbital elements of the companion eclipsing binary system.

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**Institution(s):** 1. Georgia State University

### 344.03 – The NP Draconii Multiple Star System

Otero and Dubovsky used the ASAS-3 (Pojmanski 2002), Hipparcos (Perryman et al 1997) and Northern Sky Variability Survey (NSVS; Wozniak et al 2004) databases to determine elements for 80 eclipsing binaries. NP Draconii (NSV 22984) was identified by Otero and Dubovsky (IBVS Number 5557, 2004) as a possible Algol type variable with an ephemeris of HJD Min I = 2448604.780+3.10886E days based on 84 observations over 326 days with about 2 to 4 observations on any one night. We decided to further refine the ephemeris and observe NP Dra in VRI filters, with the goal of determining the elements of the system.

NP Dra is a  $V = 9.0$  system located at J2000 = 17h 35m 16s and +55d 00' 12". We observed NP Dra August 2, 3 and September 15, 16, 17, 18, and 19 2015 UT using the Pisgah Astronomical Research Institute 0.4-m telescope in V, R, and I with 20 second exposure times in each filter. Observations in each filter were repeated about every 3 minutes each night of observing.

From our light curves we determined the period using the Date Compensated Discrete Fourier Transform function (Ferraz-Mello 1981) which is part of the open source code VSTAR (AAVSO). The period derived from the observations is 2.2755 days. Superimposed on this period is another period of 0.6398 days. We will present the V, R, and I light curves, period determination and implication

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**Institution(s):** 1. Brevard College, 2. E. A. Laney High School, 3. Enloe High School, 4. Memorial High School, 5. Pisgah Astronomical Research Inst.

### 344.04 – The first multi-color photometric study of the short-period contact Eclipsing Binary DE Lyn

We observed the contact eclipsing binary of DE Lyn using SARA 0.9 meter telescope at Kitt Peak National Observatory on February 9, 11, and 27, 2015. In this study, we obtained the first full phase coverage BVRI CCD light curves, analyzed the orbital period variation, and extracted the orbital parameters. We calculated the linear and quadratic ephemeris, and thereby found that DE Lyn has a decreasing orbital period rate of  $-5.1(\pm 0.4) \times 10^{-7} \text{ days/year}$ . We believe this decreasing trend is the result of the more massive component (secondary) transferring mass to the less massive component (primary), and we obtained a mass transfer rate of  $\text{dm/dt} = 7.06 \times 10^{-7} M_{\odot}/\text{year}$ . By using the updated Wilson & Devinney program, we found the orbital parameters of DE Lyn, which, in turn, enabled us to calculate the low degree of contact factor as  $f = 9.02(\pm 0.01)\%$ . Its degree of contact will continue to increase and will evolve into an over-contact system.

**Author(s):** Amanda Hashimoto<sup>1</sup>, Liyun Zhang<sup>2</sup>, Xianming L. Han<sup>1</sup>, Lu Hongpeng<sup>2</sup>, Daimei Wang<sup>2</sup>

**Institution(s):** 1. Butler University, 2. Guizhou University

### 344.05 – Observations and Analysis of Eclipsing Binary System SDSS J160036.83+272117.8

We report observations and analysis of the eclipsing binary system SDSS J160036.83+272117.8 (J1600). We obtained spectra sampled at different orbital phases, time-series photometry of the primary and secondary eclipses, and color photometry in and out of the primary and secondary eclipses. J1600 shows broad Balmer absorption consistent with extremely low mass (ELM) white dwarfs (WD), however, the eclipsing parameters have led us to consider other models. If J1600 is a double white dwarf system, this is the seventh discovery of such a system.

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**Institution(s):** 1. *University of Texas at Austin*

### 344.06 – Characterizing a Subset of Kepler Eclipsing Binaries Observed with SDSS/APOGEE

Eclipsing binaries are excellent laboratories for the study of stellar evolution and interactions. By combining high resolution spectra taken by the Sloan Digital Sky Survey (SDSS) APO Galactic Evolution Experiment (APOGEE) and the high-precision photometry taken by the Kepler Telescope, close binary stars may be well characterized. We examine a subset of eclipsing binaries listed in the Villanova Kepler Eclipsing Binary Catalog by cross-correlating with the Apogee APOKASC catalog. We found that infrared color magnitude and color-color diagrams, especially the H-K vs J-K diagram, allowed for a relatively clean separation of giants and dwarf stars. Presumably, dominated by the primary star in these eclipsing binaries. A catalog of well characterized eclipsing binaries is presented. In addition, a number of interesting binaries have been identified and progress towards their characterization is reported. This program is supported by SDSS/FAST grant from the Sloan Foundation.

**Author(s):** Jonathan Anselmo Delgado-Naegele<sup>1</sup>, Joni Clark<sup>1</sup>, James Lindsey Vesper<sup>1</sup>, Jason Jackiewicz<sup>1</sup>, Paul A. Mason<sup>1</sup>

**Institution(s):** 1. *New Mexico State University*

### 344.07 – An atlas of long-term AAVSO light curves of symbiotic stars

This study was conducted to provide an updated collection of light curves for symbiotic binary star systems. These are long-term light curves, spanning years to decades. The purpose for cataloguing these existing data, collected from the American Association of Variable Star Observers (AAVSO), is to stimulate further research and help classify symbiotic stars as: periodic, irregular, stable, or unstable. We also aim to identify physical sources of variability, such as pulsations of component stars, nuclear-powered nova eruptions, accretion-powered thermal instabilities, or other sources. We present an atlas of plots of light curves of 47 symbiotic star systems, in either the V- or visual band. By creating this atlas of nearly continuous and current light curves, side-by-side visual comparison makes classification much easier.

**Author(s):** Fred Ringwald<sup>1</sup>, Lorin G. Zozaya<sup>1</sup>

**Institution(s):** 1. *California State University, Fresno*

### 344.08 – A Characterization of 9,851 Contact Binaries in the CRTS Variable Sources Catalog

We have constructed a sample of over 9,000 contact binaries (W UMa systems) using the Catalina Real-Time Transient Survey (or CRTS) Variables Sources Catalog. By measuring period change rates, brightness change rates, light curve statistics, temperatures, absolute magnitudes, and distances for this large sample, we aim to improve the understanding of the evolution and dynamics of contact binaries. We show that binaries with convective outer envelopes have a different distribution of amplitudes, O'Connell effect magnitudes, and magnitude differences between eclipse minima than binaries that are radiative to the photosphere. We find that more than 2000 binaries exhibit a change in mean brightness over the 8 year timespan of CRTS measurements with at least 3-sigma significance. We note that 23.7% of binaries with convective outer envelopes exhibited a significant change in brightness, while only 5.8% of radiative binaries exhibited a significant change in brightness. In some binaries, we discover periodic trends in the mean brightness over the 8 year CRTS timespan, which may be related to the stellar

magnetic activity cycle of the primary. We also find 871 binaries that exhibit period changes at 3-sigma significance. In this work, we demonstrate how all-sky transient surveys can be used to study contact binary systems in a statistical manner, paving the way for work with future surveys.

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**Institution(s):** 1. *California Institute of Technology*

### 344.09 – Pseudosynchronization of Heartbeat Stars

A type of eccentric binary star that undergoes extreme dynamic tidal forces, known as Heartbeat stars, were discovered by the Kepler Mission. As the two stars pass through periastron, the tidal distortion causes unique brightness variations. Short period, eccentric binary stars, like these, are theorized to pseudosynchronize, or reach a rotational frequency that matches the weighted average orbital angular velocity of the system. This pseudosynchronous rate, as predicted by Hut (1981), depends on the binary's orbital period and eccentricity. We tested whether sixteen heartbeat stars have pseudosynchronized. We measure the rotation rate from obvious spot signatures in the light curve. We measure the eccentricity by fitting the light curve using PHOEBE and are actively carrying out a radial velocity monitoring program with Keck/HIRES in order to improve these orbital parameters. Our initial results show that while most heartbeat stars appear to have pseudosynchronized we find stars with rotation frequencies both longer and shorter than this rate. We thank the SETI Institute REU program, the NSF, and the Kepler Guest Observer Program for making this work possible.

**Author(s):** Mara Zimmerman<sup>1</sup>, Susan E. Thompson<sup>4</sup>, Kelly Hambleton<sup>6</sup>, Jim Fuller<sup>2</sup>, Avi Shporer<sup>3</sup>, Howard T. Isaacson<sup>5</sup>, Andrew Howard<sup>7</sup>, Donald Kurtz<sup>6</sup>

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### 344.10 – Multiyear measurements of Position Angle and Separation of selected binary stars from the Washington Double Star Catalog

We present here the multiyear data sets on separation and position angle of binary stars obtained at the NURO telescope, located east of Flagstaff Arizona at an elevation of 7200 feet. The data was analyzed at the Humacao University Observatory of the University of Puerto Rico and will be submitted for publication at the Journal of Double Star Observations. We describe the methodology for the analysis of the images we obtained.

**Author(s):** Rafael J. Muller<sup>1</sup>, Juan C Cersosimo<sup>1</sup>, Andy J Lopez<sup>1</sup>, Nelson Vergara<sup>1</sup>, Brian Torres<sup>1</sup>, Lizyan Mendoza<sup>1</sup>, Deliris Ortiz<sup>1</sup>, Yashira Del Valle<sup>1</sup>, Gabriela Espinosa<sup>1</sup>, Marjory Reyes<sup>1</sup>

**Institution(s):** 1. *Univ. of Puerto Rico, Humacao*

### 344.11 – Simplified Simulation of Mass Transfer in Double White Dwarf Systems

The behavior both stable and unstable mass transfer in semi-detached double white dwarfs triggers a cornucopia of astrophysical phenomena including Type Ia supernovae and AM CVn stars. Current 3D hydrodynamic simulations of the evolution these systems following the mass transfer, binary orbital parameters, and the self-consistent gravitational field over several tens of orbital periods have produced a wealth of data. However, these simulations can take weeks to months in high-performance computing platforms to execute. To help with the interpretation of results of such large scale simulations, and to enable a quick exploration of binary parameter space, we have developed a Mathematica code that integrates forward in time a system of 5 ODEs describing the orbit-averaged evolution of the binary separation as well as the radius, mass, and spin angular momentum of both components of the binary. By adjusting a few parameters describing the mass transfer as a function of the Roche-lobe overflow and the strength of the tidal coupling between the orbit and component spins we are able to obtain approximate fits to previously run hydrodynamic simulations.

This simplified simulation is able to run simulations similar to the hydrodynamic versions in a matter of seconds on a dual-core PC or Mac computer.

**Author(s):** Sara Vannah<sup>2</sup>, Juhan Frank<sup>1</sup>

**Institution(s):** 1. Louisiana State University, 2. Wellesley College

### 344.12 – New Long-Period Hot Subdwarf Binaries from the Hobby-Eberly Telescope

Binary population synthesis (BPS) models are able to reproduce the observed population of short-period hot subdwarf binaries with white dwarf and M dwarf companions. However, there is still a relative dearth of information regarding hot subdwarfs with F/G/K-type main sequence companions. We have monitored the radial velocities of 15 such systems from 2005-2013 using the Medium and High Resolution Spectrographs on the Hobby-Eberly Telescope. A previous analysis of six of these targets revealed long orbital periods, in excess of a year, and non-circular orbits, both of which present a challenge to BPS models. Here we present orbital solutions for additional sdB+F/G/K binaries and discuss the implications of our findings.

**Author(s):** Thomas Boudreaux<sup>1</sup>, Brad Barlow<sup>1</sup>, Richard A. Wade<sup>2</sup>

**Institution(s):** 1. High Point University, 2. Pennsylvania State University

### 344.13 – Eclipsing Binary B-Star Mass Determinations

B-stars in binary pairs provide a laboratory for key astrophysical measurements of massive stars, including key insights for the formation of compact objects (neutron stars and black holes). In their paper, Martayan et al (2004) find 23 Be binary star pairs in NGC2004 in the Large Magellanic Cloud, five of which are both eclipsing and spectroscopic binaries with archival data from VLT-Giraffe and photometric data from MACHO. By using the Wilson eclipsing binary code (e.g., Wilson, 1971), we can determine preliminary stellar masses of the binary components. We present the first results from this analysis. This study also serves as proof-of-concept for future observations with the Photonic Synthesis Telescope Array (Eikenberry et al., in prep) that we are currently building for low-cost, precision spectroscopic observations. With higher resolution and dedicated time for observations, we can follow-up observations of these Be stars as well as Be/X-ray binaries, for improved mass measurements of neutron stars and black holes and better constraints on their origin/formation.

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**Institution(s):** 1. University of Florida

### 344.14 – Investigating the Wolf-Rayet + Black Hole Binary NGC 300 X-1 With Chandra and Hubble

We observed the Wolf-Rayet + black hole binary NGC 300 X-1 twice with the *Chandra X-ray Observatory* (~65 ksec each). In the first observation, we observed a secular increase in brightness of the X-ray source, consistent with an eclipse egress. The *Chandra* data were also used to construct a spectral model of the black hole that could help us better understand how X-rays are being produced in the binary. We observe an X-ray energy dependence on the orbital phase, consistent with the black hole moving through the dense stellar wind of the donor star. Prior to our study, NGC 300 X-1 had only been observed by ground-based telescopes and these images of the system made it difficult to separate the optical source from other nearby stars. We obtained *Hubble* imaging of NGC 300 X-1 for the first time, and found a bright AGB star within the X-ray error circle, in addition to the Wolf-Rayet star. We cannot rule out the possibility that the AGB star is the companion. We have compared the X-ray light curve with the He II  $\lambda$  4648 emission line radial velocity from the literature to the X-ray light curve, and found that the He II emission line likely originates from the black hole accretion disk or from a focused wind from the donor, and not the donor star itself. These observations demonstrate that the mass of the black hole -- previously estimated at  $\sim 15 M_{\odot}$  -- may not be accurate.

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**Institution(s):** 1. University of Massachusetts Lowell, 2. University of Washington

### 344.15 – NuSTAR observations of M31: globular cluster candidates found to be Z sources

We present the results of Swift + NuSTAR observations of 4 bright globular cluster sources in M31. Three of these had previously been suggested to be black holes on the basis of their spectra. We show that all are well fit by models indicative of Z source natures for the sources. We also discuss some reasons why the long term light curves of these objects indicate that they are more likely to be neutron stars, and discuss the discrepancy between the empirical understanding of persistent sources and theoretical predictions.

**Author(s):** Thomas J. Maccarone<sup>4</sup>, Mihoko Yukita<sup>2</sup>, Ann E. Hornschemeier<sup>2</sup>, Bret Lehmer<sup>5</sup>, Vallia Antoniou<sup>1</sup>, Andrew Ptak<sup>2</sup>, Daniel R. Wik<sup>2</sup>, Andreas Zezas<sup>6</sup>, Patricia T. Boyd<sup>2</sup>, Jamie A. Kennea<sup>3</sup>, Kim Page<sup>7</sup>, Michael Eracleous<sup>3</sup>, Benjamin F. Williams<sup>8</sup>

**Institution(s):** 1. Harvard-Smithsonian, 2. NASA Goddard, 3. Penn State, 4. Texas Tech University, 5. University of Arkansas, 6. University of Crete, 7. University of Leicester, 8. University of Washington

**Contributing team(s):** NuSTAR mission team

### 344.16 – NuSTAR and Swift observations of the black hole binary GS 1354-64

We report on NuSTAR and Swift observations of the black hole binary GRS 1354-64 during its 2015 hard state outburst. Thermal continuum emission is not detected from the accretion disk. However, disk reflection is prominent in the sensitive NuSTAR spectra, and it is utilized to constrain the inner extent of the cool accretion disk, and to set a limit on the spin of this black hole. The Swift data are used to examine how much UV flux is direct, and how much is reprocessed, by examining UV versus X-ray flux trends over the outburst. Overall, modern observatories provide a much improved view of this well-known black hole X-ray binary.

**Author(s):** Adham M El-Batal<sup>1</sup>, Jon M. Miller<sup>1</sup>

**Institution(s):** 1. University of Michigan

### 344.17 – Calibration of H-alpha/H-beta Indexes for Emission Line Objects

In Joner and Hintz (2015) they report on a standard star system for calibration of H-alpha and H-beta observations. This work was based on data obtained with the Dominion Astrophysical Observatory 1.2-m telescope. As part of the data acquisition for that project, a large number of emission line objects were also observed. We will report on the preliminary results for the emission line data set. This will include a comparison of equivalent width measurements of each line with the matching index. We will also examine the relation between the absorbing line objects previously published and the emission line objects, along with a discussion of the transition point. Object types included are Be stars, high mass x-ray binaries, one low mass x-ray binary, Herbig Ae/Be stars, pre-main sequence stars, T Tauri stars, young stellar objects, and one BY Draconis star. Some of these objects come from Cygnus OB-2, NGC 659, NGC 663, NGC 869 and NGC 884.

**Author(s):** Eric G. Hintz<sup>1</sup>, Michael D. Joner<sup>1</sup>

**Institution(s):** 1. Brigham Young Univ.

### 344.18 – The Reflection Effect in Eclipsing Binaries

Using a database of eclipsing binaries (EBs) from the Kepler space telescope, we identified star systems which displayed characteristics corresponding to the reflection effect. The reflection effect is the brightening of one star due to irradiation by its companion. We found 40 candidates amongst the nearly 2,800 EBs in the database. We analyze these candidates and derive parameters and properties of each system using the PHOEBE modeling program. We examine each model fit using probabilistic inference in order to statistically evaluate the best fit model. The model critically tests the reflection effect and provides physical constraints on the principal parameters.

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**Institution(s):** 1. Villanova University

### 344.19 – Modeling and Determining the Uncertainties of M-type Stars in Occulting Stellar Light Curves

The majority of the stars that make up the Milky Way galaxy are M-type stars and, since they are faint because of their low mass, luminosity, and temperature, the only way to measure their masses and radii is by analyzing their light curves in a binary system. An issue in the theory of these low-mass stars is the discrepancy between their predicted and observed radii. M-type stars are most notable because of their flare rate and x-ray activity, which might be related with the noted discrepancy. Modeling the light curves of eclipsing binary stars with M-type companions is how their radii and other fundamental parameters can be determined. Of the data that *Kepler* has accumulated on eclipsing binary stars, we chose thirty-six star systems as possible candidates that contain at least one M-type star. We model the light curves of these systems using PHOEBE (Prša & Zwitter, 2005), and determine the uncertainties in the parameters by using Markov chain Monte Carlo (MCMC) sampling.

**Author(s):** Griffin Werner<sup>1</sup>  
**Institution(s):** 1. Villanova University

### 344.20 – To $v_\infty$ and Beyond! The He I absorption variability across the 2014.6 periastron passage of the supermassive binary $\eta$ Carinae

We monitored the massive binary star  $\eta$  Carinae with the CTIO/SMARTS 1.5 m telescope and CHIRON spectrograph from the previous apastron passage of the system through the recent 2014.6 periastron passage. Our monitoring resulted in a large, homogeneous data set with an unprecedented time-sampling, spectral resolving power, and signal-to-noise. We investigated temporal variability previously unexplored in the system and found a kinematic structure in the P Cygni absorption troughs of neutral helium (He I) wind lines. The features observed occurred prior to periastron passage and are seen as we look through the trailing arm of the wind-wind collision zone. We show that the bulk of the variability is repeatable across the last five periastron passages, and that the absorption likely occurs in the inner 230 AU of the system. In addition, we found a secondary, high-velocity ( $\sim 800$  km/s) absorption component superimposed on the P Cygni absorption troughs that has been previously unobserved in these lines, but which bears resemblance to the observations of the He I  $\lambda 10830\text{\AA}$  feature observed across previous cycles. Through a comparison with smoothed particle hydrodynamics simulations, we show that the observed variations are likely caused by instabilities in the wind-wind collision region in our line of sight, coupled with stochastic variability related to clumping in the winds. We speculate that the stochastic high-velocity absorption feature we observed before periastron was caused by a small 'blob' of dense material breaking free from the unstable WWC region and crossing our line of sight as it was accelerated by the much faster (3000 km/s) impinging wind from the hotter secondary star.

**Author(s):** Thomas Madura<sup>7</sup>, Noel Richardson<sup>10</sup>, Lucas St-Jean<sup>8</sup>, Anthony F. J. Moffat<sup>8</sup>, Theodore R. Gull<sup>3</sup>, Augusto Damineli<sup>2</sup>, Mairan Teodoro<sup>11</sup>, Michael F. Corcoran<sup>7</sup>, Frederick M. Walter<sup>6</sup>, Nicola Clementel<sup>5</sup>, Jose H Groh<sup>1</sup>, Kenji Hamaguchi<sup>3</sup>, Desmond John Hillier<sup>9</sup>, Christopher Michael Post Russell<sup>4</sup>  
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### 344.21 – Mapping the latitude dependence of the primary stellar wind of eta Carinae using the spectrum reflected on the Homunculus nebula

The binary star Eta Carinae underwent a massive eruption in the 1840s, resulting in a huge nebula of ejected material, called the Homunculus. Despite preventing us from the direct view from the central source, the Homunculus acts like a mirror, allowing us to see the spectrum of the central binary system from different stellar

latitudes. Therefore, by mapping the spectrum along the nebula we are actually probing the dependence of the spectrum with stellar latitude. Our project focuses on the P Cyg absorption component of H lines mostly in the optical and near-infrared wavelengths. In order to investigate the structure of the primary stellar wind. A full spectral mapping of the entire nebula was constructed by combining multiple dithered long slit observations using the ESO/X-Shooter high-resolution spectrograph. Such mapping allowed us to assemble a data cube containing the spectrum of each position along the nebula. Preliminary analysis confirms that the primary wind indeed has a deeper absorption component at high stellar latitudes (polar region). Also, contrary to our expectations, our analysis indicates that the polar region does not seem entirely radially symmetric in terms of density, which invites further investigation into the source of these discrepancies.

**Author(s):** Rachel Odessey<sup>1</sup>  
**Institution(s):** 1. Scripps College

### 344.22 – The Production of HMXBs in Star Clusters

High-mass X-ray binaries (HMXBs), where a black hole or neutron star accretes material from a massive donor star, often dominate the high-energy output from nearby galaxies. Most massive stars, the progenitors of HMXBs, form in star clusters, and therefore it follows that there should be a link between the production of HMXBs and clusters. We use a catalog of HMXBs based on Chandra X-ray Observatory observations and a catalog of star clusters based on Hubble Space Telescope observations to study the production of HMXBs in star clusters in the Antennae, the closest pair of actively merging galaxies. We find the highest number of HMXBs associated with very young,  $\sim 3$ -6 Myr clusters, but also find clear evidence that they form in older stellar systems. We test whether HMXBs are more likely to form in the most massive or most dense clusters (at any age), or if their production is simply governed by statistics, i.e. whether more massive clusters produce a HMXB at the same rate as a grouping of less massive clusters that have the same total mass.

**Author(s):** Paula Johns<sup>2</sup>, Rupali Chandar<sup>2</sup>, Blagoy Rangelov<sup>1</sup>  
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## 345 – Formation and Evolution of Stars and Stellar Systems Poster Session

### 345.01 – The Pan-STARRS 1 Parallax and Proper Motion Catalog

The Pan-STARRS 1 3-Pi survey produced a catalog of more than three billion objects north of  $-30^\circ$  declination with astrometric precision down to 10 milliarcseconds per observation. This excellent calibration and the multiple observations of each point of the sky over a five year internal baseline allow proper motions as small as 1-2 mas/year to be measured. The observational schedule has been designed to optimize parallax measurements for red objects. The final parallax and proper motion catalog will enable searches for and classification of stars in the local solar neighborhood, with proper motion searches extending to 200 parsecs.

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**Institution(s):** 1. Institute for Astronomy  
**Contributing team(s):** The Pan-STARRS Science Consortium

### 345.02 – A uniform catalog of candidate IR-excess and optically variable Young Stellar Objects (YSOs) across the full Orion complex: Aiding target selection for the APOGEE-2 Young Cluster Program

Precise measurements of the intrinsic (e.g.,  $T_{\text{eff}}$  &  $\log g$ ) and dynamical (e.g., radial velocity &  $v \sin i$ ) properties of young stars provide important constraints for models of star formation and early stellar evolution. The APOGEE-2 YSO Young Cluster Program aims to measure the dynamics and star formation history uniformly across the full extent of the Orion star forming complex, based on thousands of high-resolution H-band spectra that APOGEE-2 will obtain of candidate Orion members. We utilize data from wide-field

photometric surveys to select candidate YSOs throughout Orion via two complementary techniques. We follow the Koenig et al. (2014) criteria by using WISE+2MASS data to identify YSOs with IR excesses due to warm circumstellar dust; we also use multi-epoch optical PanSTARRS photometry to identify variable YSOs both with and without circumstellar disks (or circumstellar materials). The IR excess technique identifies 1729 candidates brighter than  $H=12.8$  mag, a limit selected to ensure a minimum  $S/N > 50$  for a typical 3-hour APOGEE exposure. selecting sources which display significant variability in at least 3 PanSTARRS bands similarly produces a preliminary sample of 1500 candidates with  $H < 12.8$  mag. In total, we identify nearly 2700 YSO candidates, 450 of which were identified via both selection methods. The resulting catalog exhibits clear spatial over-densities associated with known sub-regions of Orion such as the ONC, sigma Ori and L1641, and provides a uniform catalog for spectroscopic targeting over Orion's full 250+ sq. degree footprint.

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### 345.03 – Where the old neighbors go: kinematics of 150,000 nearby metal-poor stars in the SUPERBLINK proper motion survey.

A search of the SUPEBLINK proper motion catalog, now covering 75% of the sky, identifies 150,000 low-mass, metal-poor stars, with distances  $d < 500$  pc and transverse motions  $v > 90$  km/s. An analysis of transverse motions across the sky reveals that 94% of such stars have prograde orbits, with relatively low components of motion across the plane, consistent with the Galactic thick disk population. The remaining 6% stars have retrograde orbits, and appear to be drawn from a Galactic spheroidal population, with no apparent flattening. The retrograde stars also appear to be significantly more metal-poor. We find that both populations have significant scatter in their U component of motion, which suggest relatively eccentric Galactic orbits. Stars of the spheroidal population notably, appear to have many stars with largely radial orbits.

**Author(s):** Sebastien Lepine<sup>1</sup>  
**Institution(s):** 1. Georgia State University

### 345.04 – WTF- and A- Stars: Spectroscopic Analysis of Kepler Light Curves

Analysis of Kepler data in 2012 found that in a sample of about 2000 A- and F- stars, 1% of them seemed to exhibit white light flares. However, such stars are not thought to have the convective envelopes needed to produce the magnetic dynamos that yield flares. We use the same Kepler data but examine the flaring stars more comprehensively by analyzing the pixel data in order to predict whether this flare-like behavior may be caused by smaller, less luminous M dwarfs exhibiting genuine flares in the line of sight of the A- and F-stars. The implications of finding verifiable flare activity in a subset of these stars would be enough to incite further investigation of the physical processes that allow this to take place. Yet, if that were not the case, this project would further be able to demonstrate the steps necessary to correct for false-positives in finding flares in A- and F- stars.

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**Institution(s):** 1. STScI

### 345.05 – Help, my star is on fire – Carbon burning

### flames in SAGB stars.

We explore the detailed and broad properties of carbon burning in Super Asymptotic Giant Branch (SAGB) stars with a comprehensive grid of MESA models. The location of first carbon ignition, quenching location of the carbon burning flames and flashes, angular frequency of the carbon core, and carbon core mass are studied as a function of the ZAMS mass, initial rotation rate, and mixing parameters such as convective overshoot, semiconvection, thermohaline and angular momentum transport. We find the properties of carbon burning in SAGB models are not a strong function of the initial rotation profile, but are a sensitive function of the strength of overshoot mixing. Increasing the amount of overshoot decreases the initial mass needed for off center and center carbon ignitions. Carbon burning flames show a range of morphologies, which vary as a function of initial mass and convective overshoot strength, with either a series of flashes or a flame which propagates inwards towards the core. We find that only systems with overshoot values  $\geq 0.01$  and zero age main sequence (ZAMS) masses  $\approx 7.2$ -8.0  $M_{\odot}$  is carbon burning quenched at a significant distance from the center. These results have implications for the formation rate of hybrid C-O-Ne WDs, postulated as supernova Type 1a progenitors.

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**Institution(s):** 1. Arizona State University

### 345.06 – Chlorine Abundances in Cool Stars

We measured the chlorine abundance in 15 evolved giants and one M dwarf in the solar neighborhood. High resolution L-Band spectra were obtained using the Phoenix infrared spectrometer on the Kitt Peak National Observatory Mayall 4m telescope. Chlorine is thought to be primarily produced in explosive oxygen burning but stellar chlorine abundances are virtually unknown. We measured the <sup>35</sup>Cl abundance from an HCl feature at 3.69 microns.

Analysis of our full sample of giants and dwarfs found the HCl feature is only present in stars with temperatures below 3900K. The [Cl/Fe] abundances in stars with solar metallicity matches the abundance seen in the Sun. Measurements of the [Cl/O] ratio in our sample stars is also consistent with [Cl/O] ratios found in planetary nebulae and H II regions. Our measured abundances are all within one standard deviation, 0.3 dex on average, and are consistent with current chemical evolution models for chlorine in the solar neighborhood. A slight decrease in [Cl/Fe] abundance as [Fe/H] increases may be present and must be verified with future Cl abundances measurements in lower metallicity stars. The average [Cl/Fe] ratio in our sample is -0.07 with a standard deviation of 0.13. An upper limit to the <sup>37</sup>Cl isotope abundance in the star RZ Ari, measured from a feature at 3.70 microns, puts a lower limit of 2.5 on the Cl <sup>35</sup>/<sup>37</sup> isotope ratio for this star. This ratio is consistent with the solar system value of <sup>35</sup>/<sup>37</sup>=3.11.

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### 345.07 – La and Eu Abundances in Metal-poor Halo Stars

Elements with atomic number greater than  $Z=26$  (the Iron Peak) cannot be formed through fusion in a star's core; the majority of these elements are produced through one of two neutron-capture processes. Early in the history of the Galaxy, the rapid neutron-capture process (r-process) is believed to be responsible for the production of elements  $Z=56$  and beyond. These elements require at least one generation of stars to have completed their life cycle in order to be synthesized. Therefore, if we observe the heavy metal abundances in what are called Population II stars (metal-poor stars), then we can begin to make inferences about the chemistry of the earliest stars in the Galaxy. To contribute to this picture of the early universe, the Lanthanum and Europium abundances of low-metallicity stars will be measured and trends in these abundances based on comparisons to existing related literature will be sought.

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**Institution(s):** 1. University of Central Arkansas

### 345.08 – Fe-Group Elements in the Metal-Poor Star HD 84937: Abundances and their Implications

We have derived accurate relative abundances of the Fe-group elements Sc through Zn in the very metal-poor main-sequence turnoff star HD 84937. For this study we analyzed high resolution, high signal-to-noise HST/STIS and VLT/UVES spectra over a total wavelength range 2300-7000 Å. We employed only recent or newly-applied reliable laboratory transition data for all species. Abundances from more than 600 lines of non-Fe species were combined with about 550 Fe lines in HD 84937 to yield abundance ratios of high precision. From parallel analyses of solar photospheric spectra we also derived new solar abundances of these elements. This in turn yielded internally-consistent relative HD 84937 abundances with respect to the Sun. For seven of the ten Fe-group elements the HD 84937 abundances were from both neutral and ionized transitions. In all of these cases the neutral and ionized species yield the same abundances within the measurement uncertainties. Therefore standard Saha ionization balance appears to hold in the HD 84937 atmosphere. We derived metallicity  $[Fe/H] = -2.32$  with sample standard deviation of 0.06. Solid evidence is seen for departures from the solar abundance mix in HD 84937, for example  $[Co/Fe] = +0.14$ ,  $[Cu/Fe] = -0.83$ , and  $<[Sc,Ti,V/Fe]> = +0.31$ . Combining our Sc, Ti, and V abundances for this star with those from large-sample spectroscopic surveys suggests that these elements are positively correlated in stars with  $[Fe/H] < -2$ . HD 84937 is unusually enriched in Sc, Ti, and V. Our analysis strongly suggests that different types of supernovae with a large scatter of explosion energies and asymmetries contributed to the creation of the Fe-group elements early in the Galaxy's history.

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**Author(s):** Chris Sneden<sup>3</sup>, John J. Cowan<sup>5</sup>, Chiaki Kobayashi<sup>4</sup>, Marco Pignatari<sup>1</sup>, James E. Lawler<sup>6</sup>, Elizabeth Den Hartog<sup>6</sup>, Michael P. Wood<sup>2</sup>

**Institution(s):** 1. Hungarian Academy of Sciences, 2. NIST, 3. Univ. of Texas, 4. University of Hertfordshire, 5. University of Oklahoma, 6. University of Wisconsin-Madison

### 345.09 – Carbon and Oxygen Isotopic Ratios for Miras

We have measured vibration-rotation first and second overtone  $^{12}C^{16}O$ ,  $^{13}C^{16}O$ ,  $^{12}C^{17}O$ ,  $^{12}C^{18}O$  lines in 1.5 to 2.5 micron spectra of 41 Mira and SRa stars. These measurements have been used to derive  $^{12}C/^{13}C$ ,  $^{16}O/^{17}O$ , and  $^{16}O/^{18}O$  isotopic ratios. The ratios are compared to available literature values for the individual stars and the ratios are compared to isotopic ratios for various samples of evolved stars. Models for solar composition AGB stars of different initial masses are compared to the results. We find that the majority of the M stars had main sequence masses  $<1.5$  solar mass and have not experienced the third dredge up. The progenitors of the S and C Miras in the sample were more massive but no stars in the sample show evidence of hot bottom burning.

**Author(s):** Kenneth H. Hinkle<sup>2</sup>, Thomas Lebzelter<sup>3</sup>, Oscar Straniero<sup>1</sup>

**Institution(s):** 1. INAF, Osservatorio Astronomico di Collurania, 2. NOAO, 3. University of Vienna

### 345.10 – Discovering New R Coronae Borealis Stars

The R Coronae Borealis (RCB) stars are rare hydrogen-deficient, carbon-rich supergiants. Two evolutionary scenarios have been suggested, a double degenerate merger of two white dwarfs, or a final helium shell flash in a PN central star. The evidence pointing toward a white-dwarf merger or a final-flash origin for RCB stars is contradictory. The distribution on the sky and radial velocities of the

RCB stars tend toward those of the bulge population but a much larger sample of stars is needed to determine the true population. We need to discover RCB stars much more efficiently. In order to do this, we have used a series of IR color-color cuts, using the recent release of the WISE All-Sky Catalog, to produce a sample of 2200 candidates that may yield over 200 new RCB star identifications. Most of these candidates do not have lightcurves, the traditional technique of identifying RCB stars from their characteristic large and irregular light variations. We have obtained optical spectra of several hundred candidates and have confirmed over 40 new RCB stars in the Galaxy. We are attempting to develop a quantitative spectral classification system for the RCB stars so that they can be identified without an accompanying light curve. The cooler RCB stars look like carbon stars with strong  $C_2$  bands, but they can be differentiated from carbon stars by their extreme hydrogen deficiency and very low  $^{13}C/^{12}C$  ratio. Also, the red CN bands are much weaker in RCB stars than in carbon stars. The number of RCB stars in the Galaxy may be consistent with the predicted number of He/CO white-dwarf mergers. Solving the mystery of how the RCB stars evolve would be a watershed event in the study of stellar evolution that will lead to a better understanding of other important types of stellar merger events such as Type Ia SNe.

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**Institution(s):** 1. Institut d'Astrophysique de Paris, 2. Louisiana State Univ., 3. McMaster University

### 345.11 – Stellar Properties of Pulsating B Star Candidates in the Kepler Field

We measure physical properties of 31 candidate  $\beta$  Cephei, slowly pulsating B stars (SPB), and hybrid pulsating B stars in the *Kepler* field. We employ LTE Kurucz ATLAS9 model atmospheres and the TLUSTY BSTAR2006 non-LTE grid to measure the projected rotational velocity,  $v \sin i$ , effective temperature,  $T_{\text{eff}}$ , and surface gravity,  $\log g$ , from blue optical spectra for our stars. Results are plotted against the evolutionary tracks of Ekström et al. for determination of stellar masses, radii, and ages. Accurate determination of these parameters is crucial for asteroseismic analysis as it has been shown by Balona et al. that the predicted parameters in the *Kepler* Input Catalog (KIC) for these hot stars are unreliable.

We would like to thank Lehigh University for supporting this research. This work has been funded by NSF grants AST-1109247 and PHY-11359195.

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**Institution(s):** 1. Lehigh Univ.

### 345.12 – The PTI Giant Star Angular Size Survey: Effective Temperatures & Linear Radii

We report new interferometric angular diameter observations of over 200 giant stars observed with the Palomar Testbed Interferometer (PTI). These angular diameters are combined with bolometric fluxes derived from detailed spectral energy distribution (SED) fits, to produce robust estimates of effective temperature ( $T_{\text{EFF}}$ ). These SED fits include reddening estimates and are based upon fits of empirical spectral templates to literature photometry, and narrow-band photometry obtained at the Lowell 31" telescope. The 58 nights of 31" observing have produced over 45,000 new photometric data points on these stars, allowing for flux and reddening determination with unprecedented precision. Over the range from G5III to M8III,  $T_{\text{EFF}}$  estimates are precise to 50K per spectral type. Radius estimates are limited by the improved Hipparcos estimates of van Leeuwen (2007) and are typically  $\sim 10\%$  per star.

**Author(s):** Gerard van Belle<sup>3</sup>, Gennady Pilyavsky<sup>1</sup>, Kaspar von Braun<sup>3</sup>, David R. Ciardi<sup>2</sup>

**Institution(s):** 1. Arizona State University, 2. Caltech, 3. Lowell Observatory

**Contributing team(s):** PTI Collaboration

### 345.13 – VISION: A Six-Telescope Fiber-Fed Visible

### **Light Beam Combiner for the Navy Precision Optical Interferometer**

Visible-light long baseline interferometry holds the promise of advancing a number of important applications in fundamental astronomy, including the direct measurement of the angular diameters and oblateness of stars, and the direct measurement of the orbits of binary and multiple star systems. To advance, the field of visible-light interferometry requires development of instruments capable of combining more than just two or three beams at once. The Visible Imaging System for Interferometric Observations at NPOI (VISION) is a new visible light beam combiner for the Navy Precision Optical Interferometer (NPOI) that uses single-mode fibers to coherently combine light from up to six telescopes simultaneously with an image-plane combination scheme. It features a photometric camera for calibrations, and spatial filtering from single-mode fibers with two Andor Ixon electron multiplying CCDs. Here we present the VISION system, results of laboratory tests, and results of commissioning on-sky observations. We determine a new set of corrections to the power spectrum and bispectrum when using an electron-multiplying CCD to measure visibility and closure phase, by taking into account non-Gaussian statistics and read noise, as required by our post-processing pipeline. We verify our post-processing pipeline via new on-sky observations of the O-type supergiant binary Zeta Orionis A, obtaining a flux ratio, position angle and separation in good agreement with expectations from the previously published orbit.

**Author(s):** Eugenio Garcia<sup>2</sup>, Matthew W. Muterspaugh<sup>4</sup>, Gerard van Belle<sup>2</sup>, John D. Monnier<sup>5</sup>, Keivan Stassun<sup>6</sup>, Askari Ghasempour<sup>1</sup>, Samuel Swihart<sup>3</sup>

**Institution(s):** 1. HORIBA Scientific, 2. Lowell Observatory, 3. Michigan State University, 4. Tennessee State University, 5. University of Michigan, 6. Vanderbilt University

### **345.14 – The EREBOS Project: Time-Series Photometry of New HW Vir Binaries from the OGLE Survey**

Several post red giant hot subdwarf stars are found in tight binaries with cool main sequence companions. The separation distances in these so-called HW Vir systems are so small that the companions would have been inside of the envelopes of the red giant progenitors. Consequently, they are thought to be responsible for the formation of the hot subdwarfs by stripping off the outer layers of their red giant progenitor. For the past few years, fewer than 20 HW Vir binaries were known. Recently, however, 36 new candidate binaries were uncovered by the Optical Gravitational Lensing Experiment (OGLE) survey. Follow-up photometry and spectrometry are needed to determine the stellar masses of these systems. We recently started the Eclipsing Reflection Effect Binaries from the OGLE Survey (EREBOS) project to achieve this goal and determine the overall companion mass distribution for HW Vir binaries. Here we present EREBOS follow-up observations obtained with the CTIO 0.9-m telescope and discuss our current findings.

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**Institution(s):** 1. High Point University

**Contributing team(s):** EREBOS Team

### **345.15 – On the Recovery of Stellar Parameters from Eclipsing Binary Data**

We present the results of a series of simulations designed to determine the observing parameters that can reliably allow for the recovery of stellar masses and radii to better than 1% from double-line spectroscopic eclipsing binaries. This is a critical step in an ongoing program to characterize a large sample of low-mass eclipsing systems discovered by the *Kepler* Space Telescope using follow-up data from several ground based facilities.

**Author(s):** Douglas Klink<sup>3</sup>, Jonathan Swift<sup>3</sup>, Philip Steven Muirhead<sup>1</sup>, John A. Johnson<sup>2</sup>, Eunkyun Han<sup>1</sup>, Yutong Shan<sup>2</sup>

**Institution(s):** 1. Boston University, 2. Harvard University, 3. The Thacher School

### **345.16 – Properties of K/M Dwarf Eclipsing Binaries**

Stellar models of low-mass stars ( $M < 0.8 M_{\odot}$ ) have been found to be in disagreement with observed properties, the observed radii being larger and the observed temperatures being lower. To characterize this discrepancy and search for possible confounding parameters, we are observing a sample of low-mass eclipsing binaries using the McDonald 2.7-m telescope and archival Keck data for spectroscopic observations as well as the 0.8-m telescope at McDonald. This study will greatly increase the number of well-characterized low-mass stars, allowing for a better understanding of how fundamental stellar parameters ( $T_{\text{eff}}$ ,  $R_*$ ,  $M_*$ , abundances, activity, luminosity, etc.) depend on one another. We are using IGRINS, a high resolution ( $R=40,000$ ) IR (H+K) spectrograph on the McDonald 2.7-m, to measure  $T_{\text{eff}}$  and abundances of the sample to a higher precision than previously capable. Relationships between the stellar parameters could reveal the influence of extra parameters on the mass-radius relation, indicating the additional physics that must be added to stellar evolutionary models to bring them into agreement with observations.

**Author(s):** Andrew Riddle<sup>1</sup>, Adam L. Kraus<sup>1</sup>

**Institution(s):** 1. University of Texas at Austin

### **345.17 – Blue Straggler-White Dwarf binaries in Galactic field**

The mass transfer in close binaries has been identified as the most probable formation channel for field blue straggler stars (BSSs). The companions to these BSSs are white dwarf stars (WDs) and can be detected at ultraviolet (UV) wavelengths in the spectral energy distribution of the binary, if the mass transfer happened recently so that WD is young and hot.

We chose a sample of 2,188 BSSs in the temperature range of 7,000 – 9000 K and surface gravity,  $\log g > 3.8$ , using the Sloan Stellar Parameter Pipeline, from the Sloan Digital Sky Survey (SDSS). From this, a sub-sample of 80 UV excess field BSSs were identified using UV photometry from the Galaxy Evolution Explorer (GALEX). By using a chi-square minimization technique we fit the observed SED of these UVE-BSSs to set of combined BS+WD models to find the best fitting WD parameters. By considering our fitting results and the theoretical estimates of mass-temperature relation for BSSs, we find that the likely companions to our sample of UVE-BSSs are He WDs. This means that the most likely scenario of formation of these UVE-BSSs is mass transfer onto a normal main sequence star from a red giant star.

**Author(s):** Gemunu B Ekanayake<sup>1</sup>, Ronald J. Wilhelm<sup>1</sup>

**Institution(s):** 1. University of Kentucky

### **345.18 – Open Clusters Ages from Giant Star Sizes**

The nearest open clusters serve as important benchmarks for theories of stellar evolution, and with the discoveries of gas giant planets in these clusters, they are poised to serve as benchmarks for theories of planet evolution. The value of these clusters stems from members having identical relative ages, but their value would be redoubled if their absolute ages were more robustly determined. We note, in particular, that recent studies that account for the rapid stellar rotation of main sequence turnoff stars find that current age estimates are biased by ~20%. Here we present CHARA Array angular size measurements of giant stars in the Praesepe, Coma Berenices and Hyades open clusters. These measurements are used to provide independent age estimates of the clusters, and to test evolutionary models that span from the main sequence to the red giant branch.

**Author(s):** Russel J. White<sup>1</sup>, Jeremy Jones<sup>1</sup>, Samuel N. Quinn<sup>1</sup>, Tabet S. Boyajian<sup>2</sup>

**Institution(s):** 1. Georgia State University, 2. Yale University

### **345.19 – Near-infrared Photometry of the Open Cluster NGC 2420**

Open clusters have been used in numerous studies of stellar formation and evolution and have provided important constraints on theoretical stellar models. In this study, we carried out deep near-infrared imaging (*I*, *J*, *H* and *K<sub>s</sub>* bands) with the 1024×1024

CFHT-IR camera at the Cassegrain focus of the Canada-France-Hawaii 3.6 m telescope of two fields in the relatively old open cluster, NGC 2420. This cluster was selected due to its relatively low metallicity,  $[\text{Fe}/\text{H}] \sim -0.5$ , and rather high Galactic latitude (for an open cluster),  $b \approx 20^\circ$ , reducing the effects of reddening as well as reducing the extent of contamination by non-members of the cluster. The empirical data were calibrated using 2MASS and Stetson standards in the field. Non-cluster stars were removed using a field-cluster decontamination algorithm. By fitting available theoretical isochrones to the observed color-magnitude diagrams, we have been able to estimate the age, metallicity and distance of the cluster which are compared to previous studies.

**Author(s):** Neda Hejazi<sup>1</sup>, Michael M. De Robertis<sup>3</sup>, Peter C. Dawson<sup>2</sup>

**Institution(s):** 1. Georgia State University, 2. Trent University, 3. York University

### 345.20 – Sub-subgiants in Old Open Cluster NGC 6791

In an optical color-magnitude diagram sub-subgiants (SSGs) lie red of the main-sequence and fainter than the red giant branch in a region not easily populated by standard stellar evolution theory. We present radial-velocity follow-up to five SSG candidates in the old open cluster NGC 6791 (8 Gyr,  $[\text{Fe}/\text{H}] = +0.3$ ). Our observations began in 2014 July with the Hydra multi-object spectrograph on the WIYN 3.5 m telescope. We find four SSGs to be three-dimensional kinematic members of NGC 6791, with three also being short-period binary systems. The existence of these newly discovered SSGs in NGC 6791 strengthens the case that SSGs are a new class of non-standard stellar products, and that a physical mechanism must be found that explains the unusual evolutionary path of these stars. We gratefully acknowledge funding from the National Science Foundation under grant AST- 0908082 and the Wisconsin Space Grant Consortium.

**Author(s):** Katelyn E. Milliman<sup>2</sup>, Emily Leiner<sup>2</sup>, Robert D. Mathieu<sup>2</sup>, Benjamin M. Tofflemire<sup>2</sup>, Imants Platais<sup>1</sup>

**Institution(s):** 1. Johns Hopkins University, 2. University of Wisconsin-Madison

### 345.21 – CN Band Photometry in the Globular Cluster M71

We present  $g'$ ,  $r'$  and intermediate waveband photometry of the blue CN band in stars in the globular cluster M71 taken with the WIYN 0.9-m telescope. CN band strengths are correlated with measured sodium abundances to establish whether the CN band can be used to discriminate multiple stellar populations in globular clusters. This project seeks to develop methods of detecting population gradients in integrated cluster light, which can then be applied to globular clusters in other local group galaxies.

**Author(s):** William P. Bowman<sup>1</sup>, Catherine A. Pilachowski<sup>1</sup>

**Institution(s):** 1. Indiana University - Bloomington

### 345.22 – Investigating the Consistency of Stellar Evolution Models with Globular Cluster Observations via the Red Giant Branch Bump

Synthetic Red Giant Branch Bump (RGBB) magnitudes are generated with the most recent theoretical stellar evolution models computed with the Dartmouth Stellar Evolution Program (DSEP) code. They are compared to the observational work of Nataf et al. (2013), who present RGBB magnitudes for 72 globular clusters. A DSEP model using a chemical composition with enhanced  $[\alpha/\text{Fe}] = +0.4$  and an age of 13 Gyr shows agreement with observations over metallicities ranging from  $[\text{Fe}/\text{H}] = 0$  to  $[\text{Fe}/\text{H}] \approx -1.5$ , with discrepancy emerging at lower metallicities. A model-independent, density-based outlier detection routine known as the Local Outlying Factor (LOF) algorithm is applied to the observations in order to identify clusters that deviate most in magnitude-metallicity space from the bulk of the observations. Our model's fit is scrutinized with a series of  $\chi^2$  routines performed on subsets of the data from which highly anomalous clusters have been selectively removed based on LOF

identification. In particular, NGCs 6254, 6681, 6218, and 1904 are tagged recurrently as outliers. The effects of systematic and non-systematic error in metallicity are assessed, and the robustness of observational error bars is investigated.

**Author(s):** Meridith Joyce<sup>1</sup>, Brian Chaboyer<sup>1</sup>

**Institution(s):** 1. Dartmouth College

### 345.23 – The Rapid Brightening of Eta Carinae

Eta Carinae is one of the most dynamic and well-observed massive stars. Its bipolar Homunculus Nebula and other observations imply it has a strong latitude dependent stellar wind. The significant brightening of the star itself over the last two decades has been commonly explained as an evolution of the latitude structure of the wind, change in mass-loss rate, and/or clearing of circumstellar material in our direct line sight. Hubble Space Telescope images (with a much higher spatial resolution than ground-based images) document an increase in contrast between the brightness of the star and the Homunculus reflection nebula. We present measurements of the nebula's brightness, sampling the changing brightness of the star viewed from angles differing from our own direct line of sight. We also present ultraviolet photometry of the star synthesized from recent HST/STIS observations.

**Author(s):** John C. Martin<sup>2</sup>, Kris Davidson<sup>3</sup>, Andrea Mehner<sup>1</sup>, Roberta M. Humphreys<sup>3</sup>

**Institution(s):** 1. European Southern Observatory, 2. University of Illinois Springfield, 3. University of Minnesota

### 345.24 – Recovery from a Giant Eruption: The Case of Eta Car

Giant eruptions or SN Impostors are far more mysterious than "real" supernovae, because they are scarcer and because they have received far less theoretical effort. One rather special problem is the disequilibrium state of the post-eruption object. It may be partially observable by watching the star's gradual recovery; which, in principle, may offer clues to the basic instability mechanisms. So far, the only example that can be observed well enough is eta Carinae. This object's history offers tantalizing clues and counter-clues. For instance: (1) Before 2000, the recovery timescale seemed to be of order 150 years; but (2) around 2000, many attributes began to change much more rapidly; and (3) the 150-year recovery process has been punctuated by about three abrupt changes of state. This strange combination of facts has received almost no theoretical attention.

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**Institution(s):** 1. ESO, 2. Univ. of Minnesota, 3. University of Illinois

### 345.25 – Are MWC349 A and B a Physical Binary?

The age and evolutionary status of the only known hydrogen recombination line maser and laser star MWC349A, "A", is unknown because its spectrum has no absorption features for classification. Star A has an optical BoIII companion 2.4 arcsec away, MWC349B. Previous studies suggest A & B are either gravitationally bound, and therefore both a few Myr old, or not bound and A is possibly an observable 30  $M_{\text{solar}}$  star in its pre-main sequence stage. We attempt to solve the controversy by measuring the difference of radial velocities between A and B using observations from the 1.5m Tillinghast telescope and the TRES spectrometer at the Whipple Observatory. With an assumed distance of 1.2 kpc and masses of  $\sim 30 M_{\text{solar}}$ , the radial velocities cannot differ by  $> 3 \text{ km/s}$  for the stars to be gravitationally bound. We find a radial velocity with respect to the local standard of rest of  $42 \pm 18 \text{ km/s}$  for B, and compare it with the known radial velocity of  $8 \pm 2 \text{ km/s}$  for A giving a difference of  $34 \pm 20 \text{ km/s}$  - much greater than  $3 \text{ km/s}$ . We conclude that A and B are not gravitationally bound, although light contamination from star A in B's spectrum makes this result somewhat inconclusive. If confirmed, however, the known spectral type of B will not determine the age of star A and star A may be an observable 30  $M_{\text{solar}}$  star in its pre-main sequence stage. We gratefully acknowledge support from Dave Latham, Jessica Mink and the TRES instrument team. This project was supported in part by the NSF REU grant

**Author(s):** Patrick Drew<sup>3</sup>, Vladimir Strelitski<sup>2</sup>, Howard Alan Smith<sup>1</sup>

**Institution(s):** 1. Harvard CfA, 2. Maria Mitchell Observatory, 3. University of Massachusetts Amherst

**Contributing team(s):** Dave Latham Jessica Mink and the TRES instrument team, Maria Mitchell Association

### 345.26 – Integrated Spectrophotometric Properties of Multiple Stellar Populations

There is mounting evidence that almost all the Milky Way globular clusters (MWGCs) are of multiple stellar populations. Several earlier works have revealed that the color-magnitude diagrams of MWGCs are best reproduced by the combination of stellar populations with different ages and metallicities. However, their integrated spectrophotometric properties have not yet been validated. In this work, we employ the most up-to-dated stellar evolutionary tracks and isochrones from several different groups and calculate the integrated broadband colors and spectral indices for the Milky Way globular clusters and compare the theoretical predictions to the observations.

**Author(s):** Hyun-chul Lee<sup>1</sup>, Charles Cartwright<sup>1</sup>

**Institution(s):** 1. The University of Texas Rio Grande Valley

### 345.27 – Deep HST/ACS Photometry of an Arc of Young Stars in the Southern Halo of M82

We present deep HST/ACS photometry of an arc-like, overdense region of stars in the southern halo of M82, located approximately 5 kpc from its disk. This arc feature was originally identified about a decade ago. The early ground-based studies suggested that it contains young stars with ages and metallicities similar to those that formed in the tidal tails between M81, M82, and NGC3077 during their interactions. The arc is clearly presented in the spatial distribution of stars in our field with significantly higher stellar density than the background M82 halo stars. The location of the tip of the red giant branch (RGB) reveals the arc to have a similar distance to M81 and M82, therefore confirming that it belongs to this interacting system. Combining our data with those from the ACS Nearby Galaxy Survey Treasury (ANGST), we construct a color-magnitude diagram (CMD) for the arc. A sequence of young stars is clearly presented on its CMD. This young main sequence is not seen in other parts of the M82 halo. Single-metallicity isochrones are used to derive the age of the young stars in the arc. We confirm that these stars exhibit ages consistent with young stars found in the HI bridges between M81, M82 and NGC3077. Furthermore, the mean metallicity of the RGB stars is also derived from their metallicity distribution function and found to be similar to that found in the HI bridges.

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**Institution(s):** 1. University of Florida

## 346 – Star Formation Poster Session

### 346.01 – [NII] 205 $\mu$ m Line Emission Detection in High Red-shift Galaxies

The [NII] 205  $\mu$ m line has been detected in two out of three high red-shift galaxies observed with ALMA. The [NII] 205  $\mu$ m line is a sensitive ionized gas tracer that can be used to characterize the interstellar medium (ISM) and determine Star Formation Rates (SFRs). This work represents a significant expansion of the sample of high-z galaxies detected in [NII]. Importantly, it also complements a more commonly studied fine structure line, [CII] 158  $\mu$ m. Since the [NII] 205  $\mu$ m line has a higher ionization potential than hydrogen we can use it to determine if the [CII] 158  $\mu$ m line arises from ionized gas regions or photodissociation regions (PDRs). The extremely high [CII] to [NII] line ratios observed in these galaxies suggest unique structure in the ISM or potentially anomalously low metallicity. We also make a comparison of SFRs using the [NII] 205  $\mu$ m line, [CII] 158  $\mu$ m line, and the Infrared Luminosity (LIR).

**Author(s):** Michelle Nowling<sup>1</sup>

**Institution(s):** 1. University of Houston

### 346.02 – Herschel+Hubble Observations of a Multiply-Lensed Sub-millimeter Galaxy at $z \sim 3$

We present the results of our deep Keck/NIRC2 and Hubble Space Telescope Wide Field Camera 3 (HST/WFC3) observations of an extremely star forming lensed dusty Sub-Millimeter Galaxy (SMG) identified from the Herschel Astrophysical Terahertz Large Area Survey (H-ATLAS). The object under study forms a complex lensing system that consists of four foreground aligned galaxies at  $z \sim 1$  (measured from Keck/DEIMOS observations) with multiple lensing features that consist of giant arcs and counter images. Molecular line observations of the background source with Green Bank Telescope (GBT) and Combined Array for Research in Millimeter-wave Astronomy (CARMA) put it at a redshift of 2.685. Multi-band data from Keck, HST and Herschel yields a Star Formation Rate in excess of 1000 Solar masses per year putting this system among the most intensely star forming systems at  $z > 2$ . The measured SFR puts this system well above the main sequence of star forming galaxies at  $z \sim 3$ . The measured gas fraction and molecular gas surface density measurements from long wavelength observations are consistent with theoretical models and observational trends of gas rich SMGs at high redshifts.

**Author(s):** Hooshang Nayyeri<sup>3</sup>, Asantha R. Cooray<sup>3</sup>, Jae Alyson B. Calanog<sup>3</sup>, Dominik A. Riechers<sup>1</sup>, David T. Frayer<sup>2</sup>

**Institution(s):** 1. Cornell University, 2. NRAO, 3. UC Irvine

**Contributing team(s):** Herschel HERMES, H-ATLAS

### 346.03 – Star Clusters in Early-Type Galaxies

Star formation rates in early-type galaxies are notoriously hard to determine because of their very low specific star formation rates. For this project, we use Hubble Space Telescope photometric data in 4-5 visible and near-UV filters to measure the young stellar clusters in nine early-type galaxies. Aperture photometry colors were compared to colors from synthetic photometry produced by the Flexible Stellar Population Synthesis code (Conroy et. al, ApJ **699**, 486-506 (2009)), using a chi-squared likelihood method to estimate the age, metallicity and extinction for each cluster. Masses were determined using the best-fit model, the distance to each galaxy and the measured fluxes. Young clusters were selected below a cutoff age of 100 Myr, and star formation rates for each galaxy were then calculated as the combined mass of the young clusters divided by the cutoff age. Star formation rates computed in this way are far below those computed using the 22 micron emission. While some completeness effects are biasing the cluster-estimated SFRs low, the extreme difference (two orders of magnitude) may also point to SFR overestimation due to contamination from older stars in the 22 micron SFRs.

**Author(s):** Sidney David Vetens<sup>1</sup>, Alison Faye Crocker<sup>1</sup>

**Institution(s):** 1. Reed College

### 346.04 – Runaway Stars as a Possible Source of the Elliptical Ring Structure in NGC 7538

A large, approximately 500  $M_{\odot}$  elliptical ring structure has been identified in the high-mass star-forming region, NGC 7538. The origin of this ring structure is unknown. We investigate the possibility that a runaway O- or B-type star may have originated in or passed through the region and created the ring structure from its stellar winds or other mechanisms. In testing this hypothesis, we identify one candidate star, TYC-4279-2210-1, that may have formed the ring. TYC-4279-2210-1 is a B1 III star, with a mass of  $\sim 20 M_{\odot}$ , and has a surface temperature of  $\sim 25000$  K. Its position, motions, timescale, and spectral type are all consistent with the star being a candidate for having formed the ring structure in NGC 7538. The timescale for the ring formation was calculated to be  $\sim 10^6$  to  $10^7$  yrs.

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**Institution(s):** 1. Central Washington University, 2. NRC-Herzberg

### 346.05 – The Circumnuclear Starburst Ring in NGC 1097

The circumnuclear ring in galaxy NGC 1097 is bursting with star formation at a rate of five solar masses per year as previously measured through H $\alpha$  emission. The rate of star formation drops by a factor of one thousand outside the circumnuclear ring. We characterize the behavior of the dust in this region by measuring the spectral energy distribution focused exclusively on the circumnuclear ring using a selective variety of high resolution science images spanning wavelengths from ultraviolet to infrared, and adding proprietary high resolution radio data from Atacama Large Millimeter Array (ALMA) in Chile. High resolution radio data obtained from ALMA allows us to constrain the shape of the spectral energy distribution curve specifically at longer wavelengths, and therefore the rate of star formation within the circumnuclear ring. Comparing the spectral energy distribution of the entire galaxy with that of the circumnuclear ring indicates how starburst activity influences the galactic spectral energy distribution.

**Author(s):** Beverly Thackeray-Lacko<sup>1</sup>, Sabrina Stierwalt<sup>2</sup>, Kartik Sheth<sup>2</sup>

**Institution(s):** 1. California State University, San Bernardino, 2. NRAO

### 346.06 – Star Formation and Dense Gas in Galaxy Mergers from the VIXENS Survey

We present our  $\lambda = 3$  mm IRAM and NRO single dish line survey for a sample of 15 interacting galaxies in the VIRUS-P Investigation of the eXtreme ENvironments of Starbursts (VIXENS) survey. Our sample of merging galaxies range from early to late interaction stages (close pairs to merger remnants, respectively). A variety of molecular lines are detected including dense gas tracers HCN, HCO<sup>+</sup>, HNC, CS, CN (and others) as well as <sup>12</sup>CO and <sup>13</sup>CO. We compare the dense gas fractions with <sup>12</sup>CO and <sup>13</sup>CO as well as star formation efficiencies defined by infrared-to-dense gas tracer luminosity ratio and discuss trends with interaction stage. We also investigate relations between star formation and dense gas content in our merger sample and compare them to non-interacting star forming galaxies and Galactic star forming regions in the Milky Way.

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**Institution(s):** 1. The University of Virginia

**Contributing team(s):** VIXENS team

### 346.07 – Narrow-band Imaging of Massive Star-Forming Regions: Tracing Outflows and the Rate of Star-Formation

Narrowband images targeting ionized hydrogen (Brackett gamma, 2.17 microns) and molecular hydrogen (2.12 microns) were obtained for six massive star-forming regions within the Milky Way, NGC 6334, G305, G3333, G3264, G3266, and G351. These regions are within 1-4 kpc from our solar system. The narrowband flux in Brackett gamma was used as a star-formation tracer to calculate a star-formation rate for each region. This is compared with other star-formation rates found using other methods such as the count of young stars and YSOs, and rates calculated from using other tracers (e.g. 70 micron monochromatic luminosity). The molecular hydrogen narrowband images were manually searched to locate outflows from young stars. Once these outflows are identified, it may help to get a better survey of the young stellar population. A better understanding of the stellar population distribution can lead to more accurate star-formation rates to compare to those calculated from star-formation tracers. We found the regions NGC 6334 and G3266 to have the highest levels of ongoing star formation activity as indicated by the number of molecular hydrogen objects (MHOs) detected. There are a total of 279 cataloged MHOs in 181 categorized systems for the six regions. There are a total of 150 identified potential driving sources.

This work was supported in part by the NSF REU and DoD ASSURE programs under NSF grant no. 1262851 and by the Smithsonian Institution.

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### 346.08 – Connecting the Dense Gas and Young Stars in the CARMA Large Area Star Formation Survey

The CARMA Large Area Star Formation Survey (CLASSy) imaged the dense gas structure and kinematics in five, roughly 1 pc scale regions in the Serpens and Perseus clouds with 7" angular resolution. The spatial distribution and Class of the young stellar population (YSOs) is available for these regions from the Spitzer c2d and Gould Belt surveys, with added sources from the Herschel 70 micron images. Together, these datasets allow us to compare, for the first time at similar spatial resolutions, the distributions of the dense gas and YSOs over regions containing up to 90 identified YSOs. This enables a detailed look at the separation between YSOs and the nearest dense gas peak and a measure of overall relationship between the YSO and dense gas distributions. We find that most Class 0 YSOs are forming in the highest column density regions: leaves in the dendrogram analysis utilized by CLASSy. In Serpens and Perseus, we find that 29% and 38%, respectively, of the leaves have identified embedded YSOs. Class I sources are less confined to leaf locations; Class II sources are distributed throughout regions, mostly away from hierarchical peaks. This trend could be due to a modest (0.1 km/sec) velocity difference between YSOs and their natal cores, or due to the YSOs consuming or dispersing their natal cores.

**Author(s):** Lee G. Mundy<sup>4</sup>, Shaye Storm<sup>4</sup>, Leslie Looney<sup>3</sup>, Katherine I Lee<sup>1</sup>, Manuel Fernandez Lopez<sup>3</sup>, Eve C. Ostriker<sup>2</sup>, Che-Yu Chen<sup>5</sup>

**Institution(s):** 1. Center for Astrophysics, 2. Princeton University, 3. University of Illinois, 4. University of Maryland, 5. University of Virginia

**Contributing team(s):** CLASSy Team

### 346.09 – Star Formation Rate in The Solar Neighborhood and Beyond

Using a sample of confirmed Stage 0+I protostars from Heiderman et al. 2015, we test the proposed threshold star formation model (SFR =  $4.6 \times 10^{-8} \text{f}_{\text{DGMG}}$ ; Lada et al. 2012) in which the relation between the star formation rate (SFR) and gas mass is proportional. We measure the star formation rate and gas mass in 18 Gould Belt clouds in the Spitzer c2d+GB surveys. We calculate the SFRs by counting the number of protostars in a region assuming a mean mass and Stage 0+I lifetime and estimated gas masses using extinction maps. We compare our resulting SFRs and cloud masses to the Lada et al. 2012 relation and find that our cloud sample lies below the proposed threshold model.

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**Institution(s):** 1. National Radio Astronomy Observatory

### 346.10 – Census of High- and Medium-mass Protostars (CHaMP) Survey: Continuum Emission Parameter Maps and Protostellar Clump Evolution

The CHaMP survey attempts to characterize the gas properties and evolutionary timescales of all stages of massive star formation by creating the largest-yet compendium of high-resolution, unbiased observations of both line and continuum emission from molecular cloud clumps in the Milky Way. Here we present preliminary greybody parameter maps of the 209 massive molecular gas clumps previously identified in the Mopra and Nanten maps of the 20° x 6° region of the galactic plane in Centaurus, Carina, and Vela. We probe continuum emission from 8 to 870  $\mu\text{m}$  at spatial resolutions of ~30" using collated data from the LABOCA bolometer array at APEX, the PACS and SPIRE photometers on the Herschel Space Observatory, bands 3 and 4 of WISE, and the MIPS and IRAC instruments on the Spitzer Space Telescope. To these data we fit pixel-by-pixel modified Planck spectral energy distributions (SEDs) to the clumps and their immediate surroundings to map the emissivity indices, and effective temperatures and peak fluxes (of each component where both warm and cool components were found). Here we also present comparisons of the parameter maps to the line emission maps of <sup>12</sup>CO, as well as <sup>13</sup>CO, C<sup>18</sup>O, and HCO<sup>+</sup> where available.

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**Institution(s):** 1. University of Florida  
**Contributing team(s):** CHaMP Team

### 346.11 – A Survey For Embedded Clusters in the Large Magellanic Cloud

In the Milky Way, the majority of stars form in embedded clusters (Lada & Lada 2003), which makes them a fundamental unit of star formation. Despite their importance, our knowledge of cluster formation remains primitive. For example, we don't have a clear idea of how varying physical environments affects the cluster formation process. In order to address this, we have begun a comprehensive, systematic search for embedded stellar clusters in the Large Magellanic Cloud (LMC) using near-infrared data from the VISTA Magellanic Clouds Survey (Cioni et al. 2011). To date, we have searched 46% of the molecular clouds in the MAGMA CO Survey (Wong et al. 2011). We have identified 125 embedded cluster candidates. This is approximately double the number of embedded clusters that have been identified within  $\sim 2.5$  kpc of the Sun (Lada & Lada 2003). We have determined sizes, luminosities, and masses for these embedded clusters and calculated the star formation rates (SFRs) of the LMC molecular clouds containing clusters, and finally compared the LMC and Milky Way embedded cluster properties and SFRs. Our preliminary results indicate the LMC embedded clusters are larger, more luminous and more massive than the embedded clusters in the local Milky Way. However, even though the overall cluster properties differ in these two environments, the SFRs of the molecular clouds in both environments are consistent with the SFR scaling law from Lada et al. (2012). This consistency may indicate that while the details of embedded cluster formation may vary between environments, the overall star formation process within molecular clouds may be universal.

**Author(s):** Krista Romita<sup>1</sup>, Elizabeth A. Lada<sup>1</sup>, Maria-Rosa Cioni<sup>2</sup>  
**Institution(s):** 1. University of Florida, 2. University of Potsdam

### 346.12 – Comparing Herschel dust emission structures, magnetic fields observed by Planck, and dynamics: high-latitude star forming cloud L1642

The nearby high-latitude cloud L1642 is one of only two known very high latitude ( $|b| > 30$  deg) clouds actively forming stars. This cloud is a rare example of star formation in isolated conditions, and can reveal important details of star formation in general, e.g., of the effect of magnetic fields. We compare Herschel dust emission structures and magnetic field orientation revealed by Planck polarization maps in L1642, and also combine these with dynamic information from molecular line observations. The high-resolution Herschel data reveal a complex structure including a dense, compressed central blob with elongated extensions, low density striations, "fishbone" like structures with a spine and perpendicular striations, and a spiraling "tail". The Planck polarization data reveal an ordered magnetic field that pervades the cloud and is aligned with the surrounding low density striations. We show that there is a complex interplay between the cloud structure and large scale magnetic fields revealed by Planck polarization data at  $10'$  resolution. This suggests that the magnetic field is closely linked to the formation and evolution of the cloud. We see a clear transition from aligned to perpendicular structures approximately at a column density of  $N_H = 2 \times 10^{21} \text{ cm}^{-2}$ . We conclude that Planck polarization data revealing the large scale magnetic field orientation can be very useful even when comparing to the finest structures in higher resolution data, e.g. Herschel at  $\sim 18''$  resolution.

**Author(s):** Johanna Malinen<sup>1</sup>  
**Institution(s):** 1. Florida State University

### 346.13 – Bondi-like Accretion in Magnetized Supersonic Isothermal Turbulence

The Bondi and Bondi-Hoyle-Lyttleton formulas give the order of magnitude steady-accretion rate onto a point mass at rest or moving, respectively, in a uniform density gas in the limit of negligible gas self-gravity. This applies in star-forming clouds where self-gravity is negligible near protostars and new-born stars, but instead of being

uniform the gas is supersonically turbulent and threaded by dynamically important (Alven Mach number  $\sim 1$ ) large-scale magnetic fields. To determine the Bondi-like accretion rate in these environments, we used the ORION2 code to carry out grid-based 3D adaptive mesh refinement (AMR) magnetohydrodynamic (MHD) simulations of accretion onto sink particles embedded in an environment of fully developed, magnetized supersonic isothermal turbulence. We evolved the models until the median and mean accretion rates, over particles, became steady. We present a simple semi-analytic model that predicts the median and mean accretion rate from the turbulent properties of the background medium, such as the 3D Mach number and RMS plasma- $\beta$ , and show that it is highly consistent with our simulations. Numerical codes can use our semi-analytic model as an accurate sub-grid model for accretion in magnetized supersonic isothermal turbulence.

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**Institution(s):** 1. University of California Berkeley

### 346.14 – Using synthetic observations to constrain the properties of magnetic fields in protostellar cores

Magnetic fields play an essential role in the star formation process. However, due to challenges in directly observing magnetic fields, the morphology and evolution of magnetic fields within young cores are not well constrained. In order to discriminate between different star formation models, we have analyzed magnetohydrodynamic simulations of low-mass protostellar cores with outflows. Using yt, a visualization tool, we have made projections in a number of different orientations that show the properties of the protostellar cores such as magnetic fields, outflows, and density, with the goal of comparing them with high-resolution, millimeter-wave dust polarization maps. Simulations at resolutions and scales beyond those achievable in observations will provide insight into how magnetic fields change as a function of both time and spatial scale. Future work will involve using a radiative transfer module from the ARTIST package to make synthetic observations and compare them with CARMA, SMA, and future ALMA data.

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### 346.15 – The Spatial Distribution of Large and Small Dust Grains in Transitional Disks

The transitional disk stage occurs when a circumstellar disk of gas and dust goes from being optically thick to optically thin within a few Myr, leading to the existence of a prominent cavity between the forming star and the surrounding disk of material. Understanding the processes that open gaps and cavities in transitional disks, such as grain growth, photo-evaporation, or dynamical clearing, can improve our understanding of the planet formation process. With the recent commission of the Atacama Large Millimeter/Submillimeter Array (ALMA) and the upgraded Very Large Array (VLA), the sensitivity and angular resolution essential for observing transitional disks is now available to examine the structure of transitional disks and relate them to theoretical predictions. The research we present encompasses high frequency observations from ALMA Cycle 0 to observe 0.5 mm grains at 690 GHz, and VLA data using Q band frequencies (40.06GHz-47.6GHz) to observe 7 mm grains. We observed four transitional disk targets: SR 21, LkCa 15, RXJ1615.3-3255, and SAO 206462. We present multi-configuration continuum images of each object which were used to find their respective brightness temperature profiles and azimuthal averages to identify any asymmetries within the spatial distribution of the transitional disks and compare our results with existing theoretical models.

**Author(s):** Elizabeth Gutierrez<sup>2</sup>, Laura M. Perez<sup>1</sup>  
**Institution(s):** 1. National Radio Astronomy Observatory, 2. Villanova University

## 347 – Molecular Clouds, HII Regions,

## Interstellar Medium Poster Session

### 347.01 – A Search for AU-Scale C I Structure in the Diffuse ISM

We present a multi-epoch, high resolution ( $R \sim 100,000$ ) study of ultraviolet interstellar C I absorption line profiles taken by the Hubble Space Telescope. The 17 stars of this survey were chosen because each has high resolution spectra taken at least 10 years apart with the same instrument (STIS), grating (E140H), and aperture ( $0.2'' \times 0.2''$ ) thus minimizing the instrumental differences in the multi-epoch comparisons. Given the proper motions and distances of these stars, typically it was possible to observe variances in their C I line profiles which correspond to structure on scales of less than 200 AU. In 16 out of the 17 sightlines no significant differences in C I line profiles between the two epochs were detected (75% of the 68 C I velocity components were measured to vary less than 20% at the  $2\sigma$  level). A measurement of  $\sim 5\%$  of sightlines with variances is consistent with the fraction found recently by McEvoy et al. (2015) in their much larger survey of multi-epoch variance of Na I in optical spectra. However, the sightline toward HD210809 did show significant variance in its C I line profile. The C I absorption arising from both the  $J = 1$  and  $J = 2$  fine-structure states toward this star exhibits variations at an LSR velocity of  $-37$  km/s indicative of C I structure on a scale less than 200 AU. Interestingly, the sky position of HD 210809 corresponds to the edge of an intervening H I shell discovered by Suad et al. (2012) at this same LSR velocity. This connection is consistent with the optical survey of interstellar Na I by Meyer et al. (2015) who found that nearly all of their temporally-varying sightlines involved supernova remnants, H I supershells, or stellar bow shocks.

**Author(s):** Larissa Markwardt<sup>2</sup>, David M. Meyer<sup>1</sup>

**Institution(s):** 1. Northwestern University, 2. University of Arkansas

### 347.02 – Long-Term Monitoring of Molecular Masers in IRAS 18566+0408

We report results of a long-term monitoring study of 6 cm formaldehyde ( $\text{H}_2\text{CO}$ ), 6.035 GHz hydroxyl (OH), and 6.7 GHz methanol ( $\text{CH}_3\text{OH}$ ) masers in the young high-mass protostellar object IRAS 18566+0408 (G37.55+0.20). This is the only high-mass star forming region where correlated variability of three different maser species has been reported. The observations were conducted with the 305m Arecibo Radio Telescope and the Very Large Array. Together with data from the literature, we present  $\text{H}_2\text{CO}$  flux density measurements from 2002 to 2014,  $\text{CH}_3\text{OH}$  data from 2006 to 2015, and OH observations from 2008 to 2015. Our extended monitoring observations of the  $\text{H}_2\text{CO}$  maser agree with quasi-periodic variability and exponential flux density decrease during the quiescent and flare states as proposed by Araya and collaborators in 2010. We also confirm the occurrence of 6.035 GHz OH flares and a time delay with respect to the  $\text{H}_2\text{CO}$  flares (first reported by Al-Marzouk and collaborators in 2012). An analysis of the variability behavior of different  $\text{CH}_3\text{OH}$  velocity components and the  $\text{H}_2\text{CO}$  maser suggests that multiple variability mechanisms may be responsible for the  $\text{CH}_3\text{OH}$  flux density changes.

**Author(s):** Daniel Michael Halbe<sup>4</sup>, Esteban Araya<sup>4</sup>, Peter Hofner<sup>3</sup>, Hendrik Linz<sup>2</sup>, Luca Olmi<sup>1</sup>

**Institution(s):** 1. INAF-OAA, 2. Max-Planck-Institut für Astronomie, 3. New Mexico Institute of Mining and Technology, 4. Western Illinois University

### 347.03 – The Dust Cloud TGU H1192 (LDN 1525) in Auriga. II

The results of a new investigation of interstellar extinction in the direction of the emission nebulae Sh2-231 and Sh2-235 are presented. The investigation is based on CCD photometry and photometric MK classification in seven areas of  $12'$  by  $12'$  size in the Vilnius seven-color photometric system down to  $V = 19$  mag. Additionally, for the same task we applied 519 red clump giants identified in the surrounding  $1.5^\circ$  by  $1.5^\circ$  area using the results of photometry in the 2MASS and WISE surveys. The

dependence of the extinction run with distance allows determining distances to dust clouds and their extinctions. We compare these new more detailed results with the preliminary results described in our previous paper (V. Straizys et al. 2010, Baltic Astronomy, 19, 169) and the AAS communication at the AAS Meeting No. 219 (Austin), 349.12. The relation of the TGU H1192 dust cloud with the Auriga OB1 association is discussed.

**Author(s):** Richard P. Boyle<sup>1</sup>, Robert Janusz<sup>1</sup>, Vytautas Straizys<sup>2</sup>, Kazimieras Zdanavicius<sup>2</sup>, Marius Maskoliunas<sup>2</sup>, Algirdas Kazlauskas<sup>2</sup>

**Institution(s):** 1. Vatican Observatory, 2. Vilnius University

### 347.04 – Calibrating column density tracers with gamma-ray observations of the $\rho$ Ophiuchi molecular cloud

Likelihood analyses of gamma-ray counts maps require modeling a variety of presumed emission sources including their spatial extents and spectral shapes. The differences between the observed counts maps and these models often result in significant, spatially coherent residuals. These residuals are distinct from the "dark gas", and persist despite accounting for other gas phases using dust maps or various measures. Given the goal to understand the underlying cosmic ray (CR) density, spectrum, and its spatial variation through the Galactic disk, the distribution and column density of the gas with which the CRs interact must be sensitively constrained. We present a study of the gamma-ray emission from the  $\rho$  Ophiuchi molecular cloud seen by Fermi, and compare this emission to a number of column density tracers, including near IR stellar extinction and dust emission. This nearby molecular cloud exhibits a broad dynamic range in extinction, notably atypical dust properties, and a number of embedded B stars which heat the dust and may also act as local CR sources

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**Institution(s):** 1. CUNY Graduate Center, 2. CUNY Hunter College, 3. CUNY York College

### 347.05 – Physical Conditions in the Molecular Gas of the Local Group Dwarf Starburst, IC 10

We present new multi-transition mapping of the molecular gas in the nearest dwarf starburst galaxy, the Local Group dwarf IC 10. Using the IRAM 30-m telescope, we have mapped the CO(1-0), CO(2-1), and  $13\text{CO}(1-0)$  transitions over the whole area of the disk. We followed up these observations with targeted ARO SMT spectroscopy of the CO(2-1) and  $13\text{CO}(2-1)$  transitions. Together these give the most complete, sensitive view of the internal conditions in the molecular gas of a dwarf starburst galaxy to date. We present the resolved CO line ratios for this dwarf starburst and discuss their implications for the excitation, density, and optical thickness of the CO-emitting molecular gas. We consider both basic LTE calculations and comparing to the results of LVG (Radex) modeling.

**Author(s):** Lauren E. Bittle<sup>10</sup>, Kelsey E. Johnson<sup>10</sup>, Adam Leroy<sup>7</sup>, Remy Indebetouw<sup>10</sup>, Karin Sandstrom<sup>8</sup>, Amanda A. Kopley<sup>6</sup>, Andreas Schruba<sup>4</sup>, Alberto D. Bolatto<sup>9</sup>, Fabian Walter<sup>5</sup>, Jennifer Donovan Meyer<sup>6</sup>, Annie Hughes<sup>3</sup>, Laura Zschaechner<sup>5</sup>, Carsten Kramer<sup>1</sup>, Pierre Gratier<sup>2</sup>, Melanie Krips<sup>2</sup>, Cheoljong Lee<sup>7</sup>

**Institution(s):** 1. IRAM Granada, 2. IRAM Grenoble, 3. IRAP, 4. MPE Garching, 5. MPIA Heidelberg, 6. NRAO, 7. Ohio State University, 8. University of Arizona, 9. University of Maryland, 10. University of Virginia

### 347.06 – Radiation Hydrodynamics with GIZMO: The Disruption of Giant Molecular Clouds by Stellar Radiation Pressure

We present a numerical implementation of radiation hydrodynamics for the meshless code GIZMO. The radiation transport is treated as an anisotropic diffusion process combined with radiation pressure effects, photoionization with heating and cooling routines, and a multifrequency treatment of an arbitrary number of sources. As a first application of the method, we investigate the disruption of giant molecular clouds by stellar radiative feedback. Specifically, what fraction of the gas must a GMC convert into stars to cause

self-disruption? We test a range of cloud masses and sizes with several source luminosities to probe the effects of photoheating and radiation pressure on timescales shorter than the onset of the first supernovae. Observationally, only ~1-10% of gas is converted into stars, an inefficiency that is likely the result of feedback from newly formed stars. Whether photoheating or radiation pressure dominates is dependent on the given cloud properties. For denser clouds, we expect photoheating to play a negligible role with most of the feedback driven by radiation pressure. This work explores the necessary parameters a GMC must have in order for radiation pressure to be the main disruption process.

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**Institution(s):** 1. Caltech, 2. Pomona College

### 347.07 – Spatial Distribution of Small Organics in Prestellar and Protostellar Cores

In the interstellar medium, formaldehyde ( $\text{H}_2\text{CO}$ ) has efficient formation pathways in both the gas-phase and on the surfaces of dust grains. Methanol ( $\text{CH}_3\text{OH}$ ), on the other hand, is believed to form exclusively on grains as there are no efficient gas-phase reactions leading to  $\text{CH}_3\text{OH}$ . We present observations taken with the IRAM 30m telescope of several  $\text{H}_2\text{CO}$  and  $\text{CH}_3\text{OH}$  lines in a prestellar and protostellar core. We investigated the formation pathways of  $\text{H}_2\text{CO}$  and  $\text{CH}_3\text{OH}$  by comparing their spatial distributions. We find that in the prestellar core, the two species are anti-correlated in the densest region, while their emission is correlated in the low-density region. In contrast, for the protostellar core we find a correlation in the distribution of both species. We conclude that in the protostellar source,  $\text{H}_2\text{CO}$  and  $\text{CH}_3\text{OH}$  form together on grains and have been thermally desorbed due to the central newly formed star. In the prestellar core, however,  $\text{CH}_3\text{OH}$  forms on the ices and remains depleted in the coldest regions, while  $\text{H}_2\text{CO}$  can form efficiently in the gas-phase. This work was supported in part by the NSF REU and DoD ASSURE programs under NSF grant no. 1262851 and by the Smithsonian Institution.

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**Institution(s):** 1. Harvard-Smithsonian Center for Astrophysics, 2. University of Michigan

### 347.08 – The Galactic Arecibo L-Band Feed Array Survey Data Release 2

We present the Galactic Arecibo L-Band Feed Array HI Survey Data Release 2 (GALFA-HI DR2). Data Release 2 is a map of neutral hydrogen in the Galaxy at 4' angular resolution, 184 m/s spectral resolution, and covering the sky from  $-1^\circ < \text{dec} < 38^\circ$ . The data were taken commensally over 2000 hours of observations at the Arecibo 305 meter telescope. We present advanced data reduction methods we employed to produce a much more pristine data product than the first data release, including "über-cal"-style self-calibration with LASSO methods, and more sophisticated baseline ripple suppression methods. In addition to the 450 GB of HI data cubes, we also will be providing two ancillary data products. The first is a column density map of the sky in HI, useful for many kinds of extragalactic observations including extinction and X-ray attenuation. The second will be an HI fiber map, tracing out the fine linear structure of the ISM, which has been shown to be a useful tool for ISM magnetic field orientation and CMB polarization foregrounds.

**Author(s):** Joshua Eli Goldston Peek<sup>3</sup>, Brian L Babler<sup>5</sup>, Kevin A Douglas<sup>2</sup>, Yong Zheng<sup>1</sup>, Susan Clark<sup>1</sup>, Mary E. Putman<sup>1</sup>, Snezana Stanimirovic<sup>5</sup>, Carl E. Heiles<sup>4</sup>, Steven J. Gibson<sup>6</sup>, Eric J. Korpela<sup>4</sup>  
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### 347.09 – Kinematics of Filaments in Serpens and Perseus

Following up on the CARMA Large Area Star Formation Survey (CLASSy), we observed specific filaments in the Serpens and Perseus clouds using  $\text{H}^{13}\text{CO}^+$ ,  $\text{H}^{13}\text{CN}$ , and  $\text{HNC } J=1-0$  transitions at 7" angular resolution and 0.16 km/s spectral resolution. The

isotopologues containing  $^{13}\text{C}$  are optically thin; hence they trace the high column density regions of dense gas ( $n_{\text{crit}} \sim 10^5 \text{ cm}^{-3}$ ) better than their more abundant  $^{12}\text{C}$  counterparts which were observed previously (Lee et al. 2014). The HNC lines show significant self-absorption features from overlying lower density gas along many lines of sight. Many of the filaments showed velocity gradients perpendicular to the long axis of filaments in  $\text{H}^{13}\text{CO}^+$  and  $\text{H}^{13}\text{CN}$  emission, thereby supporting the model by Chen and Ostriker (2014) in which filaments form in the dense layer created by colliding turbulent cells. The signature velocity gradient occurs because the filaments are primarily accreting material in a 2-D flow within the dense layer.

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**Institution(s):** 1. University of Maryland

### 347.10 – The Southern HII Region Discovery Survey

HII regions are zones of ionized gas surrounding recently formed high-mass (OB-type) stars. They are among the brightest objects in the sky at radio wavelengths. HII regions provide a useful tool in constraining the Galactic morphological structure, chemical structure, and star formation rate. We describe the Southern HII Region Discovery Survey (SHRDS), an Australia Telescope Compact Array (ATCA) survey that discovered ~80 new HII regions (so far) in the Galactic longitude range 230 degrees to 360 degrees. This project is an extension of the Green Bank Telescope HII Region Discovery Survey (GBT HRDS), Arecibo HRDS, and GBT Widefield Infrared Survey Explorer (WISE) HRDS, which together discovered ~800 new HII regions in the Galactic longitude range -20 degrees to 270 degrees. Similar to those surveys, candidate HII regions were chosen from 20 micron emission (from WISE) coincident with 10 micron (WISE) and 20 cm (SGPS) emission. By using the ATCA to detect radio continuum and radio recombination line emission from a subset of these candidates, we have added to the population of known Galactic HII regions.

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### 347.11 – CO Spectral Line Energy Distributions in Orion Sources: Templates for Extragalactic Observations

Relative populations in the excited rotational levels of CO are sensitive to conditions in the interstellar medium. Emission lines originating in these levels can thus be used in constraining parameters such as density, temperature, and radiation field. The Herschel Space Observatory has enabled the observation of CO emission lines arising from the  $J=4$  through  $J=48$  rotational levels, many of which are detected in different sources within the Orion star-forming region. We present observations of CO emission toward Orion KL, Orion H2 Peak 1, Orion South, and the Orion Bar, all of which show distinctive CO spectral line energy distributions (SLEDs) indicating the different excitation mechanisms at work. Using the high spectral resolution HIFI observations, we decompose emission line profiles into multiple components (e.g., shock, outflow, photodissociation region, ambient cloud) in order to characterize the CO SLED associated with each component. In doing so, we generate templates for the various excitation mechanisms that can be applied toward understanding the processes occurring in unresolved star-forming regions where CO observations have been made.

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### 347.12 – OH Zeeman Studies of Magnetic Field

## Strengths in Molecular Clouds

Although stars have long been known to form in the gravitational collapse of molecular clouds, the details of the formation process are not well understood. There are many questions surrounding the formation mechanism of the clouds and the timescales on which they collapse. Star formation within the Galaxy has been found to be extremely inefficient, with stars forming at only 1-3% of the expected rate. Multiple theories addressing this inefficiency have emerged, placing varying degrees of emphasis on the magnetic fields and turbulence within the interstellar medium. One major difference in leading theories is the strength of the magnetic fields permeating the clouds and the extent to which they can provide support against cloud collapse. One way to determine the effect of magnetic fields is to determine the ratio between the gravitational and magnetic energies, called the mass-to-flux ratio, within the clouds to determine whether they are magnetically subcritical or supercritical. Much work has been done to determine this ratio in the cores of molecular clouds, but little is currently known about the fields in the envelopes of the clouds where most of the mass resides. We present the results of an extensive observational survey aimed at characterizing the fields in molecular clouds as a whole. We use the Arecibo telescope to determine mass-to-flux ratios in clouds distributed throughout the sky via the Zeeman effect in 18 cm OH absorption lines. This statistical study provides magnetic field and mass-to-flux results for 41 clouds located along 22 lines-of-sight. We find the first evidence for subcritical molecular gas along individual lines-of-sight, and a statistical analysis suggests that the mass-to-flux ratio in the envelopes of molecular clouds is approximately critical overall.

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## 347.13 – Leaking Photons from the HII Region NGC 7538

Using data from the NRAO Green Bank Telescope and the INT Photometric H-Alpha Survey of the Northern Galactic Plane (IPHAS), we analyze the ionizing radiation that is escaping the photo-dissociation region (PDR) boundary of the HII region NGC 7538. We find extended radio continuum and radio recombination line (RRL) emission outside the PDR toward the north and east of the region. This suggests that a non-uniform PDR morphology is affecting the amount of radiation “leaking” through the PDR. We quantify the leaking photon fraction along the line of sight, and use a numerical model to estimate the leaking photon fraction in three dimensions of both radio continuum and H-alpha emission. We detect carbon RRL emission near the PDR and find a decrease in the helium-to-hydrogen ionic abundance ratio with increasing distance from the central position. This indicates a softening of the radiation field within the PDR. Using Herschel Space Observatory data, we create a dust temperature map of the region and show that small dust temperature enhancements to the north and east of NGC 7538 coincide with extended radio emission. We discuss implications for maintaining the ionization of the warm interstellar medium by HII regions.

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## 347.14 – Interstellar Extinction in the Direction of NGC 7380 (Sh2-142)

Multi-wavelength polarization measurements of stars in NGC 7380, centered on the emission nebula Sh2-142 are presented. The polarization is found to be in the direction of the magnetic field of the galaxy for this region with the degree of polarization ranging from 1.8% to 3.3%. The wavelength of maximum polarization ranges from 0.413  $\mu\text{m}$  to 0.661  $\mu\text{m}$ . Using the dependence of the ratio of total to selective extinction  $R = (5.6 \pm 0.3)\lambda_{\text{max}}$  an average value of  $R = 3.05 \pm 0.09$  results. The wavelength of maximum polarization is also shown to be strongly correlated to  $E(B - V)$  color excess.

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## 347.15 – A Search for Gravitationally Bound Cloud Cores within the CMZ

In general, current star formation theories successfully model the rate at which stars are forming throughout our Galaxy as well as others, with the star formation rate (SFR) in a given region being proportional to the amount of gas above a threshold density. The Central Molecular Zone (CMZ) of our Galaxy is an excellent place to test these models. It is home to the highest amount of dense, molecular gas within our Galaxy—and yet, the SFR within this region is an order of magnitude lower than would be expected using current star formation models. This project utilizes data taken from the SMA Legacy Survey of the CMZ, in a search for gravitationally bound structures within three small gas clouds near the Galactic Center, as well as the 1.6 degree cloud. Dense gas structures are detected using H<sub>2</sub>CO—a dense gas tracer, and 1.3mm cold, dust continuum. These regions are catalogued using dendrograms to identify which structures have continuous and significant H<sub>2</sub>CO emission. Gravitationally bound candidates were identified by deriving each structure’s virial ratio. Within the three clouds near the GC, 40 structures were catalogued, with one structure that was found to be gravitationally bound. Very large virial ratios are the result of large H<sub>2</sub>CO line widths, possibly due to a high degree of tidal compression. This analysis is also performed on the 1.6 degree cloud, in a region with two suspected bound cores. One of these two cores is close to virial equilibrium and likely gravitationally bound, thus providing support for the use of this method on other clouds within the CMZ. This work supported in part by the NSF REU and DoD ASSURE programs under grant no. 1262851 and by the Smithsonian Institution.

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## 347.16 – Constraining the Properties of Cold Interstellar Clouds

Since the interstellar medium (ISM) plays an integral role in star formation and galactic structure, it is important to understand the evolution of clouds over time, including the processes of cooling and condensation that lead to the formation of new stars. This work aims to constrain and better understand the physical properties of the cold ISM by utilizing large surveys of neutral atomic hydrogen (HI) 21cm spectral line emission and absorption, carbon monoxide (CO) 2.6mm line emission, and multi-band infrared dust thermal continuum emission. We identify areas where the gas may be cooling and forming molecules using HI self-absorption (HISA), in which cold foreground HI absorbs radiation from warmer background HI emission.

We are developing an algorithm that uses total gas column densities inferred from Planck and other FIR/sub-mm data in parallel with CO and HISA spectral line data to determine the gas temperature, density, molecular abundance, and other properties as functions of position. We can then map these properties to study their variation throughout an individual cloud as well as any dependencies on location or environment within the Galaxy.

Funding for this work was provided by the National Science Foundation, the NASA Kentucky Space Grant Consortium, the WKU Ogden College of Science and Engineering, and the Carol Martin Gattton Academy for Mathematics and Science in Kentucky.

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## 347.17 – The Wisconsin H-Alpha Mapper Sky Survey

We present the first all-sky, kinematic survey of H $\alpha$  from the Milky Way, combining survey observations taken with the Wisconsin H-Alpha Mapper (WHAM) from Kitt Peak (1997-2007) and Cerro Tololo (2009-present). The WHAM Sky Survey (WHAM-SS) reaches sensitivity levels of about 0.1 R (EM  $\sim 0.2 \text{ pc cm}^{-6}$ ) with emission detected toward every direction in the sky. Each pointing of the survey comprises a spatially integrated spectrum from a one-degree

beam on the sky covering at least 200 km/s around the Local Standard of Rest with 12 km/s spectral resolution. WHAM was designed primarily to study the pervasive warm ionized medium (WIM) component of the interstellar medium (ISM) but also reveals many large-scale, locally-ionized regions throughout the Galaxy. The WIM is a diffuse but thick component of the ISM that extends several kiloparsecs into the Galactic halo with a kinematic signature that traces the gaseous spiral arms of the Galaxy. In addition to this fairly smooth global emission, the H $\alpha$  sky contains many individual H II regions and supernova remnants, a few revealed in the WHAM-SS for the first time. Some locations are dominated by complex filamentary network of diffuse ionized gas where the ISM has been shaped by past winds and supernovae and is now powered by a new wave of star formation. At high latitudes, faint emission from intermediate-velocity clouds is also regularly present. The success of WHAM as a fully remote observing facility for nearly two decades is due in no small part to the excellent and responsive support staff at KPNO in Arizona and CTIO in Chile. WHAM has been designed, built, and operated primarily through support of the National Science Foundation. The current research presented here is funded by award AST-1108911.

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### 347.18 – The All-sky Kinematics of Diffuse Galactic H-alpha Emission from WHAM

WHAM-SS (Wisconsin H-alpha Mapper Sky Survey) is the first all-sky velocity-resolved survey of the faint optical emission line radiation from the diffuse ionized gas of the Milky Way Galaxy. With an angular resolution of one degree, velocity resolution of 12 km/s, and velocity range of 200 km/s, it allows for the study of the kinematics of the ionized gas across the Galaxy. We present first results on the all-sky velocity distribution of this gas. We show the results of Gaussian decomposition of line profiles as well as first and second moment maps both in the disk and at high latitude, and compare our results with some simple models for the density and velocity field of this gas. As in Haffner et al. (2003), we find that the high-latitude sky is characterized by a low velocity “infall” (toward the plane) in H-alpha, although there are also regions of outflow. We also present the variation in line widths as a function of direction and show how these widths correlate with different structures in the warm ionized medium. This program was supported by NSF Award AST-1108911 (for WHAM) and NSF Award AST-1004881 for the Wisconsin REU program in Astrophysics.

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**Institution(s):** 1. University of Wisconsin-Madison, 2. University of Wisconsin-Whitewater

### 347.19 – WHAM observations of ionized gas in the inner Milky Way

We present Wisconsin H-Alpha Mapper (WHAM) observations of ionized gas in the southern Milky Way. We include spectroscopic maps of H-Alpha, [S II], and [N II]. The data includes the Scutum-Centaurus Arm, for which we measure an exponential scale height about 20% less than that in the Perseus Arm in the outer Galaxy. The H-alpha scale height suggests a lower electron scale height in both arms than is measured locally from pulsar dispersion. The [N II] and [S II] data provide information about the temperature and ionization state of the gas: gas in the warm ionized medium is generally warmer ( $\approx 8000$  K) and in lower ionization states than gas in classical H II regions. WHAM research and operations are supported through NSF Award AST-1108911.

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### 347.20 – Discovery and Characterization of Large-Angular Size Ionized Nebulae with WHAM

We present a catalog of large-angular size (radius  $> 0.25$  deg) ionized nebula detected as part of the WHAM-SS (Wisconsin H-alpha Mapper Sky Survey). Starting with the the combined H-alpha surveys of WHAM, SHASSA (Southern H-alpha Sky Survey Atlas), and VTSS (Virginia Tech Spectral Survey), we identified 758 nebula candidates for follow-up study; 105 of these were not previously cataloged. From this list, we selected all nebulae larger than 0.25 degree that contained the center of a WHAM (one-degree) beam. We present the H-alpha Doppler shift velocities, H-alpha line-widths, nebular emission measures, and when possible the [S II]/H alpha ratio for each of these objects and compare them to typical Galactic HII regions and the diffuse warm ionized medium. Using kinematic distances, we also examining the size and spatial distribution of these sources and compare our results to recent catalogs of Galactic HII regions.

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**Institution(s):** 1. Texas Southern University, 2. University of Wisconsin-Madison, 3. University of Wisconsin-Whitewater

### 347.21 – WHAM Observations of High-latitude Supernova Remnants

The Wisconsin H-Alpha Mapper Sky Survey (WHAM-SS) traces numerous large-angle, diffuse regions containing filamentary and shell-like structures. The largest of these are complex supershells that harbor recent and on-going star formation, such as the Orion-Eridanus complex, the Gum Nebula, and the extended emission above and below the W3/W4/W5 star-forming regions in the Perseus Arm. Several large-diameter regions with simpler morphologies are also present, which we focus on here. While some of these structures are diffuse H II regions powered by nearby, isolated stars, others are clearly supernova remnants (SNRs) due to their association with X-ray or non-thermal radio emission. We highlight the structure, kinematics, and multi-wavelength properties of several SNRs using H $\alpha$  maps from the WHAM-SS and data from on-going WHAM multi-wavelength surveys. WHAM research and operations are supported through NSF Award AST-1108911.

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## 348 – Computation, Data Handling, Image Analysis Poster Session

### 348.01 – Making your code citable with the Astrophysics Source Code Library

The Astrophysics Source Code Library (ASCL, ascl.net) is a free online registry of codes used in astronomy research. With nearly 1,200 codes, it is the largest indexed resource for astronomy codes in existence. Established in 1999, it offers software authors a path to citation of their research codes even without publication of a paper describing the software, and offers scientists a way to find codes used in refereed publications, thus improving the transparency of the research. It also provides a method to quantify the impact of source codes in a fashion similar to the science metrics of journal articles. Citations using ASCL IDs are accepted by major astronomy journals and if formatted properly are tracked by ADS and other indexing services. The number of citations to ASCL entries increased sharply from 110 citations in January 2014 to 456 citations in September 2015. The percentage of code entries in ASCL that were cited at least once rose from 7.5% in January 2014 to 17.4% in September 2015. The ASCL's mid-2014 infrastructure upgrade added an easy entry

submission form, more flexible browsing, search capabilities, and an RSS feeder for updates. A Changes/Additions form added this past fall lets authors submit links for papers that use their codes for addition to the ASCL entry even if those papers don't formally cite the codes, thus increasing the transparency of that research and capturing the value of their software to the community.

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### 348.02 – Monitoring Polaris and Seeing Conditions at PARI

Pisgah Astronomical Research Institute (PARI) was originally built by NASA to track and collect data from satellites. The location in the Pisgah National Forest was chosen due to the excellent ability of the surrounding mountains to block radio interference and light pollution. The PARI observatory has been monitoring Polaris for over 10 years and has amassed a large collection of images of the star and those surrounding it. While several telescopes have been used throughout the project, we are currently using a Omni XLT Series Celestron and an SBIG ST-8300M CCD camera with a 0.70 arcsecond/pixel ratio. The software is run on Windows, however, we will be making a switch to Linux and implementing a new program to control the camera. The new images, once converted to a usable format (ST10 to FITS), can be automatically fed into an in-house Java program to track the variability of the star and simultaneously determine the seeing conditions experienced on the campus. Since we have several years worth of data, the program will also be used to provide a history of variability and seeing conditions. We ultimately hope to be able to track the possible changes in variability of Polaris, as it's current location on the HR diagram is being studied. The data could also prove valuable for our on-site scientists and many visiting students to study on campus. We are also developing a relative scale for our seeing conditions, accompanied by FWHM measurements in arcseconds that will can be compared to those of surrounding observatories in mountainous areas.

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**Institution(s):** 1. Pisgah Astronomical Research Institute

### 348.03 – Sky Background Variability Measured on Maunakea at Gemini North Observatory

Gemini North has recently implemented a Quality Assessment Pipeline (QAP) that automatically reduces images in realtime to determine sky condition quantities, including background sky brightness from the optical to near-infrared. Processing archived images through the QAP and mining the results allows us to look for trends and systematic issues with the instruments and optics during the first decade of Gemini.

Here we present the results of using the QAP calculated values to quantify how airglow affects the background sky brightness of images taken with Gemini's imaging instruments, GMOS and NIRI, as well as searching for other factors that may cause changes in the sky brightness. By investigating the dependence of measured sky brightness as a function of a variety of variables, including time after twilight, airmass, season, distance from the moon, air temperature, etc., we quantify the effect of sky brightness and its impact on the sensitivity of Gemini optical and near-infrared imaging data. These measurements will be used to determine new sky background relationships for Maunakea, and to improve the Gemini Integration Time Calculators (ITCs).

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**Institution(s):** 1. Gemini Observatory

### 348.04 – Refining Sunrise/set Prediction Models by Accounting for the Effects of Refraction

Current atmospheric models used to predict the times of sunrise and sunset have an error of one to four minutes at mid-latitudes (0° - 55° N/S). At higher latitudes, slight changes in refraction may cause significant discrepancies, including determining even whether the Sun appears to rise or set. While different components of refraction are known, how they affect predictions of sunrise/set has not yet been quantified. A better understanding of the contributions from temperature profile, pressure, humidity, and aerosols, could significantly improve the standard prediction. Because sunrise/set times and meteorological data from multiple locations will be necessary for a thorough investigation of the problem, we will collect this data using smartphones as part of a citizen science project. This analysis will lead to more complete models that will provide more accurate times for navigators and outdoorsman alike.

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**Institution(s):** 1. Michigan Technological University, 2. United States Naval Observatory

### 348.05 – 3D Visualization of Machine Learning Algorithms with Astronomical Data

We present innovative machine learning (ML) methods using unsupervised clustering with minimum spanning trees (MSTs) to study 3D astronomical catalogs. Utilizing Python code to build trees based on galaxy catalogs, we can render the results with the visualization suite Blender to produce interactive 360 degree panoramic videos. The catalogs and their ML results can be explored in a 3D space using mobile devices, tablets or desktop browsers. We compare the statistics of the MST results to a number of machine learning methods relating to optimization and efficiency.

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**Institution(s):** 1. NRAO

### 348.06 – User extensibility of the Firefly astronomical visualization software

We have developed mechanisms for extending the functionality of the open-source Firefly astronomical visualization software with user-supplied code. Firefly is a toolkit for the construction of Web-based applications for visualizing astronomical images and tabular data, with the software distribution also including a basic general-purpose pre-built application. The Firefly tools are the base for NASA's IRSA archive as well as other web applications developed at IPAC.

Recent releases include new public APIs allowing the extension of Firefly functionality in various ways. New Javascript APIs allow customization of the interface presented in the browser, including the ability to define buttons for custom actions that can be performed on points, lines, and regions in images. New Python APIs allow the invocation of operations in a Firefly-based application, allowing it to serve as a display engine for FITS images and other astronomical data. In addition, the Firefly web server side has been enhanced with the ability to invoke user-supplied processes that can produce either image or tabular results based on operations on data from the application or external sources. For instance, the user can define an operation to perform source detection on a graphically selected region in an image and return the results for display as a table and/or x-y plot. User processes can be defined in any language supported on the server host; our current efforts have focused on Python. This mechanism has been used to support the integration of Firefly with the LSST project's software stack, with reusable "tasks" from the LSST stack configurable as extensions to Firefly.

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**Institution(s):** 1. California Institute of Technology / IPAC

### 348.07 – Understanding and Using the Fermi Science Tools

The Fermi Science Support Center (FSSC) provides information, documentation, and tools for the analysis of Fermi science data, including both the Large-Area Telescope (LAT) and the Gamma-ray Burst Monitor (GBM). Source and binary versions of the Fermi Science Tools can be downloaded from the FSSC website, and are supported on multiple platforms. An overview document, the Cicerone, provides details of the Fermi mission, the science instruments and their response functions, the science data preparation and analysis process, and interpretation of the results. Analysis Threads and a reference manual available on the FSSC website provide the user with step-by-step instructions for many different types of data analysis: point source analysis - generating maps, spectra, and light curves, pulsar timing analysis, source identification, and the use of python for scripting customized analysis chains. We present an overview of the structure of the Fermi science tools and documentation, and how to acquire them. We also provide examples of standard analyses, including tips and tricks for improving Fermi science analysis.

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**Institution(s):** 1. Fermi Science Support Center

**Contributing team(s):** Fermi Science Support Center Team

### 348.08 – Fermi Science Support Center Data Servers and Archive

The Fermi Science Support Center (FSSC) provides the scientific community with access to Fermi data and other products. The Gamma-Ray Burst Monitor (GBM) data is stored at NASA's High Energy Astrophysics Science Archive Research Center (HEASARC) and is accessible through their searchable Browse web interface. The Large Area Telescope (LAT) data is distributed through a custom FSSC interface where users can request all photons detected from a region on the sky over a specified time and energy range. Through its website the FSSC also provides planning and scheduling products, such as long and short term observing timelines, spacecraft position and attitude histories, and exposure maps. We present an overview of the different data products provided by the FSSC, how they can be accessed, and statistics on the archive usage since launch.

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**Institution(s):** 1. Goddard Space Flight Center

**Contributing team(s):** FSSC, LAT Collaboration

### 348.09 – A Refreshable, On-line Cache for HST Data Retrieval

We discuss upgrades to the HST Data Processing System, with an emphasis on the changes Hubble Space Telescope (HST) Archive users will experience. In particular, data are now held on-line (in a cache) removing the need to reprocess the data every time they are requested from the Archive. OTFR (on the fly reprocessing) has been replaced by a reprocessing system, which runs in the background. Data in the cache are automatically placed in the reprocessing queue when updated calibration reference files are received or when an improved calibration algorithm is installed. Data in the on-line cache are expected to be the most up to date version. These changes were phased in throughout 2015 for all active instruments.

The on-line cache was populated instrument by instrument over the course of 2015. As data were placed in the cache, the flag that triggers OTFR was reset so that OTFR no longer runs on these data. "Hybrid" requests to the Archive are handled transparently, with data not yet in the cache provided via OTFR and the remaining data provided from the cache. Users do not need to make separate requests.

Users of the MAST Portal will be able to download data from the cache immediately. For data not in the cache, the Portal will send the user to the standard "Retrieval Options Page," allowing the user to direct the Archive to process and deliver the data.

The classic MAST Search and Retrieval interface has the same look and feel as previously. Minor changes, unrelated to the cache, have been made to the format of the Retrieval Options Page.

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**Institution(s):** 1. Computer Sciences Corp.

**Contributing team(s):** DPAS Team

### 348.10 – Proper coaddition of speckle images - diffraction limited ground-based imaging with high dynamic range

We present a method to conduct high spatial resolution imaging using an extension of the optimal coaddition method presented in Zackay & Ofek 2015 to stacks of short exposures with durations less than the atmospheric correlation time scale. We show that this method has major advantages over popular techniques like speckle interferometry and lucky imaging. We demonstrate the efficacy of this method by application to a stack of 100Hz R-band speckle images taken with a 40 cm telescope ( $\lambda/D=0.31''$ ), under 3" seeing condition (total exposure of 8min). We resolve 0.5" separation binaries with a contrast of about 5 magnitudes.

Scaling this result to larger telescopes located at better observing sites, we argue that this method may have important consequences for medium-contrast ( $10^{-4}$  -  $10^{-5}$ ) imaging at close angular separations.

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**Institution(s):** 1. Weizmann Institute of Science

### 348.11 – Optimal Image Subtraction

Transient detection and flux measurement via image subtraction are fundamental to time domain astronomy. Starting from first principles, we develop the optimal linear statistic for transient detection and flux measurement and any other image-difference hypothesis testing. We derive a simple closed-form statistic that: (1) Is mathematically proven to be the optimal subtraction statistic in the limit of background-dominated noise within the family of linear solutions, that contains all previously suggested methods; (2) Does not leave subtraction or deconvolution artifacts, even in the vicinity of bright stars; (3) Is an order of magnitude faster to compute than popular methods; (4) Allows automatic transient detection down to the theoretical sensitivity limit by providing a reliable, well-defined detection significance; (5) Is symmetric to the interchange of the new and reference images; (6) Is numerically stable; and (7) Is trivial to implement. We demonstrate that the correct way to prepare a reference image is the proper image co-addition presented in Zackay & Ofek 2015. Finally, we show a proper image subtraction statistic, that, along with its point spread functions, is a sufficient statistic for any decision or measurement on the difference image. This allows accurate filtration of image artifacts such as cosmic rays and hot pixels. We demonstrate this method on simulated data as well as on observations from the Palomar Transient Factory.

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**Institution(s):** 1. Weizmann Institute of Science

### 348.12 – Proper coaddition of astronomical images - One image that contains the information from all the images

We present image coaddition methods for source detection and flux measurement under both the background- and source-dominated noise regimes, that are optimized to achieve the highest possible signal-to-noise ratio (S/N). We also derive a coaddition method, which provides a sufficient statistic for any further signal processing of the data, such as source detection, star/galaxy separation or shape measurements, in the background-noise dominated case. This means that any hypothesis testing or measurement that can be done on all the individual images simultaneously, can be equivalently performed on the coadded image without any loss of information, leading to significant reduction in data storage and transmission requirements. In addition, our method produces an image with a PSF which is typically narrower than that of the highest quality image in the original ensemble, and its noise is Gaussian white noise. For seeing-limited surveys, we argue that

by using these methods an increase of between a few percents to 20% in survey speed is possible relative to simple weighted coaddition techniques. We demonstrate this claim using simulated data as well as data from the Palomar Transient Factory data release 2. This method has important implications for multi-epoch seeing-limited deep surveys, weak lensing, galaxy shape measurements, and diffraction-limited imaging via speckle observations.

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### 348.13 – The Next Generation of the Montage Image Mosaic Engine

We have released a major upgrade of the Montage image mosaic engine (<http://montage.ipac.caltech.edu>), as part of a program to develop the next generation of the engine in response to the rapid changes in the data processing landscape in Astronomy, which is generating ever larger data sets in ever more complex formats. The new release (version 4) contains modules dedicated to creating and managing mosaics of data stored as multi-dimensional arrays ("data cubes"). The new release inherits the architectural benefits of portability and scalability of the original design. The code is publicly available on Git Hub and the Montage web page. The release includes a command line tool that supports visualization of large images, and the beta-release of a Python interface to the visualization tool. We will provide examples on how to use these features. We are generating a mosaic of the Galactic Arecibo L-band Feed Array HI (GALFA-HI) Survey maps of neutral hydrogen in and around our Milky Way Galaxy, to assess the performance at scale and to develop tools and methodologies that will enable scientists inexperienced in cloud processing to exploit cloud platforms for data processing and product generation at scale. Future releases include support for an R-tree based mechanism for fast discovery of and access to large data sets and on-demand access to calibrated SDSS DR9 data that exploits its support for the Hierarchical Equal Area isoLatitude Pixelization (HEALPix) scheme, now standard for projects investigating cosmic background radiation (Gorski et al 2005); support for the Tessellated Octahedral Adaptive Subdivision Transform (TOAST), the sky partitioning sky used by the WorldWide Telescope (WWT); and a public applications programming interface (API) in C that can be called from other languages, especially Python.

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### 348.14 – Shape Information for Photometric Redshifts with a Support Vector Machine Algorithm

We present the results of using a custom support vector machine regression method to determine the effects of including galaxy morphological parameters in photometric redshift estimation. We also present a comparison with other methods. Support vector machine algorithms can be a useful estimator of the additional information contained in parameters, such as those describing morphology, because they utilize the information content of data in a way that can treat different input types symmetrically. We use a set of 2600 galaxies with imaging and five band photometric magnitudes with known spectroscopic redshifts as test data to evaluate the estimation.

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### 348.15 – The LSST Software Stack

The Large Synoptic Survey Telescope (LSST) is an 8-m optical ground-based telescope being constructed on Cerro Pachon in Chile. LSST will survey half the sky every few nights in six optical bands. The data will be transferred to the data center in North America and within 60 seconds it will be reduced using difference imaging and an alert list be generated for the community. Additionally, annual data releases will be constructed from all the data during the 10-year mission, producing catalogs and deep co-added images with

unprecedented time resolution for such a large region of sky. In the paper we present the current status of the LSST stack including the data processing components, Qserv database and data visualization software, describe how to obtain it, and provide a summary of the development road map.

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**Contributing team(s):** LSST Data Management Team

### 348.16 – Development of a Data Reduction Pipeline to Measure Stellar Radial Velocities Using Kutztown University's On-Campus Research Observatory

The Kutztown University Observatory (KUO) houses a 0.6m Ritchey–Chrétien telescope with a focal ratio of f/8. It is a dedicated observatory collecting data every clear night using the eShel model (Shelyak Instruments) echelle spectrograph. The spectral resolution is  $R = 11,000$  and the final dispersion is  $0.050 \text{ \AA/pixel}$  over the range of  $4300 \text{ \AA}$  to  $8100 \text{ \AA}$ .

It is paramount to ensure accurate radial velocity (RV) measurements when conducting projects for research and education. RV measurements at KUO are used to determine the masses of spectroscopic binary stars, study pulsations of stellar photospheres (Cepheid variables), and to perform reconnaissance RV measurements of exoplanet candidates (reflex motion of host star). We present a data reduction pipeline program that produces RV measurements from observed spectra. After using the eShel's built in ThAr lamp for wavelength calibration, the program continuum normalizes the spectrum, creates a non-moving template (synthetic and/or observed spectrum), and corrects for barycentric motion. Finally, the program performs a cross correlation of the data and template to produce accurate RV measurements. Examples of completed and on-going projects at KUO are presented. We also demonstrate our ability to observe stellar RV's with uncertainties as good as  $0.13 \text{ km/s}$ . The eShel spectrograph is commercially available and is becoming popular among users of smaller telescopes. This data reduction pipeline will be useful to the increasing number of researchers utilizing the eShel spectrograph.

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### 348.17 – Easy XMM-Newton Data Analysis with the Streamlined ABC Guide!

The US XMM-Newton GOF has streamlined the time-honored XMM-Newton ABC Guide, making it easier to find and use what users may need to analyze their data. It takes into account what type of data a user might have, if they want to reduce the data on their own machine or over the internet with Web Hera, and if they prefer to use the command window or a GUI. The GOF has also included an introduction to analyzing EPIC and RGS spectra, and PN Timing mode data. The guide is provided for free to students, educators, and researchers for educational and research purposes. Try it out at: <http://heasarc.gsfc.nasa.gov/docs/xmm/sl/intro.html>

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### 348.18 – Comparison of Stellar Classification Accuracies Using Automated Algorithms

Machine learning algorithms can be used to reduce the dimensionality of stellar spectra, and make automated classification using these spectra faster and more efficient. Much work has been done in applying one such algorithm, Principal Component Analysis (PCA), to spectra, but PCA assumes that the data is linear globally, which is not the case for spectral data. Other work has been done to examine the possibilities of applying nonlinear dimension reduction algorithms, such as Locally Linear Embedding (LLE) and Isometric Mapping (Isomap). These algorithms only require local linearity in the data, which is satisfied by spectral data. We apply PCA, LLE and Isomap to spectra of K-type stars from SDSS, and use a trained Support Vector Machine to determine subclasses of these stars. We then compare these subclasses to those given by SDSS to determine

the accuracy of the classifications. This allows us to compare the classification accuracies of PCA, LLE, and Isomap.

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### 348.19 – Variable Star Signature Classification using Slotted Symbolic Markov Modeling

With the advent of digital astronomy, new benefits and new challenges have been presented to the modern day astronomer. No longer can the astronomer rely on manual processing, instead the profession as a whole has begun to adopt more advanced computational means. Our research focuses on the construction and application of a novel time-domain signature extraction methodology and the development of a supporting supervised pattern classification algorithm for the identification of variable stars. A methodology for the reduction of stellar variable observations (time-domain data) into a novel feature space representation is introduced. The methodology presented will be referred to as Slotted Symbolic Markov Modeling (SSMM) and has a number of advantages which will be demonstrated to be beneficial; specifically to the supervised classification of stellar variables. It will be shown that the methodology outperformed a baseline standard methodology on a standardized set of stellar light curve data. The performance on a set of data derived from the LINEAR dataset will also be shown.

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### 348.20 – Supernova Photometric Lightcurve Classification

This is a preliminary report on photometric supernova classification. We first explore the properties of supernova light curves, and attempt to restructure the unevenly sampled and sparse data from assorted datasets to allow for processing and classification. The data was primarily drawn from the Dark Energy Survey (DES) simulated data, created for the Supernova Photometric Classification Challenge. This poster shows a method for producing a non-parametric representation of the light curve data, and applying a Random Forest classifier algorithm to distinguish between supernovae types. We examine the impact of Principal Component Analysis to reduce the dimensionality of the dataset, for future classification work. The classification code will be used in a stage of the ANTARES pipeline, created for use on the Large Synoptic Survey Telescope alert data and other wide-field surveys. The final figure-of-merit for the DES data in the r band was 60% for binary classification (Type I vs II). Zaidi was supported by the NOAO/KPNO Research Experiences for Undergraduates (REU) Program which is funded by the National Science Foundation Research Experiences for Undergraduates Program (AST-1262829).

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### 348.21 – Python Program to Select HII Region Models

HII regions are areas of singly ionized Hydrogen formed by the ionizing radiation of upper main sequence stars. The infrared fine-structure line emissions, particularly Oxygen, Nitrogen, and Neon, can give important information about HII regions including gas temperature and density, elemental abundances, and the effective temperature of the stars that form them. The processes involved in calculating this information from observational data are complex. Models, such as those provided in Rubin 1984 and those produced by Cloudy (Ferland et al, 2013) enable one to extract physical parameters from observational data. However, the multitude of search parameters can make sifting through models tedious. I digitized Rubin's models and wrote a Python program that is able to take observed line ratios and their uncertainties and find the Rubin or Cloudy model that best matches the observational data. By creating a Python script that is user friendly and able to quickly sort through models with a high level of accuracy, this work increases efficiency and reduces human error in matching HII region models to observational data.

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### 348.22 – Recovering Astrophysical Signals of Background Variable Sources in Kepler Data by Means of Custom Aperture Photometry

Originally designed for exoplanet discovery, the NASA *Kepler* mission conducted long-baseline observations of hundreds of thousands of stars, providing a wealth of high-precision photometric data useful for a wide variety of scientific investigations (multiple stellar systems, long-period variables, asteroseismology, etc.). By examining astrophysical targets in the *Kepler* data set and performing pixel-level data analysis and custom aperture photometry, we seek to identify contaminating astrophysical sources of variability. We are using our own customized suite of Python programs to perform photometry, visualization, data reduction, and differential image analysis, all of which will aid us in determining whether the variability identified in the released *Kepler* light curves is a result of true variation in the target stars (i.e. eclipsing binaries, pulsating variables, etc.) or if the photometric signals have been contaminated by the presence of background astrophysical sources. In the case of the latter, we obtain optimized light curves for the background variables using the custom apertures.

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### 348.23 – The NIRSPEC Data Reduction Pipeline for the Keck Observatory Archive

The Keck Observatory Archive (KOA), a collaboration between the NASA Exoplanet Science Institute and the W. M. Keck Observatory, serves science and calibration data for all current and retired instruments from the twin Keck Telescopes. In addition to the raw data, we publicly serve quick-look, reduced data products for four instruments (HIRES, LWS, NIRC2 and OSIRIS), so that KOA users can easily assess the quality and scientific content of the data. In this paper we present the design and implementation of the data reduction pipeline (DRP) for the NIRSPEC instrument for use with KOA. We discuss the publicly available reduction packages for NIRSPEC, the challenges encountered when designing this fully automated DRP and the algorithm used to determine wavelength calibration from sky lines. The reduced data products from the NIRSPEC DRP are expected to be available in KOA by mid-2016.

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**Contributing team(s):** KOA Team

### 348.24 – Open Source Science: The Gravitational Wave Processing-Enabled Archive for NANOGrav

The North American Nanohertz Gravitational Wave Observatory (NANOGrav) dataset comprises pulsar timing data and data products from a continuing decades-long campaign of observations and high-precision analysis of over 40 millisecond pulsars conducted with the intent to detect nanohertz gravitational waves. Employing a team of developers, researchers and undergraduates, we have built an open source interface based on iPython/Jupyter notebooks allowing programmatic access and processing of the archived raw data and data products in order to greatly enhance science throughput. This is accomplished by: allowing instant access to the current dataset, subject to proprietary periods; providing an intuitive sandbox environment with a growing standard suite of analysis software to enhance learning opportunities for students in the NANOGrav science areas; and driving the development and sharing of new open source analysis tools. We also provide a separate web visualization interface, primarily developed by undergraduates, that allows the user to perform natural queries for data table construction and download, providing an environment for plotting both primary science and diagnostic data, with the next iteration allowing for real-time analysis tools such as model fitting and high-precision timing.

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**Contributing team(s):** NANOGrav consortium

## 349 – Catalogs, Surveys and Large Programs Poster Session

### 349.01 – Creation of a Mock Universe: Photometric Astronomy on Simulation

A major focus in astronomy is to understand how galaxies form and evolve in the Universe. The current model known as  $\Lambda$ CDM explains that galaxies form and evolve in halos composed of cold dark matter. In an effort to understand galactic processes in relation to halos, researchers have developed statistical methods to connect galaxies to their halos. One of these approaches is abundance matching: a technique in which the galaxy number density of a property is connected to a theoretical halo number density. In this study, we exploit the abundance matching technique and create a massive photometric mock catalog. We populate millions of dark matter halos in the Bolshoi-Planck Simulation with highly defined galaxies that each has: luminosities, magnitudes, fluxes, masses, and Sérsic profiles. Our catalog acts as an interface between cold dark matter theory and observations: astronomers can use this mock galaxy catalog to compare  $\Lambda$ CDM predictions to observations as well as constrain galaxy formation models. Using our catalog, we can make powerful predictions about both theoretical data and about future astronomical surveys. We demonstrate the usability of our catalog through angular power spectra. Specifically, we shed light on the controversial intrahalo light phenomena. We *emphasize* that this is the first catalog of this accuracy and size and has incredible potential for application.

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### 349.02 – Geographically Distributed Citizen Scientist Training for the 2017 Citizen CATE Experiment

The solar eclipse of 21 August 2017 will be visible to over a half billion people across the entire North American continent. The roughly 100-mile wide path of totality, stretching from Oregon to South Carolina, will be the destination for tens of millions of people. In the decades since 1979, when the last total solar eclipse was visible from the continental USA, the phenomenon of Internet enabled citizen science has grown to be an accepted mode for science. The Citizen Continental-America Telescopic Eclipse (Citizen CATE) experiment has been funded as one of the three 2017 eclipse related NASA STEM agreements to engage citizen scientists in a unique, cutting-edge solar physics experiment. Teams across the USA will be trained to use standardized refracting telescope and digital imager set-ups to observe the solar corona during the eclipse, acquiring multiple exposures to create one high dynamic range image. After observing during the eclipse, the CATE volunteers will upload the combined image to a cloud-storage site and the CATE team will then work to properly orient and align all the images collected from across the continent to produce a continuous 90-minutes movie. A time-compressed first cut of the entire sequence will be made available to media outlets on the same afternoon of the eclipse, with hope that high quality images will encourage the most accurate coverage of this Great American Eclipse. We discuss overall the project, as well as details of the initial tests of the prototype set-up (including in the Faroe Islands during the March 2015 total solar eclipse) and plans for the future night-time and day-time observing campaigns, and for a handful of observing teams positioned for overlapping observations of the March 2016 total solar eclipse in the South Pacific.

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### 349.03 – The SDSS-IV in 2015: Report of the Committee on the Participation of Women in the Sloan Digital Sky Survey

Given that many astronomers now participate in large international scientific collaborations, it is important to examine whether these structures foster a healthy scientific climate that is inclusive and diverse. The Committee on the Participation of Women in the Sloan Digital Sky Survey (CPWS) was formed to evaluate the climate and demographics within the SDSS collaboration and to make recommendations for how best to establish the scientific and technical leadership team for SDSS-IV. Building on the work described in Lundgren et al. (2015), the CPWS conducted a demographic survey in Spring 2015 that included questions about career and leadership status, racial / ethnic identity, gender identity, identification with the LGBT community, disability, partnership status, and level of parental education. For example, 71% of survey respondents identify as male and 81% do not identify as a racial or ethnic minority at their current institution. This reflects the under-representation of women and men from minority groups (e.g., people of color in the United States) and women from majority groups (e.g., white women in the United States) in the field of astronomy. We have focused our analysis on the representation of scientists from these groups among the SDSS-IV leadership and the full collaboration. Our goal is to use these quantitative data to track the demographics of SDSS-IV membership and leadership over time as we work to assess and improve the climate of SDSS-IV.

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**Contributing team(s):** SDSS-IV Collaboration

### 349.04 – White Dwarfs for Calibrating the Dark Energy Survey

The Dark Energy Survey (DES) is surveying some 5000 square degrees in the southern hemisphere in the grizY filter system using the new Dark Energy Camera. In order to verify meeting photometric calibration requirements, we are obtaining imaging of several hundred white dwarfs (confirmed and candidates) to select nearly 100 or more hydrogen atmosphere (DA) white dwarfs for spectroscopy in the DES footprint. The spectra that are obtained will be extracted and used to derive synthetic spectra that can be compared with DES measurements from imaging in each of the DES grizY filters. This comparison should be able to verify and help calibrate the survey to a level better than 2% photometrically and to better than 0.5% in colors. We will discuss the observational and modeling effort required to develop a well-characterized DAs sample and present some preliminary results. This set would form the basis of a larger set of southern hemisphere survey calibration stars, and additionally serve as a legacy calibration set in the upcoming era of the LSST survey and the giant segmented mirror observatories. These stars will be used to establish and monitor the color zero points for the DES photometric system and can be used to search for systematic errors in the color zero points over the DES footprint. These stars will also be used as some of the primary standards for the DES photometric system which will allow nightly atmospheric monitoring during DES operations.

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### 349.05 – SpIES: The *Spitzer* IRAC Equatorial Survey

We describe the first data release from the *Spitzer*-IRAC Equatorial Survey (SpIES); a large-area survey of the Equatorial SDSS Stripe 82 field using Warm *Spitzer*. SpIES was designed to probe enough volume to perform measurements of the  $z > 3$  quasar clustering and luminosity function in order to test various “AGN feedback” models. Additionally, the wide range of multi-wavelength, multi-epoch ancillary data makes SpIES a prime location to identify both high-redshift ( $z > 6$ ) quasars as well as obscured quasars missed by optical surveys. SpIES maps  $\sim 115\text{deg}^2$  of Stripe 82 to depths of 6.3 uJy (21.9 AB Magnitudes) and 5.75 uJy (22.0 AB Magnitudes) at [3.6] and [4.5] microns respectively; depths significantly greater than WISE. Here we define the SpIES survey parameters and describe the image processing, source extraction, and catalog production methods used to analyze the SpIES data. Amongst our preliminary science results, we show high significance detections of spectroscopically confirmed,  $z \sim 5$  quasars in the SpIES data. This work is based [in part] on observations made with the *Spitzer* Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. Support for this work was provided by NASA through an award issued by JPL/Caltech.

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**Contributing team(s):** SpIES Team

### 349.06 – The Fermi Guest Investigator program: Impactful Science and Groundbreaking Results

As an all-sky surveyor, the science impact from the Fermi Gamma-ray Space Telescope is limited by the number of scientists performing data analysis, and not by the number of objects observed by the spacecraft. To encourage this, the Fermi guest investigator (GI) program supports a variety of scientific inquiries that benefit overall Fermi science. The GI program also provides access to radio, optical, X-ray and VHE gamma-ray data and/or observing time, encouraging and enabling relevant multi-wavelength studies. This approach has allowed for new analyses and ideas to flourish, leading to world-class groundbreaking science and a number of unexpected discoveries. The program has also supported a number of multi-year, multi-wavelength observing programs resulting in a rich variety of publicly available resources. Here we describe the most significant results from the Fermi GI program, including those resulting from both sky-survey and target of opportunity pointed observations. We discuss the public resources the program has supported, both for broad-band data acquisition and for the development of new analysis methods and techniques. Additionally, we consider the ramifications of the existence of long-term multi-wavelength datasets, such as those enabled by the Fermi GI program, for future scientific inquiry.

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**Contributing team(s):** on behalf of the Fermi Science Support Center

### 349.07 – The DAWN and FLARE Surveys

Lyman alpha galaxy populations at redshifts 8 and 9 offer a unique probe of cosmological reionization. Resonant scattering by neutral hydrogen should obscure such galaxies if the intergalactic medium is

neutral, implying a steep decline in their observed counts at redshifts prior to the central phases of reionization. We are pursuing a pair of ambitious near-infrared narrow bandpass surveys to probe these populations: The Cosmic Deep and Wide Narrowband (DAWN) survey, using the NEWFIRM camera at the National Optical Astronomy Observatory's 4m Mayall telescope, and the First Light And Reionization Experiment (FLARE), using the FourStar camera at the 6.5m Magellan Telescopes. DAWN is an NOAO survey program, covering a total of five NEWFIRM fields (one square degree in all) to a limiting sensitivity around  $9e-18 \text{ erg/cm}^2/\text{s}$  for emission lines at 1.06 micron wavelength, corresponding to redshift 7.7 for Lyman alpha. FLARE uses the larger aperture of the Magellan telescope to push to still higher redshift, with a limiting line flux near  $5e-18 \text{ erg/cm}^2/\text{s}$  in the COSMOS field, and with additional coverage of a half dozen strongly lensed fields where we can probe still further down the Lyman alpha luminosity function. Imaging observations are largely complete for both surveys, and we are now pursuing spectroscopic followup at both near-IR and optical wavelengths. We will summarize initial results from both surveys in this meeting. With two nights of Keck+MOSFIRE observations complete already (and more scheduled in late 2015), we have numerous emission line confirmations-- both including many H alpha and Oxygen emitters in the foreground, and at least one Lyman alpha galaxy in the epoch of reionization.

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**Contributing team(s):** The FLARE team, the DAWN team

### 349.08 – The CLU Nearby Galaxy Catalog: Preliminary Results

The intermediate Palomar Transient Factory (iPTF) has been undertaking the Census of the Local Universe (CLU) project to complete our survey of galaxies out to 200 Mpc. CLU deploys four contiguous narrow-band filters to search for extended, emission line (H $\alpha$ ) sources across  $3\pi$  of the sky. The estimated 5 $\sigma$  limiting flux for a point source is  $2 \times 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$  (Rau et al., 2009), which corresponds to a star formation rate (SFR) of  $10^{-3} M_{\odot} \text{ yr}^{-1}$  at a distance of 200 Mpc. Thus, the CLU galaxy catalog will capture 85% of the B-band light and 92% of the H $\alpha$  luminosity out to 200 Mpc resulting in tens-of-thousands of newly discovered galaxies. We present the narrowband imaging characteristics, the criteria used for selecting galaxy candidates, and a sub-set of newly discovered galaxies that have been spectroscopically confirmed.

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**Contributing team(s):** iPTF

### 349.09 – The Stripe 82X Multiwavelength Survey of Supermassive Black Hole Growth in Powerful AGN

Deep multiwavelength surveys over the past 15 years have told us that most black hole growth in low- to moderate-luminosity AGN is obscured, and thus not well sampled by optical or soft X-ray surveys. To study whether this also holds for high-luminosity AGN, however, requires a large volume survey (because luminous AGN are rare) that is sensitive to hard X-ray plus infrared emission out to high redshifts. Stripe 82X is exactly this survey — it adds X-ray coverage at  $F(0.5-10 \text{ keV}) \geq 10^{-15} \text{ ergs/cm}^2/\text{s}$  to an equatorial legacy field with abundant data at other wavelengths, including far- and mid-infrared imaging (Herschel, *Spitzer*, WISE, UKIDSS, VHS, VICS82), deep

radio imaging (VLA), deep optical imaging (SDSS, HSC, DES, CFHT), UV imaging (GALEX medium-depth), and extensive optical spectroscopy (~800 spectra per square degree). The current 31.3 deg<sup>2</sup> X-ray catalog has 6181 unique X-ray sources, of which 88% have optical or infrared counterparts and 1842 have spectroscopic redshifts. We present the characteristics of this source population and describe our search for high-luminosity and/or high-redshift obscured quasars.

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**Contributing team(s):** Stripe 82X Collaboration

### 349.10 – Characterizing imaging distortion for the Intermediate Palomar Transient Factory

The advent of time-domain surveys has put a premium on accurate astrometry determined in near-real-time. The Intermediate Palomar Transient Factory (iPTF) employs astrometric solvers from SCAMP in the Astromatic suite and from Astrometry.net. Distortion is computed by these solvers for each individual image and exposure. We present an analysis of the distortion solutions in iPTF data, and some approaches for improving astrometry for iPTF and the upcoming Zwicky Transient Facility. Additionally, Astrometry.net currently uses the SIP convention to represent distortion in FITS image headers, while the Astromatic suite uses the TPV convention. We describe a conversion between these two conventions which has now been extended to 7th-order polynomials.

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**Contributing team(s):** Intermediate Palomar Transient Factory Collaboration

### 349.11 – A Machine-learning Model to Separate Stars and Galaxies in iPTF Images

The Intermediate Palomar Transient Factory (iPTF) is a dedicated time-domain survey optimized for the rapid characterization of fast transients. While significant efforts have been devoted to the development of software that quickly and reliably identifies new transients, there are currently no mechanisms to automatically classify these sources. The first component in deriving a classification is understanding whether or not the newly discovered transient is galactic or extragalactic in its origin. Here, we present our development of a new framework for classifying sources in iPTF reference images as either stars or galaxies. The framework utilizes the random forest algorithm and is trained with nearly 3 million sources that have Sloan Digital Sky Survey (SDSS) spectra. The final optimized model achieves a cross-validation accuracy of ~96%, which represents a significant improvement over the automated classification provided by the SExtractor algorithm. This accuracy, while slightly worse than that provided by the SDSS photometric classifier, can be extended over the entire iPTF footprint, which covers >5000 deg<sup>2</sup> that have not been imaged by SDSS. Associating transients with galactic or extragalactic origin is the first step in delivering automated classifications of newly discovered transients.

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**Contributing team(s):** on behalf of the Intermediate Palomar Transient Factory

### 349.12 – Supernovae in the First Two Years of the Dark Energy Survey

The Dark Energy Survey Supernova Program (DES-SN) is a five year, 30 square degree cadenced search for type Ia supernovae (SNe Ia) using the Dark Energy Camera on the 4m Blanco Telescope. The goal of DES-SN is to accurately measure more than 3000 SNe Ia over a redshift range of  $0.1 < z < 1.2$  to derive the most precise constraints for cosmological parameters of any supernova survey. I will present an overview of the data from the full first two seasons of DES-SN and a preliminary analysis using both spectroscopically- and photometrically-classified SNe Ia.

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**Contributing team(s):** The Dark Energy Survey

### 349.13 – Extragalactic Transients Discovered by the All-Sky Automated Survey for Supernovae

Even in the modern era, only human eyes can scan the entire optical sky for the violent, variable, and transient events that shape our universe. The "All-Sky Automated Survey for Supernovae" (ASAS-SN or "Assassin") is changing this by monitoring the extra-galactic sky down to V~17 mag every 2-3 days using multiple telescopes, hosted by Las Cumbres Observatory Global Telescope Network, in the northern and southern hemispheres. The primary goal of ASAS-SN is to discover bright, nearby supernovae (SNe), we are discovering more than 60% of supernovae with V<17. Since June 2013, we have discovered 224 supernovae, 133 in 2015 alone (as of September 30, 2015). ASAS-SN has also discovered many other interesting extragalactic transients, including the three closest tidal disruption events (TDEs) ever discovered at optical wavelengths. The nearby nature of ASASSN discoveries allows detailed follow-up across a wide wavelength coverage; here we present some of these data on recent ASAS-SN extragalactic transients.

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**Contributing team(s):** ASAS-SN

### 349.14 – Catalina Real-Time Transient Survey (CRTS): A Time Domain Resource for the Entire Community

Catalina Real-Time Transient Survey (CRTS; <http://crts.caltech.edu>) is systematically exploring and characterizing the faint, variable sky. It uses data streams generated by the Catalina Sky Survey, which searches for near-Earth asteroids, to search for variable objects and transient events. The CRTS survey has been in operation since 2008, with the archival data going back to 2005. The survey covers the total area of ~33,000 deg<sup>2</sup>, down to ~19-21 mag per exposure, with time baselines from 10 min to ~10 years, and growing; there are now typically ~200-400 exposures per pointing, and coadded images reach deeper than ~23 mag. The area coverage rate will increase substantially as new cameras are being deployed, and possible new data streams opened. The survey has so far detected nearly 11,000 unique, high-amplitude transients, including ~3,000 confirmed or likely supernovae (for the 5 years in a row we published more supernovae than any other survey), at least 1,500 CVs (the great majority of them previously uncatalogued), >3,000 of blazars and other AGN, and a broad variety of other types of objects.

CRTS is intended to be a data resource for the entire astronomical community. We have a completely open data policy: all discovered transient events are published in real time with no proprietary delay period, and all data are made public, in order to better serve the entire community, and maximize the scientific returns. This includes an archive of ~500 million light curves, which are being updated continuously. This is an unprecedented data set for the exploration of the time domain, in terms of the area, depth, and temporal coverage.

Numerous scientific projects have been enabled by this data stream, including: discoveries of ultraluminous and otherwise peculiar SNe; unusual CVs and dwarf novae; mapping of the structure in the Galactic halo using RR Lyrae; variability-based discovery of AGN and probes of their physics; etc. We also have a major effort on the automated classification of transient and variable sources. CRTS is both a scientific and methodological precursor to LSST, and its data are open to the entire community.

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### 349.15 – Measuring Redshifts of Emission-line Galaxies Using Ramp Filters

Photometric redshifts are routinely obtained for galaxies without emission using broadband photometry. It is possible in theory to derive reasonably accurate ( $< 200$  km/sec) photometric redshift values for emission-line objects using “ramp” filters with a linearly increasing/decreasing transmission through the bandpass. To test this idea we have obtained a set of filters tuned for isolating H-alpha at a redshift range of 0-10,000 km/sec. These filters consist of two that vary close to linearly in transmission, have opposite slope, and cover the wavelength range from 655nm – 685nm, plus a Stromgren y and 697nm filter to measure the continuum. Redshifts are derived from the ratio of the ramp filters indices after the continuum has been subtracted out. We are finishing the process of obtaining photometric data on a set of about 100 galaxies with known redshift to calibrate the technique and will report on our results.

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### 349.16 – Extreme Variability in a Broad Absorption Line Quasar

We report on extreme spectral variability seen in a broad absorption line quasar over the past decade, initially identified from the Catalina Real-time Transient Survey (CRTS). Photometrically, the source had a visual magnitude of  $V = 17.3$  between 2002 and 2008. Then, over the following 5 years, the source slowly brightened by approximately one magnitude, to  $V = 16.2$ . A combination of archival and newly acquired spectra reveal the source to be an iron low-ionization broad absorption line (Fe-LoBAL) quasar with extreme changes in its absorption spectrum. Some absorption features completely disappear over the 9 years of optical spectra, while other features remain essentially unchanged. Absorption systems separated by several 1000 km/s in velocity show coordinated changes in the depths of their troughs, correlated with the flux changes. Therefore, we interpret the variability in the absorption troughs to be due to changes in photoionization, rather than due to motion of material into our line of sight. This source highlights the sort of rare transition objects that astronomy will now be finding through dedicated time domain surveys.

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### 349.17 – J-PAS: The Javalambre-Physics of the Accelerating Universe Astrophysical Survey

The Javalambre-Physics of the Accelerating Universe Astrophysical Survey (J-PAS) is a narrow band, very wide field Cosmological Survey to be carried out from the Javalambre Astrophysical Observatory in Spain with a dedicated 2.5m telescope and a  $4.7\text{deg}^2$  camera with 1.2Gpix. Starting in 2016, J-PAS will observe  $8600\text{deg}^2$  of the Northern Sky and measure  $0.003(1+z)$  precision

photometric redshifts for nearly 1E08 LRG and ELG galaxies plus several million QSOs, sampling an effective volume of  $\sim 14\text{Gpc}^3$  up to  $z = 1.3$ . J-PAS will also detect and measure the mass of more than a hundred thousand galaxy clusters, setting constraints on Dark Energy which rival those obtained from BAO measurements. The key to the J-PAS potential is its innovative approach the combination of 54  $145^\circ\text{A}$  filters, placed  $100^\circ\text{A}$  apart, and a multi-degree field of view (FOV) which makes it a powerful “redshift machine”, with the survey speed of a 4000 multiplexing low resolution spectrograph, but many times cheaper and much faster to build. Moreover, since the J-PAS camera is equivalent to a very large,  $4.7\text{deg}^2$  “IFU”, it will produce a time-resolved, 3D image of the Northern Sky with a very wide range of Astrophysical applications in Galaxy Evolution, the nearby Universe and the study of resolved stellar populations. J-PAS will have a lasting legacy value in many areas of Astrophysics, serving as a fundamental dataset for future Cosmological projects. Here, we present the overall description, status and scientific potential of the survey.

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### 349.18 – A 6 GHz Synoptic Survey of the COSMOS Deep Field with the JVLA

The Cosmic Evolution Survey (COSMOS) covers two square degrees, and is observed over a large portion of the electromagnetic spectrum from X-ray to Radio. Key science goals of COSMOS include probing the evolution of galaxies, AGN, and large scale structures of the Universe. As well as constraining cosmological models and the star and structure formation history of the Universe. The wide range of frequencies and deep surveys are suitable for many astrophysical studies.

Beginning in 2013, observations of the COSMOS field in C-band (4 - 8 GHz) using the JVLA have been carried out in every configuration spanning 21 months (April 2013 – Jan 2015) for a total of 13 observations. The observations are comprised of 1 hour time blocks using a technique called On-The-Fly Mosaicking (OTFM). Using OTFM we see an increased efficiency for an allotted observation block by collecting data as the array scans across the field, rather than a pointed mosaic which requires settle down time after each new pointing. Each observation consists of 2160 1-second integrations on 432 phase centers that require calibration and image processing before they can be mosaicked to create the final image of the entire COSMOS field.

The primary science goal of this survey is to identify, catalog, and study the variable and transient radio sources in the COSMOS field, comparing these to other radio, optical, IR, and X-ray observations. The main class of variables we are interested in Active Galactic Nuclei.

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### 349.19 – The Arecibo Galaxy Environment Survey: Observations towards the NGC 7817/7798 Galaxy Pair

The Arecibo Galaxy Environment Survey (AGES) examines the environment of neutral hydrogen gas in the interstellar medium. AGES uses the 305m Arecibo Radio Telescope and the Arecibo L-Band Feed Array to create a deep field neutral hydrogen survey which we used to detect galaxies in an area five square degrees around the galaxy pair NGC 7817/7798. By finding and investigating hydrogen rich galaxies we hope to gain a better understanding of how the environment affects galaxy evolution. H1 line profiles were made for the detected H1 emission and ten galaxies which had the characteristic double-horned feature were found. NGC 7798 was not detected, but NGC 7817 and the other galaxies were cross-identified in NASA/IPAC Extragalactic Database as well as in Sloan Digital Sky Survey to obtain optical data. Out of the ten, two of the sources were uncatalogued. We analyzed the hydrogen spectra and aperture photometry to learn about the characteristics of these galaxies such as their heliocentric velocity, flux, and mass of the neutral hydrogen.

Furthermore, we graphed the Tully-Fisher and the Baryonic Tully-Fisher of the ten sources and found that most followed the relation. One that is the biggest outlier is suspected be a galaxy cluster while other outliers may be caused by ram pressure stripping deforming the galaxy.

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**Institution(s):** 1. Whittier College

**Contributing team(s):** Robert Minchin

### 349.20 – The Jansky VLA Frontier Field Public Legacy Survey

Using the Karl G. Jansky Very Large Array (VLA), we are conducting a multi-configuration continuum imaging survey to enrich the legacy of the Frontier Fields by providing unique measurements derived from deep 3 and 6 GHz images. While the deep HST and Spitzer/IRAC data provide unprecedented constraints on stellar populations, stellar masses, and galaxy morphologies, they are only sensitive to unobscured star-formation activity. Our radio images each have a depth of  $\sim 1 \mu\text{Jy}$  and reach a resolution of 0.3 arcsec (similar to WFC3) at 6 GHz. Consequently, these new radio data provide unobscured, integrated star formation rates for highly magnified systems out to  $z \sim 8$ ; radio morphologies of  $L^*$  galaxies out to  $z \sim 3$ ; sub-kpc resolution for highly magnified sources at  $z > 1$ ; and AGN diagnostics via polarization maps and radio spectral indices. Together with the HST and Spitzer data, these new radio images will inform a variety of extragalactic topics, including the importance of dusty star-forming galaxies at high redshift; the evolution of supermassive black holes; the nature of starburst galaxies out to  $z \sim 3$ ; and the rapid evolution of galaxies in the lensing clusters themselves. To ensure that the legacy of this combined data set is realized, we will publicly distribute radio images, radio source catalogs, band-merged catalogs, a morphological analysis of the multi-wavelength HST images for all radio sources, and multi-band cutouts centered on the radio detections. Here we present initial results from our program.

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**Contributing team(s):** The VLA Frontier Field team

## 401 – Physical Properties of High Redshift Galaxies

### 401.01 – The Star Formation Rate Efficiency of Atomic-dominated Hydrogen Gas from $z \sim 1$ to $z \sim 3$

Current observational evidence suggests that the star formation rate (SFR) efficiency of neutral atomic hydrogen gas measured in Damped Lyman-alpha System (DLAs) at  $z \sim 3$  is a factor of 10 lower than predicted by the Kennicutt-Schmidt relation. To understand the origin of this deficit, we measure the SFR efficiency of atomic gas at  $z \sim 1$ ,  $z \sim 2$ , and  $z \sim 3$  to investigate possible coevolution with galactic properties. We use new robust photometric redshifts to create galaxy stacks in these three redshift bins, and measure the SFR efficiency by combining DLA absorber statistics with the observed rest-frame UV emission in the galaxies' outskirts. Contrary to simulations and models that predict a reduced SFR efficiency with decreasing metallicity and thus with increasing redshift, we find no significant evolution in the SFR efficiency. We conclude that the reduced SFR efficiency is driven by the low molecular content of this atomic-dominated phase, with metallicity playing a second order effect in regulating the conversion between atomic and molecular gas. This interpretation is supported by the similarity between the observed SFR efficiency and that observed in local atomic-dominated gas, such as in the outskirts of local spiral galaxies or local dwarf galaxies.

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**Institution(s):** 1. Durham University, 2. Goddard Space Flight Center, 3. Infrared Science Archive (IRSA), 4. UCO/Lick Observatory

**Contributing team(s):** UVUDF

### 401.02 – The Formation of Bulges and Disks in the CANDELS survey

We examine a sample of 1500 galaxies in the CANDELS fields to determine the evolution of the bulge to disk ratio for massive galaxies at the epoch  $1 < z < 3$  when the Hubble sequence forms from irregular/peculiar systems to normal spirals and ellipticals. We fit all of these galaxies' light profiles with a single Sérsic fits, as well as with a combination of exponential and Sérsic profile. The latter is done in order to describe a galaxy with a disk and a bulge. We use three classification method (visual, F-test and the RFF method) to separate our sample into one-component galaxies (disk/spheroids-like galaxies) and 2-component galaxies (galaxies formed by a bulge and a disk). We then compare the results from using these three different ways to classify our galaxies. We find that the fraction of galaxies selected as 2-component galaxies increases on average 50% from the lowest mass bin to the most massive galaxies, and decreases with redshift by a factor of four from  $z=1$  to  $z=3$ . We furthermore examine how the sizes of the bulges and disks components in these galaxies evolve with time as well as the dependence of stellar mass on these results. The implications for models and ideas of galaxy formation will also be discussed.

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**Institution(s):** 1. Univ. of Nottingham

**Contributing team(s):** CANDELS team

### 401.03D – Galaxy Proto-clusters as an Interface Between Structure, Cluster, and Galaxy Formation

Proto-clusters, the progenitor large-scale structures of present day galaxy clusters, are unique laboratories to study dark matter assembly, cosmic baryon cycle, galaxy growth, and environmental impact on galaxy evolution. In this dissertation talk, I will present our recent progress in this subject, both theoretical and observational. Using a set of cosmological N-body simulations and semi-analytic galaxy models, we extract the mass, size, and overdensity evolution for  $\sim 3000$  simulated clusters from  $z=8$  to  $z=0$ . In line with the scenario of cosmic downsizing, the models predict that the fraction of cosmic star formation rate occurs in (proto-)clusters increases from  $<1\%$  at  $z=0$  to 20–30% at  $z=8$ . This result demonstrates that the seemingly sharp distinction when discussing field and cluster galaxy evolution has to be blurred at high redshift, and a significant fraction of cosmic reionization was done by cluster progenitors. Observationally, we focus on the epoch of  $z \approx 2$  when the first cluster scale halos ( $10^{14} M_\odot$ ) were about to form. We perform a systematic proto-cluster search using a photometric redshift catalog in the COSMOS field, revealing a large sample of 36 candidate proto-clusters at  $1.6 < z < 3.1$ . Several structures in this catalog have been confirmed spectroscopically. I will present the confirmation and detailed characterization of a "proto-Virgo" cluster in this field at  $z=2.44$  with  $M_{Z=0} = 10^{14.5 \pm 0.4} M_\odot$  using a sample of Ly $\alpha$  emitters (LAE) in the HETDEX Pilot Survey with a highly homogeneous selection function in 3D redshift space. Compared to the cosmic mean, this structure shows a LAE overdensity of 4 on a scale of few tens cMpc, a 5 times higher fraction of extended Ly $\alpha$  blobs, a 2 times higher median stellar mass of NIR selected galaxies with photometric redshift, and a significantly enhanced intergalactic gas revealed in the Ly $\alpha$  absorption maps of Lee et al. (2014, 2015). With these results, I will discuss proto-clusters in the context of cluster formation and galaxy evolution, highlighting their unique roles linking scales from large to small, and epochs from active star-formation to quenching.

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**Institution(s):** 1. UT Austin

### 401.05 – UV Absorption Lines as Metallicity Estimator and the Metal Content of Star-forming Galaxies at $z=5$

Probing the metal content of high redshift galaxies is essential to study their formation and evolution in the early universe. However, the spectral features used to measure the metallicity are shifted out of the wavelength range of current spectrographs at high- $z$  and therefore alternative methods must be used.

We measure the relation between four prominent UV absorption

complexes and metallicity for more than 50 local galaxies and, by using a sample of more than 20 galaxies at  $z \sim 2-3$ , verify that this relation holds up to  $z \sim 3$ . We then apply this method to a sample of  $\sim 220$  galaxies at  $3.5 < z < 6.0$  in COSMOS, for which unique UV spectra from DEIMOS and accurate stellar mass estimates from SPLASH are available. The  $z \sim 5$  galaxies at  $9 < \log(m/M_\odot) < 11$  are characterized by 0.3 - 0.4 dex (in units of  $12 + \log(O/H)$ ) lower metallicities than galaxies at  $z \sim 2$  but comparable to  $z \sim 3-3.5$  galaxies. In the same stellar mass range, we do not find a significant relation between stellar mass and metallicity (MZ relation), suggesting that the MZ relation at  $z \sim 5$  is very shallow or breaking down. Since we verify a correlation between dust obscuration (measured by  $\beta$ ) and UV absorption strength (i.e., metallicity), we argue that the process of dust production and metal enrichment in the first billion years of galaxy formation is more stochastic than at later times. Using a "bathtub" model approach, we find that an exponential build up of stellar mass within a short time of several 100 Myr can explain a shallow MZ relation at  $z \sim 5$ . Furthermore, we find a weak anti-correlation between star-formation rates and UV absorption strength (i.e., metallicity), indicative of these galaxies being fueled by the inflow of pristine (metal-poor) gas. The galaxy sample presented in this work is unique to further test these scenarios using ALMA and the upcoming James Webb Space Telescope.

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**Contributing team(s):** COSMOS Team

#### 401.06 – The Impossibly Early Galaxy Problem

The current hierarchical merging paradigm and  $\Lambda$ CDM predict that the  $z \sim 4-8$  universe should be a time in which the most massive galaxies are transitioning from their initial halo assembly to the later baryonic evolution seen in star-forming galaxies and quasars. However, no evidence of this transition has been found in many high redshift galaxy surveys including CFHTLS, CANDELS and SPLASH, the first studies to probe the high-mass end at these redshifts. Indeed, if halo mass to stellar mass ratios estimated at lower-redshift continue to  $z \sim 6-8$ , CANDELS and SPLASH report several orders of magnitude more  $M \sim 10^{12-13} M_\odot$  halos than are possible to have formed by those redshifts, implying these massive galaxies formed impossibly early. We consider various systematics in the stellar synthesis models used to estimate physical parameters and possible galaxy formation scenarios in an effort to reconcile observation with theory. Although known uncertainties can greatly reduce the disparity between recent observations and cold dark matter merger simulations, even taking the most conservative view of the observations, there remains considerable tension with current theory.

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**Institution(s):** 1. Caltech, 2. Harvard

#### 401.07 – The Atacama Cosmology Telescope: Spectroscopic Redshifts for Dusty Star-Forming Galaxies

The Atacama Cosmology Telescope (ACT) detects high-redshift dusty star-forming galaxies (DSFGs) as point sources with rising spectra across its 148, 218, and 277 GHz bands. In a survey of a 470 square degree area along the celestial equator, ACT has detected tens of bright DSFGs that our team has localized spatially with high-resolution imaging at radio, millimeter, and submillimeter wavelengths. This talk will present the first results of our campaign to determine redshifts for these sources via spectroscopy of CO rotational emission lines, primarily using dedicated wide-bandwidth instruments on the Large Millimeter Telescope (LMT) and the Green Bank Telescope (GBT). Redshifts and CO line parameters suggest that the ACT DSFGs are gravitationally lensed, with a median redshift that is significantly higher than that of "classical"

submillimeter galaxy samples selected at 850 microns.

This research has been supported by the National Science Foundation via grant AST-0955810.

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**Contributing team(s):** ACT Collaboration

#### 401.08 – Cosmic Evolution of X-ray Binary Populations: Probes of Changing Chemistry and Aging Stellar Populations in the Universe

The 2-10 keV emission from normal galaxies is dominated by X-ray binary (XRB) populations. The formation of XRBs is sensitive to galaxy properties like stellar age and metallicity---properties that have evolved significantly in the broader galaxy population throughout cosmic history. The 6 Ms Chandra Deep Field-South (CDF-S) allows us to study how XRB emission has evolved over a significant fraction of cosmic history (since  $z \sim 4$ ), without significant contamination from AGN. Using constraints from the CDF-S, I will show that the X-ray emission from normal galaxies from  $z = 0-7$  depends not only on star-formation rate (SFR), but also on stellar mass (M) and redshift. Our analysis shows that low-mass X-ray binary emission scales with stellar mass and evolves as  $LX(LMXB)/M \sim (1+z)^3$ , and high-mass X-ray binaries scale with SFR and evolve as  $LX(HMXB)/SFR \sim (1+z)$ , consistent with predictions from population synthesis models, which attribute the increase in LMXB and HMXB scaling relations with redshift as being due to declining host galaxy stellar ages and metallicities, respectively. These findings have important implications for the X-ray emission from young, low-metallicity galaxies at high redshift, which are likely to be more X-ray luminous per SFR and play a significant role in the heating of the intergalactic medium.

**Author(s):** Bret Lehmer<sup>11</sup>, Antara Basu-Zych<sup>6</sup>, Stefano Mineo<sup>5</sup>, W. Niel Brandt<sup>8</sup>, Rafael T. Eufrazio<sup>6</sup>, Tassos Fragos<sup>1</sup>, Ann E. Hornschemeier<sup>6</sup>, Bin Luo<sup>8</sup>, Yongquan Xue<sup>14</sup>, Franz E. Bauer<sup>9</sup>, Marat Gilfanov<sup>5</sup>, Vassiliki Kalogera<sup>7</sup>, Piero Ranalli<sup>2</sup>, Donald P. Schneider<sup>8</sup>, Ohad Shemmer<sup>13</sup>, Paolo Tozzi<sup>3</sup>, Jonathan Trump<sup>8</sup>, Cristian Vignali<sup>12</sup>, JunXian Wang<sup>14</sup>, Mihoko Yukita<sup>4</sup>, Andreas Zezas<sup>10</sup>

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## 402 – Binary Stellar Systems, X-ray Binaries II

#### 402.01 – Young, Low-Mass Spectroscopic Binaries in Nearby Moving Groups

Young spectroscopic binaries (SB) allow us to determine dynamical masses of young stars, which are needed to constrain evolutionary models and processes. During a search for new young moving group (YMG) members with ages between 10 and 300 Myr, we collected optical spectra of many nearby low-mass stars. These data allow us to measure key youth indicators and kinematics. The spectra may also reveal double-lined SBs. Here we present several new, young, low-mass SBs. We calculated mass ratios and systemic velocities for these systems. Additionally, one of these SBs is not a kinematic match to any known YMG, yet has an age of less than 20 Myr. It may be the first system of a yet-to-be identified YMG.

**Author(s):** Laura Flagg<sup>4</sup>, Evgenya L Shkolnik<sup>1</sup>, Alycia J. Weinberger<sup>3</sup>, Brendan P. Bowler<sup>2</sup>, Adam L. Kraus<sup>6</sup>, Michael C. Liu<sup>5</sup>  
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#### 402.02D – Variability of Optical Counterparts to X-ray Selected Sources in the Galactic Bulge Survey

The Galactic Bulge Survey (GBS) is a wide-field, multi-wavelength survey of new X-ray sources in the Galactic Bulge detected with the Chandra X-ray Observatory. The goals of the GBS are to test binary population models by uncovering quiescent Low-Mass X-Ray Binaries (LMXB), and to identify suitable systems for follow-up mass determination using multi-wavelength observations. This follow-up is essential to better determine black hole and neutron star mass distributions. We present preliminary results from the southernmost portion of the GBS positioned 1.5–2.0 degrees below the Galactic Center which contains 424 unique X-ray sources. The optical photometry presented here were acquired using the DECam imager and the previous Mosaic-II imager on the 4m Blanco telescope at Cerro-Tololo Inter-American Observatory (CTIO). We combine photometry with optical spectroscopy from several different telescopes to help characterize the detected X-ray sources. To accomplish this goal, we analyze the light curve morphology and the spectroscopic features of the optical counterparts to classify these binary systems. I will describe the technique for determining the correct optical counterpart within the error circle using image subtraction and report on the statistics of the sample. I will then summarize the candidate LMXBs we have identified so far and highlight other interesting sources. This work was supported by the National Science Foundation under Grant No. AST-0908789 and by NASA through Chandra Award Number AR3-14002X issued by the Chandra X-ray Observatory Center, which is operated by the Smithsonian Astrophysical Observatory for and on behalf of the National Aeronautics Space Administration under contract NAS8-03060. We also acknowledge support from a Graduate Student Research Award administered by the Louisiana Space Grant Consortium (LaSPACE).

**Author(s):** Christopher Johnson<sup>1</sup>, Robert I. Hynes<sup>1</sup>, Peter Jonker<sup>2</sup>, Manuel Torres<sup>2</sup>, Thomas J. Maccarone<sup>3</sup>, Christopher Britt<sup>3</sup>, Danny Steeghs<sup>4</sup>

**Institution(s):** 1. *Louisiana State University*, 2. *SRON*, 3. *Texas Tech University*, 4. *University of Warwick*

**Contributing team(s):** Galactic Bulge Survey Collaboration

#### 402.03D – Is the Binary Mass Ratio Distribution Separation-Dependent?

Recent discoveries of planets orbiting retired A-stars on close orbits and young A-stars on very wide orbits have renewed interest in the properties of nearby intermediate-mass stars. Especially interesting are the young stars because directly-imaged planets orbiting them may be bright enough for characterization (e.g. HR 8799, Beta Pictoris, etc). However, intermediate-mass stars and especially young intermediate mass stars are part of multiple systems more often than not. Close stellar companions may affect the formation and orbital evolution of any planets, and the properties of the companions can help constrain the binary formation mechanism. The mass ratio distribution of a population of binary stars, especially if the distribution for close companions is significantly different from that of wide companions, is helpful to distinguish companions that were born in or affected by the circumstellar disk from those which formed through fragmentation of the molecular core. Previous imaging surveys have found that binary systems with A-type primary stars tend to have cool companions with extreme mass ratios. There are hints at a much flatter mass ratio distribution for close companions, but strong completeness effects complicate the picture. We have conducted a spectroscopic survey of ~400 nearby main sequence A- and B-type stars, aimed at detecting stellar companions as late as M4 for all orbital separations <100 AU. We have searched for companions to the stars by cross-correlating the spectra against model templates for F-M type stars; a significant peak in the cross-correlation function indicates a detection. Our cross-correlation technique can detect low-mass companions with orbits that are too

wide to detect with radial velocity monitoring and too small to detect with imaging techniques, making it complementary to work already done. We will present results from our survey and compare the mass ratio distribution we measure to the corresponding distribution for wide companions.

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**Institution(s):** 1. *University of Texas Austin*

#### 402.04 – Radial velocity monitoring of Kepler heartbeat stars with Keck/HIRES

Heartbeat stars are an emerging class of eccentric binary stars with close periastron passages. The characteristic heartbeat signal evident in their light curves is produced by a combination of tidal distortion, reflection, and Doppler boosting near orbital periastron. Many heartbeat stars continue to oscillate after periastron and along the entire orbit, indicative of the tidal excitation of oscillation modes within one or both stars. These systems are among the most eccentric binaries known, and they constitute an exciting opportunity to observe tidal effects in action. We are carrying out a radial velocity monitoring of *Kepler* heartbeat stars using Keck/HIRES, in order to measure the orbit and characterize the two stars. Our sample currently includes over 30 systems, which is the largest sample of these unique systems where the orbit was measured with radial velocities. Our goal is to understand the formation and evolution of heartbeat stars, and to use them to study the processes of tidal dissipation and orbital migration. The physics learned from them will apply to many other astrophysical systems, such as high-eccentricity planet migration and eccentricity-induced mergers in triple systems.

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#### 402.05D – Fundamental Parameters of Eclipsing Binaries in the Kepler Field of View

Accurate knowledge of stellar parameters such as mass, radius, composition, and age inform our understanding of stellar evolution and constrain theoretical models. Binaries and, in particular, eclipsing binaries make it possible to directly measure these parameters without reliance on models or scaling relations. In my dissertation I derive fundamental parameters of stars in close binary systems with and without (detected) tertiary companions and obtain accurate masses and radii of the components to compare with evolutionary models. Radial velocities and spectroscopic orbits are derived from optical spectra, while Doppler tomography is used to determine effective temperatures, projected rotational velocities, and metallicities for each component of the binary. These parameters are then combined with *Kepler* photometry to obtain accurate masses and radii through light curve and radial velocity fitting with the binary modeling software ELC. Here, I present spectroscopic orbits, atmospheric parameters, and estimated masses for 41 eclipsing binaries (including seven with tertiary companions) that were observed with *Kepler* and have periods less than six days. Further analysis, including binary modeling and comparison with evolutionary models is shown for a sub-sample of these stars.

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#### 402.06 – The Supernova Impostor SN 2010da

Supernova impostors are optical transients that, despite being assigned a supernova designation, do not signal the death of a massive star or accreting white dwarf. Instead, many impostors are thought to be major eruptions from luminous blue variables. Although the physical cause of these eruptions is still debated, tidal interactions from a binary companion has recently gained traction as a possible explanation for observations of some supernova impostors. In this talk, I will discuss the particularly interesting

impostor SN 2010da, which exhibits high-luminosity, variable X-ray emission. The X-ray emission is consistent with accretion onto a neutron star, making SN 2010da a likely high mass X-ray binary in addition to a supernova impostor. SN 2010da is a unique laboratory for understanding both binary interactions as drivers of massive star eruptions and the evolutionary processes that create high mass X-ray binaries.

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## 403 – AGN, QSO, Blazars: Gamma Ray and Cosmic Ray Sources

### 403.01 – Methods for Identifying Pair Halos

The flux of very high energy gamma rays from active galactic nuclei (AGN) is attenuated via interactions with extragalactic background photons and is converted into  $e^+e^-$  pairs. With non-zero intergalactic magnetic fields, the electrons and positrons will deflect as they propagate and simultaneously lose energy by upscattering cosmic microwave background photons. "Pair halos," the visible consequences of these electromagnetic cascades, are faint and difficult to observe against their AGN counterparts. We investigate three methods for indirectly identifying pair halos, using a two-component approach to model the AGN core/halo image. We estimate each method's sensitivity by utilizing a new, detailed Monte Carlo pair-halo simulation.

**Author(s):** Brendan Wells<sup>1</sup>, Regina Caputo<sup>1</sup>, William Atwood<sup>1</sup>, Steven M. Ritz<sup>1</sup>

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### 403.02 – Evidence for quasi-periodic modulation in the gamma-ray blazar PG 1553+113

For the first time a gamma-ray and multiwavelength nearly-periodic oscillation in an active galactic nucleus is reported using the Fermi Large Area Telescope (LAT). A quasi-periodicity in the gamma-ray flux ( $E > 100$  MeV and  $E > 1$  GeV) is observed from the well-known GeV/TeV BL Lac object PG 1553+113 (Ackermann et al. submitted). The significance of the  $2.18 \pm 0.08$  year-period gamma-ray modulation, seen in 3.5 oscillation maxima observed, is supported by significant cross-correlated variations observed in radio and optical flux light curves, through data collected in the OVRO, Tuorla, KAIT, and CSS monitoring programs and Swift UVOT. The optical cycle, appearing in about 10 years of data, has a similar period, while the radio-band oscillation observed at 15 GHz is less regular and coherent. The available X-ray flux data obtained by Swift XRT appears also to be linearly correlated with the gamma-ray flux. Further long-term multi-wavelength monitoring of this blazar may discriminate among the possible explanations for this first evidence of periodicity.

**Author(s):** Sara Cutini<sup>2</sup>, Stefano Ciprini<sup>2</sup>, Stefan Larsson<sup>1</sup>, David John Thompson<sup>4</sup>, Antonio Stamerra<sup>3</sup>

**Institution(s):** 1. *KTH Royal Institute of Technology*, 2. *ASDC*, 3. *INAF*, 4. *NASA Goddard Space Flight Center*

**Contributing team(s):** Fermi LAT collaboration

### 403.04 – 2FHL: The second Catalog of Hard Fermi-LAT Sources

The second catalog of hard Fermi Large Area Telescope (LAT) sources (2FHL) adopts the highest energy threshold (50 GeV) and reaches the highest energies (2 TeV) among any Fermi-LAT catalogs. This catalog comprises 360 well-localized sources and provides a census and spectral characterization of the whole sky in the 50 GeV – 2 TeV energy band. This was enabled by the the long-term exposure acquired by the LAT and the performance improvements delivered by Pass 8, the newest event-level analysis. The 2FHL closes the energy gap between the observations performed at GeV energies

by Fermi-LAT on orbit and the observations performed at higher energies by Cherenkov telescopes from the ground. In this contribution, we will discuss the properties of the extragalactic and Galactic source populations with an emphasis on the detection of spatially extended sources in the plane of our Galaxy. We will also present evidence that 2FHL extragalactic sources are absorbed by the extragalactic background light.

**Author(s):** Marco Ajello<sup>2</sup>, Alberto Dominguez<sup>2</sup>, Jamie Cohen<sup>3</sup>, Sara Cutini<sup>1</sup>, Dario Gasparrini<sup>1</sup>

**Institution(s):** 1. *ASI Science Data Center*, 2. *Clemson*, 3. *University of Maryland*

**Contributing team(s):** Fermi-LAT Collaboration

### 403.05 – Pushing the Limits: High Redshift Fermi-LAT Blazars

High-redshift blazars detected by the Fermi Large Area Telescope (LAT) are of great astrophysical import as they are extreme objects whose energetics remain a mystery. Such blazars are intrinsically interesting since they inform us about the evolution of gamma-ray blazars and are, by definition, some of the more luminous blazars in the LAT sample. They are also an excellent tool to study the EBL and thus the gamma-ray horizon. We present the latest high redshift blazar detections in the LAT and discuss some of their implications.

**Author(s):** Roopesh Ojha<sup>3</sup>, Dario Gasparrini<sup>2</sup>, Benoit Lott<sup>1</sup>, Sara Cutini<sup>2</sup>

**Institution(s):** 1. *CNRS*, 2. *INFN*, *ASI Science Data Center*, 3. *NASA/GSFC*

**Contributing team(s):** on behalf of the Fermi-LAT Collaboration

### 403.06 – Highlights from the VERITAS Active Galactic Nuclei Observing Program

The VERITAS Observatory, located at the Fred Lawrence Whipple Observatory near Tucson, Arizona is one of the world's most sensitive detectors of very-high-energy (VHE;  $E > 100$  GeV) gamma rays. With an array of four 12-m telescopes, VERITAS detects the Cherenkov light emitted from air showers initiated by astrophysical gamma rays. A sequence of upgrades completed in 2012 aimed at lowering the energy threshold resulted in the instrument being sensitive to gamma rays between 85 GeV and 30 TeV. Fully operational since 2007, VERITAS has so far detected 54 VHE gamma-ray objects in eight different source classes. The active galactic nuclei (AGN) class comprises the majority of these detections, with 34 sources that include several radio galaxies but are predominantly blazars (AGN with relativistic jets pointing towards Earth). The scientific importance of VHE detections of AGN includes studying the details of emission mechanisms in blazars and elucidating whether they are sources of ultra-high-energy cosmic rays and astrophysical neutrinos. Additionally VHE gamma-ray observations can be used to gain cosmological insights such as placing limits on the intergalactic magnetic field (IGMF) and the extragalactic background light (EBL), which comprises all the diffuse starlight in the universe. This presentation will summarize the VERITAS AGN observing program and highlight a few recent results.

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**Contributing team(s):** For the VERITAS Collaboration

### 403.07 – PKS 1441+25: Insights from a New Gamma-ray Quasar

Gamma-ray quasars provide insights on the relativistic jets of active galactic nuclei, and can constrain the diffuse radiation fields that fill the Universe. Detecting significant emission above 100 GeV from a distant quasar shows that some of the radiated gamma rays are not affected by pair-production interactions with low-energy photons such as the radiation near the supermassive black hole lying at the jet's base, or the extragalactic background light (EBL). During April 2015, VERITAS detected gamma-ray emission up to  $\sim 200$  GeV from PKS 1441+25 ( $z = 0.939$ ); this was a period of high activity across all wavelengths. Before PKS 1441+25, only four confirmed gamma-ray emitting quasars had been detected at very high energies, three of them much less distant. Utilizing the recent release of Pass-8

Fermi-LAT data, we observe an integrated flux (100 MeV – 100 GeV) one to two orders of magnitude larger than the value reported in the 3FGL catalog and a slight preference for curvature in the spectrum during the contemporaneous VERITAS observations. These gamma-ray observations of PKS 1441+25 suggest that the emitting region is located thousands of Schwarzschild radii away from the black hole. The gamma-ray detection also sets a strict upper limit on the near-ultraviolet to near-infrared EBL intensity. This suggests that galaxy surveys have resolved most, if not all, of the sources contributing to the EBL at these wavelengths.

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**Institution(s):** 1. University of California, Santa Cruz

**Contributing team(s):** VERITAS Collaboration, Multiwavelength Partners

#### **403.08 – Spectacular variability of gamma-ray emission in blazar 3C279 during the large outburst in June 2015**

The Flat Spectrum Radio Quasar 3C 279 has been one of the brightest gamma-ray blazars in the sky. In Dec. 2013, April 2014, and June 2015 it showed powerful outbursts with the gamma-ray flux higher than  $1 \times 10^{-5}$  ph/cm<sup>2</sup>/s (above 100 MeV). The December 2013 outburst showed an unusually hard power-law gamma-ray spectrum (index ~1.7), and an asymmetric light curve profile with a few-hour time scale variability. The outburst in June 2015 was extreme, revealing a record-breaking integral flux above 100 MeV of  $4 \times 10^{-5}$  ph/cm<sup>2</sup>/s, more than an order of magnitude higher than the average gamma-ray flux of the Crab. At the same time, the X-ray flux also showed the highest level of soft X-ray flux ever measured by Swift-XRT. The high flux prompted a Fermi-LAT ToO pointing observation. The increase of exposure and the very high flux state of the source allowed us to resolve the gamma-ray flux on a sub-orbital time scales. Our analysis of the LAT data revealed variability on time scales of tens of minutes. In this contribution, we will present the observational results of those outbursts from 3C279 together with multi-wavelength observations, with a focus on detailed analysis of the 2015 June outburst.

**Author(s):** Grzegorz Maria Madejski<sup>4</sup>, Masaaki Hayashida<sup>2</sup>, Katsuaki Asano<sup>2</sup>, David John Thompson<sup>3</sup>, Krzysztof Nalewajko<sup>4</sup>, Marek Sikora<sup>1</sup>

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**Contributing team(s):** Fermi-LAT team

#### **403.09 – Ultra-High Energy Cosmic Rays**

The search for the origin(s) of ultra-high energy (UHE) cosmic rays (CR) remains one of the cornerstones of high energy astrophysics. The previously proposed sources of acceleration for these UHECRs were gamma-ray bursts (GRB) and active galactic nuclei (AGN) due to their energetic activity and powerful jets. However, a problem arises between the acceleration method and the observed CR spectrum. The CRs from GRBs or AGN jets are assumed to undergo Fermi acceleration and a source injection spectrum proportional to  $E^{-2}$  is expected. However, the most recent fits to the spectrum and nuclear composition suggest an injection spectrum proportional to  $E^{-1}$ . It is well known that such a hard spectrum is characteristic of unipolar induction of rotating compact objects. When this method is applied to the AGN cores, they prove to be much too luminous to accelerate CR nuclei without photodisintegrating, thus creating significant energy losses. Instead, here we re-examine the possibility of these particles being accelerated around the much less luminous quasar remnants, or dead quasars. We compare the interaction times of curvature radiation and photodisintegration, the two primary energy loss considerations with the acceleration time scale. We show that the energy losses at the source are not significant enough as to prevent these CRs from reaching the maximum observed energies. Using data from observatories in the northern and southern sky, the Telescope Array and the Pierre Auger Observatory respectively, two hotspots have been discerned which have some associated quasar remnants that help to motivate our study.

**Author(s):** Rafael Antonio Colon<sup>2</sup>, Roberto Moncada<sup>1</sup>, Juan Guerra<sup>2</sup>, Luis Anchordoqui<sup>2</sup>

**Institution(s):** 1. CUNY City College, 2. Lehman College

## **404 – Formation and Evolution of Stars and Stellar Systems**

### **404.02 – Binaries at Birth: Stellar multiplicity in embedded clusters from radial velocity variations in the IN-SYNC survey**

We study the nature of stellar multiplicity in young stellar systems using the INfrared Spectroscopy of Young Nebulous Clusters (IN-SYNC) survey, carried out in SDSS III with the APOGEE spectrograph. Multi-epoch observations of thousands of low-mass stars in Orion A, NGC2264, NGC1333 and IC348 have been carried out, yielding H-band spectra with  $R=22,500$  for sources with  $H<12$  mag. Radial velocity sensitivities  $\sim 0.3$  km/s can be achieved, depending on the spectral type of the star. We search the IN-SYNC radial velocity catalog to identify sources with radial velocity variations indicative of spectroscopically undetected companions, analyze their spectral properties and discuss the implications for the overall multiplicity of stellar populations in young, embedded star clusters.

**Author(s):** Karl Oskar Jaehnig<sup>1</sup>, Keivan Stassun<sup>3</sup>, Jonathan C. Tan<sup>2</sup>, Kevin R. Covey<sup>4</sup>, Nicola Da Rio<sup>2</sup>

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### **404.03 – Signatures of planet formation in high-precision elemental abundances of twin stars**

The process of planet formation is likely to have left a detectable signature in the chemical composition of stars. Highly precise abundance analyses of stars which are very similar to each other (stellar twins) have revealed interesting correlations between relative elemental abundance and dust condensation temperature, which can be interpreted as signatures of the formation of gas giant and/or terrestrial planets. The proposed connection between host star chemical abundances and planet formation will be discussed, as well as how it could be used to find or confirm the presence of exoplanets and what these findings could tell us about the way stars and planets form.

**Author(s):** Ivan Ramirez<sup>1</sup>

**Institution(s):** 1. University of Texas at Austin

### **404.04 – The EREBOS Project: Determining the Influence of Substellar Objects on Stellar Evolution**

Planets and brown dwarfs in close orbits around main sequence stars will interact with their stellar hosts once they ascend the red giant branch. The details of these interactions and their outcomes are currently unclear. Recent discoveries of brown dwarfs orbiting post-red giant branch “hot subdwarf” stars imply that (i) the angular momentum resident in an orbiting substellar object is sufficient for ejecting the outer layers of a red giant’s atmosphere and (ii) the substellar object can survive this interaction. Thirty-six new eclipsing hot subdwarf binaries with cool, low-mass companions were discovered from light curves obtained through the Optical Gravitational Lensing Experiment (OGLE) project, tripling the number of known systems. We recently started the Eclipsing Reflection Effect Binaries from the OGLE Survey (EREBOS) project to obtain follow-up spectroscopy and determine the stellar masses in these systems. The companion mass distribution resulting from this work will allow us to determine whether there is a lower mass limit for substellar objects to eject a red giant’s envelope and survive engulfment, as suggested by theory. Here we give a brief overview of the EREBOS project and discuss progress towards this goal.

**Author(s):** Brad Barlow<sup>1</sup>, Veronika Schaffenroth<sup>2</sup>, Rodrigo Catalan-Hurtado<sup>1</sup>

**Institution(s):** 1. *High Point University*, 2. *University of Innsbruck*

**Contributing team(s):** The EREBOS Team

#### 404.05 – High-resolution analysis of carbon-enhanced metal-poor stars with Magellan

We report chemical abundances for carbon-enhanced metal-poor stars observed with Magellan/MIKE. The various subclasses of CEMP stars are presented in the context of the astrophysical sites of production of the elements. Of particular importance are the new discoveries and analysis of CEMP-no stars with  $[\text{Fe}/\text{H}] < -3.5$ , which exhibit no neutron-capture-element enhancements. We find that the abundance patterns of the lowest-metallicity stars in the sample reveal new clues regarding the origin(s) of early CNO production in the Universe.

**Author(s):** Catherine R. Kennedy<sup>2</sup>, Vinicius M Placco<sup>1</sup>, Timothy C. Beers<sup>1</sup>

**Institution(s):** 1. *University of Notre Dame*, 2. *University of Tampa*

#### 404.06 – The Frequency of Lithium-Rich Giants in Globular Clusters

Although red giants destroy lithium, some giants are Li-rich. Intermediate-mass asymptotic giant branch (AGB) stars can generate Li through the Cameron-Fowler conveyor, but the existence of Li-rich, low-mass red giant branch (RGB) stars is puzzling. Globular clusters are the best sites to examine this phenomenon because it is straightforward to determine membership in the cluster and to identify the evolutionary state of each star. In 72 hours of Keck/DEIMOS exposures in 25 clusters, we found four Li-rich RGB and two Li-rich AGB stars. There were 1696 RGB and 125 AGB stars with measurements or upper limits consistent with normal abundances of Li. Hence, the frequency of Li-richness in globular clusters is  $(0.2 \pm 0.1)\%$  for the RGB,  $(1.6 \pm 1.1)\%$  for the AGB, and  $(0.3 \pm 0.1)\%$  for all giants. Because the Li-rich RGB stars are on the lower RGB, Li self-generation mechanisms proposed to occur at the luminosity function bump or He core flash cannot explain these four lower RGB stars. We propose the following origin for Li enrichment: (1) All luminous giants experience a brief phase of Li enrichment at the He core flash. (2) All post-RGB stars with binary companions on the lower RGB will engage in mass transfer. This scenario predicts that 0.1% of lower RGB stars will appear Li-rich due to mass transfer from a recently Li-enhanced companion. This frequency is at the lower end of our confidence interval.

**Author(s):** Evan N Kirby<sup>1</sup>, Puragra Guhathakurta<sup>7</sup>, Andrew J Zhang<sup>6</sup>, Jerry Hong<sup>4</sup>, Michelle Guo<sup>5</sup>, Rachel Guo<sup>2</sup>, Judith G. Cohen<sup>1</sup>, Katia M. L. Cunha<sup>3</sup>

**Institution(s):** 1. *California Institute of Technology*, 2. *Irvington High School*, 3. *Observatório Nacional*, 4. *Palo Alto High School*, 5. *Stanford University*, 6. *The Harker School*, 7. *University of California Santa Cruz*

#### 404.07 – The asteroseismic signature of strong magnetic fields in the cores of red giant stars

Internal stellar magnetic fields are inaccessible to direct observations and little is known about their amplitude, geometry and evolution. I will discuss how strong magnetic fields in the cores of red giant stars can be identified with asteroseismology. The fields manifest themselves via depressed dipole stellar oscillation modes, which arises from a magnetic greenhouse effect that scatters and traps oscillation mode energy within the core of the star. Physically, the effect stems from magnetic tension forces created by sufficiently strong fields, which break the spherical symmetry of the wave propagation cavity. The loss of wave energy within the core reduces the mode visibility at the stellar surface, and we find that our predicted visibilities are in excellent agreement with a class of red giants exhibiting depressed dipole oscillation modes. The Kepler satellite has already observed hundreds of these red giants, which we identify as stars with strongly magnetized cores. Field strengths larger than roughly  $10^5$  G can produce the observed depression,

and in one case we measure a core field strength of  $10^7$  G.

**Author(s):** Jim Fuller<sup>1</sup>, Matteo Cantiello<sup>3</sup>, Dennis Stello<sup>4</sup>, Rafael Garcia<sup>2</sup>, Lars Bildsten<sup>3</sup>

**Institution(s):** 1. *California Institute of Technology*, 2. *CEA*, 3. *Kavli Institute for Theoretical Physics*, 4. *University of Sydney*

#### 404.08 – First results from the Bulge Asymmetries and Dynamic Evolution survey

The goal of the Bulge Asymmetries and Dynamic Evolution (BAaDE) project is to undertake the largest ever survey of red giant SiO maser sources ( $\sim 20,000$ ) in the bulge and inner Galaxy. This survey will provide a confusion-free, extinction-free, densely sampled set of point-masses in the regions of the Galaxy that are not reachable with optical surveys (concentrated along  $0^\circ < l < 360^\circ$ ,  $-3^\circ < b < +3^\circ$ ). VLA and ALMA observations of the stellar SiO maser lines give accurate line-of-sight velocities and positions, thus the SiO stars are used as point-mass tracers of the dynamics. These new kinematic probes will be used to significantly improve our understanding of the dynamics and structure of the bulge and inner Galaxy and may help clarifying the range of age in the bulge population. With these data it will be possible to find kinematic substructures, e.g., traces of dwarf galaxies that have been ingested by the bulge over the past  $\sim 1$ -3 Gyr. Complementary near-infrared spectroscopy will be performed for a subsample of the stars, and higher resolution VLBA observations will be used to determine proper motions, parallaxes and orbit families for a subset of sources. Here we will describe the project aims and report on the first results.

**Author(s):** Ylva Pihlstrom<sup>3</sup>, Lora Sjouwerman<sup>1</sup>, Robert Michael Rich<sup>2</sup>, Mark J. Claussen<sup>1</sup>, Mark Morris<sup>2</sup>

**Institution(s):** 1. *NRAO*, 2. *UCLA*, 3. *Univ. of New Mexico*  
**Contributing team(s):** BAaDE Collaboration

#### 404.09 – Probing the dusty inhabitants of the Local Group Galaxies: JWST/MIRI colors of infrared stellar populations

The assembly of galaxies involves the life cycle of mass, metal enrichment and dust that JWST will probe. Detailed studies of nearby galaxies provides guidance for interpreting the more distant forming galaxies. JWST/MIRI will enable stellar population studies akin to work done with HST on the Local Group galaxies but over a new wavelength range. MIRI's imaging capability over nine photometric bands from 5 to 28 microns is particularly suited to survey stars with an infrared excess and to detangle the extinction or thermal emission from various species of dust. These dusty stellar populations include young stellar objects, evolved stars and supernovae that are bright in the infrared. Using the rich Spitzer-IRS spectroscopic dataset and spectral classifications from the Surveying the Agents of Galaxy Evolution (SAGE)-Spectroscopic survey of over a thousand objects in the Magellanic Clouds, we calculate the expected flux – densities and colors in the MIRI broadband filters for these prominent infrared sources. We use these fluxes to illustrate what JWST will see in stellar population studies for other Local Group galaxies. JWST/MIRI observations of infrared sources in Local Group Galaxies will constrain the life cycle of galaxies through their dust emission. For example, how much of the interstellar dust is supplied by dying stars? Do the number of young stellar objects agree with star formation diagnostic for the galaxy? We discuss the locations of the post- and pre-main-sequence populations in MIRI color-color and color-magnitude space and examine which filters are best for identifying populations of sources. We connect these results to existing galaxies with HST data for instance Andromeda and M33.

**Author(s):** Olivia Jones<sup>1</sup>, Margaret Meixner<sup>1</sup>

**Institution(s):** 1. *STScI*

#### 405 – Relativistic Astrophysics, Gravitational Lenses & Waves

##### 405.01 – Finally Here - The launch of LISA Pathfinder and the road to detecting Gravitational Waves in space

The LISA Pathfinder spacecraft was launched in late 2015 and will begin science operations in early 2016. Led by the European Space Agency with contributions from a number of European national agencies, universities, and NASA, LISA Pathfinder will demonstrate several key technologies and measurement techniques for future space-based gravitational wave observatories. A successful LISA Pathfinder will retire much of the technical risk for such missions, which are the only proposed instruments capable of observing gravitational waves in the milliHertz band, a source-rich region expected to include signals from merging extragalactic massive black holes, capture of stellar-mass compact objects by massive black holes, and millions of individual close compact binaries in the Milky Way. I will present an overview of the LISA Pathfinder mission, its current status, and the plans for operations and data analysis.

**Author(s):** James Thorpe<sup>1</sup>

**Institution(s):** 1. NASA GSFC

**Contributing team(s):** The LISA Pathfinder Team

#### 405.02 – NASA’s Preparations for ESA’s L3 Gravitational Wave Mission

In November 2013, the European Space Agency (ESA) selected the science theme, the “Gravitational Universe,” for its third large mission opportunity, known as ‘L3,’ under its Cosmic Vision Programme. The planned launch date is 2034. NASA is seeking a role as an international partner in L3. NASA is supporting: (1) US participation in early mission studies, (2) US technology development, (3) pre-decadal preparations, (4) ESA’s LISA Pathfinder mission and (5) the ST7 Disturbance Reduction System project. This talk summarizes NASA’s preparations for a future gravitational-wave mission.

**Author(s):** Robin T. Stebbins<sup>1</sup>

**Institution(s):** 1. NASA GSFC

#### 405.03 – Evaluation of new technologies for the LISA gravitational reference sensor using the UF torsion pendulum

The Laser Interferometer Space Antenna (LISA) is the most mature concept for detecting gravitational waves from space. The LISA design has been studied for more than 20 years as a joint effort between NASA and the European Space Agency. LISA consists of three Sun-orbiting spacecraft that form an equilateral triangle, with each side measuring 1-5 million kilometers in length. Each spacecraft houses two free-floating test masses, which are protected from all disturbing forces so that they follow pure geodesics. A single test mass together with its protective housing and associated components is referred to as a gravitational reference sensor. A drag-free control system is supplied with measurements of the test mass position from these sensors and commands external microneutron thrusters to force the spacecraft to fly in formation with the test masses. Laser interferometry is used to measure the minute variations in the distance, or light travel time, between these purely free-falling TMs, caused by gravitational waves. We have constructed a new torsion pendulum facility with a force sensitivity in the range of  $\text{pN}/\text{Hz}^{1/2}$  around 1 mHz for testing new gravitational reference sensor technologies. This experimental facility consists of a vacuum enclosed torsion pendulum that suspends mock-ups of the LISA test masses, surrounded by their electrode housings. With the aid of this facility, we are (a) developing a novel test mass charge control scheme based on ultraviolet LEDs, (b) examining alternate test mass and electrode housing coatings, and (c) evaluating alternate operational modes of the LISA gravitational reference sensor. This presentation will describe this facility and the development status of these new technologies.

**Author(s):** John Conklin<sup>1</sup>, Andrew Chilton<sup>1</sup>, Taiwo Olatunde<sup>1</sup>, Stephen Apple<sup>1</sup>, Michael Aitken<sup>1</sup>, Giacomo Ciani<sup>1</sup>, Guido Mueller<sup>1</sup>

**Institution(s):** 1. University of Florida

#### 405.04D – Rate and Followup of Advanced LIGO-Virgo Events

Compact binary coalescences (CBCs) are the most promising

gravitational wave sources for the LIGO/Virgo detectors. We predict the detectable rate of CBCs from short GRB observations, and constrain the GRB beaming angles from the non-detection of mergers in existing LIGO/Virgo data. The gravitational wave signals are almost impossible to obscure via dust absorption or other astrophysical processes, allowing us to derive the universal distribution of signal-to-noise ratios (SNR) for gravitational wave detection. This distribution guarantees the existence of high SNR events, and these provide the best constraints on source parameters such as sky locations. We discuss low-latency localization from these high SNR CBC detections, and optimizing EM follow-up of CBC sources.

**Author(s):** Hsin-Yu Chen<sup>1</sup>, Daniel Holz<sup>1</sup>

**Institution(s):** 1. University of Chicago

**Contributing team(s):** LIGO

#### 405.05 – An Automated Search for Gravitationally Lensed Quasars in the Sloan Digital Sky Survey

Quasar lensing is a powerful tool in deciphering the characteristics of dark matter and dark energy. Given the availability of “big data” on quasars, including the SDSS DR12 and the recently released DES data set, a robust automated algorithm for the detection of lensed quasars is rapidly becoming a necessity. We report results from an automated search for lensed quasars consisting of two complementary algorithms: a morphological algorithm directed at finding wide-separation lens candidates and a PSF-difference-based algorithm aimed at identifying close-separation lens candidates. This research started with a baseline data set of over 450,000 quasars and 996,317 spatial neighbors within 16 arcseconds of each quasar in the SDSS DR12. This threshold can identify quasars lensed by galaxy-scale to cluster-scale matter concentrations. The first part of the automated method matched redshift and color characteristics of images and compared key emission lines in the spectrum of the quasars and their neighbors. The second portion applied image segmentation techniques to deblend close-separation candidates identified as one photometric object by SDSS. Cross-matching with observations of the same targets across other bands of the electromagnetic spectrum and elimination of confirmed binary quasars increased the confidence level of the resulting candidate list. The automated search efficiently produced output consistent with results reported in the literature. In addition, the algorithms identified many new lens candidates not yet reported in the literature which warrant detailed follow-up observations.

**Author(s):** Pranav Sivakumar<sup>1</sup>, Janani N. Sivakumar<sup>2</sup>, Paul J. Nebres<sup>1</sup>

**Institution(s):** 1. Illinois Mathematics and Science Academy, 2. Indiana University

#### 405.06 – Investigating Parameter Space for Resonant Stellar Absorption of Gravitational Waves

We investigate the resonant absorption of gravitational waves (GW) by stars and related objects, to determine which stars will be the most efficient absorbers. Stars with quadrupolar oscillation modes at frequencies matching GW sources will behave as driven damped harmonic oscillators and can absorb significant amounts of energy. We compute the total energy absorbed by various types of stars as a function of mass and radius, given simplified assumptions about the mode-frequency structure of such objects. We include considerations of saturated versus unsaturated driving, and consider a wide range of binary GW sources. We will discuss optimal stellar targets for observing a luminosity increase due to absorption of GW.

**Author(s):** K.E. Saavik Ford<sup>1</sup>, Barry McKernan<sup>1</sup>, Susan Blackburn<sup>1</sup>

**Institution(s):** 1. CUNY Borough of Manhattan Community College

#### 405.07 – Multi-Messenger Sources For Pulsar Timing Arrays

Recent Pulsar Timing Array (PTA) upper limits on the gravitational wave strain in the nanohertz frequency band are impacting our understanding of the binary supermassive black hole population.

Understanding this population is crucial to understanding the final stage of galaxy mergers, in which a binary supermassive black hole will form and eventually coalesce. We have begun to explore the potential of using electromagnetic (EM) observations of binary supermassive black holes to characterize the statistics of the binary population. In this work, we explore the expected number density of EM observable sources versus redshift and host-mass/optical luminosity. We assess different EM detection methods to determine the likelihood that one could turn up a multi-messenger target for a viable PTA sensitivity level, and show that some multi-messenger sources are viable in the near future. Finally, we explore how the number of potentially observable sources is effected by a low frequency turn-over, which recent PTA limits have shown to be likely.

**Author(s):** Joseph Simon<sup>2</sup>, Sarah Spolaor<sup>1</sup>

**Institution(s):** 1. NRAO Socorro, 2. University of Wisconsin-Milwaukee

#### 405.08 – Towards robust detection of gravitational waves by pulsar timing

Precision timing of highly stable milli-second pulsars is a promising technique for detecting very low frequency sources of gravitational waves. In any one pulsar, the gravitational wave signal appears as an additional source of timing noise, and it is only by considering the coherent response across a network of pulsars that the signal can be distinguished from other sources of noise. In the limit where there are many gravitational wave sources, or in the limit where there are many pulsars in the array, the waves produce a unique tensor correlation pattern that depends only on the angular separation of each pulsar pair. It is this distinct fingerprint that is used to search for gravitational waves using pulsar timing arrays. Here we consider how the prospects for detection are diminished when there are a finite number of signals and pulsars, which breaks the statistical isotropy of the timing array and of the gravitational wave sky. We also study the use of "sky-scrambles" to break the signal correlations in the data as a way to increase confidence in a detection.

**Author(s):** Neil J. Cornish<sup>1</sup>, Laura Sampson<sup>2</sup>

**Institution(s):** 1. Montana State Univ., 2. Northwestern University

### 406 – Extrasolar Planets: Hosts, Interactions, Formation, and Interiors

#### 406.01 – How Many Exoplanets Does it Take to Constrain the Origin of Mercury?

The origin of Mercury's enhanced iron content is a matter of ongoing debate. The characterization of rocky exoplanets promises to provide new independent insights on this topic by constraining the occurrence rate and physical and orbital properties of iron-enhanced planets orbiting distant stars. The ultra-short-period transiting planet candidate KOI-1843.03 (0.6 Earth-radius, 4.245 hour orbital period) represents the first exo-Mercury planet candidate ever identified. For KOI-1843.03 to have avoided tidal disruption on such a short orbit, it must have a mean density of at least 7g/cc and be at least as iron rich as Mercury (Rappaport et al. 2013). In contrast, Dressing et al. (2015) have noted that, to date, all confirmed transiting small (< 1.5 Earth-radius) exoplanets with masses measured to better than 20% precision have mean densities that are consistent with Earth-like bulk compositions, though significant compositional dispersion is also admitted within the observational uncertainties. This presentation will describe the application of hierarchical Bayesian models to constrain the underlying distribution of rocky exoplanet iron contents from a sample of noisy mass-radius measurements coupled to rocky planet interior structure models. In addition to deriving constraints on the distribution of iron-enhanced exo-Mercuries from the exoplanet mass-radius measurements in hand, we also apply this approach to simulated data sets to predict how the constraints should improve as increasing numbers of exoplanets are characterized. The work outlines an observational pathway toward using exoplanets to place Mercury into context.

**Author(s):** Leslie Rogers<sup>1</sup>

**Institution(s):** 1. University of California, Berkeley

#### 406.02 – A variable polytrope index applied to planet and material models

We introduce a new approach to a century-old assumption which enhances not only planetary interior calculations but also high-pressure material physics. We show that the polytropic index is the derivative of the bulk modulus with respect to pressure. We then augment the traditional polytrope theory by including a variable polytrope index within the confines of the Lane-Emden differential equation. To investigate the possibilities of this method, we create a high-quality universal equation of state, transforming the traditional polytrope method to a tool with the potential for excellent predictive power. The theoretical foundation of our equation of state is the same elastic observable which we found equivalent to the polytrope index, the derivative of the bulk modulus with respect to pressure. We calculate the density-pressure of six common materials up to  $10^{18}$  Pa, mass-radius relationships for the same materials, and produce plausible density-radius models for the rocky planets of our Solar system. We argue that the bulk modulus and its derivatives have been underutilized in previous planet formation methods. We constrain the material surface observables for the inner core, outer core, and mantle of planet Earth in a systematic way including pressure, bulk modulus, and the polytrope index in the analysis. We believe that this variable polytrope method has the necessary apparatus to be extended further to gas giants and stars. As supplemental material we provide computer code to calculate multi-layered planets.

**Author(s):** Kevin Thielen<sup>1</sup>, Stephen Weppner<sup>1</sup>, Alexander Zielinski<sup>1</sup>

**Institution(s):** 1. Eckerd College

#### 406.03 – How Giant Planets Shape the Characteristics of Terrestrial Planets

The giant planets in the Solar System likely played a defining role in shaping the properties of the Earth and other terrestrial planets during their formation. Observations from the Kepler spacecraft indicate that terrestrial planets are highly abundant. However, there are hints that giant planets a few AU from their stars are not ubiquitous. It therefore seems reasonable to assume that many terrestrial planets lack a Jupiter-like companion. We use a recently developed, state-of-the-art N-body model that allows for collisional fragmentation to perform hundreds of numerical simulations of the final stages of terrestrial planet formation around a Sun-like star -- with and without giant outer planets. We quantify the effects that outer giant planet companions have on collisions and the planet accretion process. We focus on Earth-analogs that form in each system and explore how giant planets influence the relative frequency of giant impacts occurring at late times and the delivery of volatiles. This work has important implications for determining the frequency of habitable planets.

**Author(s):** Thomas Barclay<sup>1</sup>, Elisa V. Quintana<sup>1</sup>

**Institution(s):** 1. NASA Ames Research Center

#### 406.04 – The Effect of Orbital Configuration on the Possible Climates and Habitability of Kepler-62f

As lower-mass stars often host multiple rocky planets, gravitational interactions among planets can have significant effects on climate and habitability over long timescales. Here we explore a specific case, Kepler-62f (Borucki et al., 2013), a potentially habitable planet in a five-planet system with a K2V host star. N-body integrations reveal the stable range of initial eccentricities for Kepler-62f is  $0.00 \leq e \leq 0.32$ , absent the effect of additional, undetected planets. We simulate the tidal evolution of Kepler-62f in this range and find that, for certain assumptions, the planet can be locked in a synchronous rotation state. Simulations using the three-dimensional (3-D) "Laboratoire de Météorologie Dynamique" (LMD) Generic global climate model (GCM) indicate that the surface habitability of this planet is sensitive to orbital configuration. With 3 bars of CO<sub>2</sub> in its atmosphere, we find that Kepler-62f would only be warm enough for surface liquid water at the upper limit of this eccentricity range,

providing it has a high planetary obliquity (between  $60^\circ$  and  $90^\circ$ ). A climate similar to modern-day Earth is possible for the entire range of stable eccentricities if atmospheric  $\text{CO}_2$  is increased to 5-bar levels. In a low- $\text{CO}_2$  case (Earth-like levels), simulations with version 4 of the Community Climate System Model (CCSM4) GCM indicate that increases in planetary obliquity and orbital eccentricity coupled with an orbital configuration that places the summer solstice at or near pericenter permit regions of the planet with above-freezing surface temperatures. This may melt ice sheets formed during colder seasons. If Kepler-62f is synchronously rotating and has an ocean,  $\text{CO}_2$  levels above 3 bars would be required to distribute enough heat to the night side of the planet to avoid atmospheric freeze-out and permit a large enough region of open water at the planet's substellar point to remain stable. Overall, we find multiple plausible combinations of orbital and atmospheric properties that permit surface liquid water on Kepler-62f.

**Author(s):** Aomawa Shields<sup>1</sup>, Rory Barnes<sup>2</sup>, Eric Agol<sup>2</sup>, Benjamin Charnay<sup>2</sup>, Cecilia Bitz<sup>2</sup>, Victoria Meadows<sup>2</sup>

**Institution(s):** 1. UCLA/Harvard, 2. University of Washington

**Contributing team(s):** NASA Astrobiology Institute's Virtual Planetary Laboratory

#### 406.05 – Solar and Stellar Flares over Time: Effects on Hosted Planets

The effects of flares from the Sun on Earth and other solar-system planets are presented. Also discussed are the flare properties of cooler, commonplace main-sequence K-M stars. Data from our "Sun in Time" program are used to study the flare properties of the Sun and solar-type stars from youth to old age. These studies are based on ground-based observations, UV and X-ray space missions (*IUE* & *HST*, *ROSAT* & *Chandra*) as well as a wealth of data from the *Kepler Mission*. The ultra-high precision photometry available from the *Kepler Mission* (and *K2*) has made it possible to study starspots, flare properties, and rotations of thousands of G, K, M stars. Superflares (defined as  $E > 10^{33}$  ergs  $\sim$  X-100 flares) on hundreds of mostly G and K stars have been found. (See e.g. Shibayama et al. 2013; Maehara et al. 2015; Notsu et al. 2013/15; Saar et al. 2015; Guinan et al. 2015). Using our Age-Rotation relations, we determine correlations of flares properties of the Sun and solar-type over a wide range of ages. We also compare these flare histories with the cooler, more common K- and M-type stars. The analysis of these datasets imply that the young Sun had numerous, very powerful flares that may have played major roles the evolution of the early atmospheres of Earth and other terrestrial planets. The strong X-UV fluxes and proton fluences from flares and associated plasmas from coronal mass ejection events can greatly affect the photochemistry of planetary atmospheres as well as ionizing and possibly eroding their atmospheres. Some examples are given. Also discussed are the effects of superflares from the present Sun on the Earth. Even though solar superflares are rarer ( $\sim 1$  per 300-500 yrs) than from the young Sun ( $> 1$ -2 per year), they could cause significant damage to our communication and satellite systems, electrical networks, and threaten the lives of astronauts in space..

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**Author(s):** Edward F. Guinan<sup>1</sup>, Laurence E. DeWarf<sup>1</sup>, Scott G. Engle<sup>1</sup>, Jeffrey Gropp<sup>1</sup>

**Institution(s):** 1. Villanova Univ.

#### 406.07 – Dynamical Constraints on the Core Mass of Hot Jupiter HAT-P-13b

HAT-P-13b is a Jupiter-mass transiting exoplanet that has settled onto a stable, short-period, and mildly eccentric orbit due to the action of tidal dissipation and perturbations from a second, highly eccentric, outer companion. Due to the special orbital configuration of the HAT-P-13 system, the magnitude of HAT-P-13b's eccentricity is in part dictated by its Love number, i.e. the degree of central mass concentration in its interior. We can therefore directly constrain the fraction of HAT-P-13b's mass contained in its core by measuring its orbital eccentricity. This method offers considerable advantages over the standard approach of inferring core size based on mass and

radius measurements alone. In this study we derive new constraints on the value of HAT-P-13b's eccentricity by observing two secondary eclipses of HAT-P-13b with the Infrared Array Camera on board the Spitzer Space Telescope. We fit the measured secondary eclipse times simultaneously with radial velocity measurements and find that the eccentricity of HAT-P-13b is  $0.00696 \pm 0.00096$ . We then use octupole-order secular perturbation theory to find that the corresponding Love number is  $0.31 (+0.11, -0.05)$ . Applying structural evolution models, we then find, with 68% confidence, that the core mass lies between 0-25 Earth masses, with a most likely value of the core mass of 11 Earth masses. This is the tightest constraint, to date, on the core mass of an exoplanet. We also compare the measured secondary eclipse depths, in the 3.6 and 4.5 micron bands, to the predictions of a suite of atmosphere models and find that the depths are best matched by models with a dayside temperature inversion and relatively efficient day-night circulation.

**Author(s):** Peter Benjamin Buhler<sup>2</sup>, Heather Knutson<sup>2</sup>, Konstantin Batygin<sup>2</sup>, Benjamin James Fulton<sup>4</sup>, Adam Seth Burrows<sup>1</sup>, Jonathan J. Fortney<sup>3</sup>

**Institution(s):** 1. Astrophysical Sciences, Princeton University, 2. California Institute of Technology, 3. Department of Astronomy and Astrophysics, University of California, Santa Cruz, 4. Institute for Astronomy, University of Hawaii at Manoa

#### 406.08D – Diagnostics of models and observations in the contexts of exoplanets, brown dwarfs, and very low-mass stars.

When studying isolated brown dwarfs and directly imaged exoplanets with insignificant orbital motion, we have to rely on theoretical models to determine basic parameters such as mass, age, effective temperature, and surface gravity. While stellar and atmospheric models are rapidly evolving, we need a powerful tool to test and calibrate them. In my thesis, I focussed on comparing interior and atmospheric models with observational data, in the effort of taking into account various systematic effects that can significantly influence the data analysis.

As a first step, about 460 candidate member os the Hyades were screened for companions using diffraction limited imaging observation (both our own data and archival data). As a result I could establish the single star sequence for the Hyades comprising about 250 stars (Kopytova et al. 2015, accepted to A&A). Open clusters contain many coeval objects of the same chemical composition and age, and spanning a range of masses. We compare the obtained sequence with a set of theoretical isochrones identifying systematic offsets and revealing probable issues in the models. However, there are many cases when it is impossible to test models before comparing them with observations.

As a second step, we apply atmospheric models for constraining parameters of WISE 0855-07, the coolest known Y dwarf (Kopytova et al. 2014, ApJ 797, 3). We demonstrate the limits of constraining effective temperature and the presence/absence of water clouds.

As a third step, we introduce a novel method to take into account the above-mentioned systematics. We construct a "systematics vector" that allows us to reveal problematic wavelength ranges when fitting atmospheric models to observed near-infrared spectra of brown dwarfs and exoplanets (Kopytova et al., in prep.). This approach plays a crucial role when retrieving abundances for these objects, in particularly, a C/O ratio. The latter parameter is an important key to formation scenarios of brown dwarf and exoplanets. We show the way to constrain a C/O ratio while eliminating systematics effects, which significantly improves the reliability of a final result and our conclusions about formation history of certain exoplanets and brown dwarfs.

**Author(s):** Taisiya Kopytova<sup>1</sup>

**Institution(s):** 1. Max Planck Institute for Astronomy

## 407 – Cosmology, CMB, and Dark Matter III

### 407.01 – Probing B-mode foregrounds using estimators of isotropy violation

We propose an isotropy-violation test as a diagnostic for foreground contamination to the Cosmic Microwave Background (CMB). Using polarized Planck 353 GHz data, we construct a map that indicates B-mode foreground dust emission, and helps to indicate the least contaminated lines-of-sight. This estimate, constructed in harmonic space via the bipolar spherical harmonic basis, has higher signal-to-noise than previous estimates of the dust B-mode power. We compare the contamination levels in several low-foreground regions of the sky, including the BICEP2 region. This information, and similar statistics, may be useful to ground-based CMB projects when planning observations to hunt for primordial B-mode signatures. Today, this tool can assess clean portions of the sky, but in the future it will allow null tests for foreground contamination in claimed detections of primordial B-modes.

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**Institution(s):** 1. Florida State University

### 407.02D – The Scale-Dependence of Halo Assembly Bias

The clustering of dark matter halos is influenced by halo properties besides mass, a phenomenon referred to as halo assembly bias. It is because halos of the same mass in different environments have different assembly histories and cluster differently. There have been several studies showing such environmental effects on the linear bias of halos. The halo bias on small scales, however, is scale-dependent. I will present the first study of the scale-dependence of halo assembly bias using the depth of the gravitational potential well,  $V_{\text{max}}$ , as our secondary halo property. We find that assembly bias in low-mass halos exhibits a pronounced scale-dependent "bump" at 500 kpc/h - 5 Mpc/h. This feature weakens and eventually vanishes for halos of higher mass. We show that this scale-dependent signature can primarily be attributed to a special subpopulation of ejected halos, defined as present-day host halos that were previously members of a higher-mass halo at some point in their past history. A corollary of our results is that galaxy clustering on scales of  $r \sim 1\text{--}2$  Mpc/h can be impacted by up to  $\sim 15\%$  by the choice of the halo property used in the halo model, even for stellar mass-limited samples.

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**Institution(s):** 1. Kavli Institute for the Physics and Mathematics of the Universe The University of Tokyo, 2. Yale University

### 407.03 – Fisher Matrix Optimization of Cosmic Microwave Background Interferometry

We describe a method for forecasting errors in interferometric measurements of polarization of the cosmic microwave background (CMB) radiation, based on the use of the Fisher matrix calculated from the visibility covariance and relation matrices. In addition to noise and sample variance, the method can account for many kinds of systematic error by calculating an augmented Fisher matrix, including parameters that characterize the instrument along with the cosmological parameters to be estimated. The method is illustrated with examples of gain errors and errors in polarizer orientation. The augmented Fisher matrix approach is applicable to a much wider range of problems beyond CMB interferometry.

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### 407.04 – Associations between small-scale structure in the GALFA survey data of HI in the galactic disk and similar features in the Cosmic Microwave Background observed by PLANCK

High-resolution HI data obtained as part of the Arecibo GALFA survey have been compared with PLANCK data at 143 GHz and 857 GHz. The analysis confirms what has been reported previously, that sources of high-frequency continuum radiation exist in the galactic

interstellar medium that produce structure that has been incorrectly interpreted as being cosmological in origin. The mechanism appears to be free-free emission from electron concentrations in regions where the dust and HI are similarly clumped or otherwise enhanced due to geometric effects. By comparing model calculations with the data it is concluded that the source of the radiation is relatively close to the sun, or order 25 to 50 pc distant. The required ionization fraction relative to HI is of order 0.05 – 0.08 for the areas tested.

**Author(s):** Gerrit L. Verschuur<sup>1</sup>

**Institution(s):** 1. Arecibo Observatory

### 407.05 – Gravitational Lensing Science with the Atacama Cosmology Telescope Polarization Survey

The gravitational lensing of the cosmic microwave background (CMB) has emerged as a new probe of precision cosmology. The Atacama Cosmology Telescope is currently undergoing its second year surveying the CMB sky at arcminute angular resolution. CMB maps obtained from this survey can be used to reconstruct the density of dark matter along the line of sight between us and the CMB last-scattering surface. These maps can be used both on their own and in cross-correlation with other probes of large scale structure to trace the history of structure growth in the Universe. In this talk I will summarize recent results from these analyses, highlighting constraints on the neutrino mass and dark energy as well as the history of star formation obtained from cross-correlation with maps of the cosmic infrared background.

**Author(s):** Alexander Van Englen<sup>1</sup>

**Institution(s):** 1. CITA

**Contributing team(s):** Atacama Cosmology Telescope team

### 407.06 – Polarization predictions for cosmological models with large-scale power modulation

Several "anomalies" have been noted on large angular scales in maps of the cosmic microwave background (CMB) radiation, although the statistical significance of these anomalies is hotly debated. Of particular interest is the evidence for large-scale power modulation: the variance in one half of the sky is larger than the other half. Either this variation is a mere fluke, or it requires a major revision of the standard cosmological paradigm.

The way to determine which is the case is to make predictions for future data sets, based on the hypothesis that the anomaly is meaningful and on the hypothesis that it is a fluke. We make predictions for the CMB polarization anisotropy based on a cosmological model in which statistical isotropy is broken via coupling with a dipolar modulation field. Our predictions are constrained to match the observed Planck temperature variations. We identify the modes in CMB polarization data that most strongly distinguish between the modulation and no-modulation hypotheses.

**Author(s):** Emory F. Bunn<sup>1</sup>, Qingyang Xue<sup>1</sup>

**Institution(s):** 1. Univ. of Richmond

### 407.07 – Diffuse gamma-ray emission modeling near the Galactic Center and the 3 GeV excess

The region near the Galactic Center (GC) is one of the most complex in the gamma-ray sky. Several groups have reported excess emission in gamma rays peaking around 3 GeV relative to expectations from conventional models for the interstellar emission. We study the uncertainty of the excess emission in Pass 8 Fermi-LAT data due to modeling of the various emission components in that direction. In particular, we quantify the uncertainties on the excess by refitting with several GALPROP models of Galactic diffuse emission, an alternative distribution of gas along the line of sight based on starlight extinction data, a model of the Fermi bubbles at low latitudes, and including templates for additional sources of cosmic-ray (CR) electrons near the GC. In all models that we have tested the excess emission remains significant. The most important contributions to the uncertainties are modeling of the Fermi bubbles and including templates for additional sources of CR electrons. We also consider several models for the population and emission of millisecond pulsars (MSPs) in the inner Galaxy. Although the MSP

contribution has large uncertainties, MSPs can explain the GC excess under plausible assumptions.

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**Institution(s):** 1. SLAC National Accelerator Laboratory

**Contributing team(s):** The Fermi-LAT Collaboration

#### 407.08 – Eliminating the optical depth nuisance from the CMB with 21cm cosmology

Amongst standard model parameters that are constrained by cosmic microwave background (CMB) observations, the optical depth stands out as a nuisance parameter. While the optical provides some crude limits on reionization, it also degrades constraints on other cosmological parameters. In this talk we explore how 21 cm cosmology--as a direct probe of reionization--can be used to independently predict the optical depth in an effort to improve CMB parameter constraints. We show how the errors on the amplitude of primordial fluctuations can be reduced by a factor of 4 compared to Planck, and how 21cm observations can complement Stage 4 CMB experiments to yield a 5-sigma detection of the neutrino mass even if the "reionization bump" polarization feature cannot be measured to high precision.

**Author(s):** Adrian Liu<sup>2</sup>, Jonathan R. Pritchard<sup>1</sup>, Rupert Allison<sup>3</sup>, Aaron Parsons<sup>2</sup>, Uros Seljak<sup>2</sup>, Blake Sherwin<sup>2</sup>

**Institution(s):** 1. Imperial College, 2. University of California Berkeley, 3. University of Oxford

#### 408 – Structure and Physics of Galaxies at $z < \sim 0.2$

##### 408.01 – GAMA: Stellar Mass Assembly in Galaxy Bulges and Disks

The Galaxy And Mass Assembly (GAMA) survey has to date obtained spectra, redshifts, and 21-band multi-facility photometry for over 200,000 galaxies in five survey regions that total nearly 300 square degrees on sky. We consider here a low-redshift ( $z < 0.06$ ), volume-limited subsample of  $\sim 8,000$  GAMA galaxies that have been morphologically classified by the survey team. In order to quantify the separate bulge and disk properties of these galaxies, we apply a large-scale automated procedure for fitting images with 2D, multi-component structure models, including evaluation of fit convergence using a grid of input parameter values for each galaxy. From this analysis, we calculate the total bulge and disk contributions to the local galaxy stellar mass budget and derive mass-size relations for both pure spheroid/disk systems and the separate bulge/disk components of multi-component galaxies. We further examine the fraction of total stellar mass assembled in spheroid and disk structures as a function of galaxy environment, where environment is quantified on multiple scales from membership in large-scale filaments to groups/clusters and down to local pairings. We then discuss the effect of environmental conditions on the mechanisms of stellar mass assembly, including the implied balance between merger accumulation and in situ mass growth in different environment regimes.

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**Contributing team(s):** the GAMA team

##### 408.02D – The Evolution of Galaxies (via SF activity and gas content) versus Environment

My dissertation work concerns the accurate mapping of the large-scale structure (LSS), traced by galaxies, and the assessment of the dependence of fundamental galaxy properties (e.g. star-formation activity, color, and gas content) on their environment. Mapping of the LSS is done with two complementary techniques, and together they provide both a local measure of the density field and a more global characterization of the environment of a galaxy, thereby allowing for a more complete measure of a galaxy's environment. I have applied this LSS mapping technique to the entire Sloan Digital

Sky Survey (SDSS) spectroscopic galaxy sample at  $z < 0.05$ , divided into multiple redshift bins, to explore the environmental dependence on galaxy evolution over a significant volume and a large dynamic range of environments. I will also present a more focused study looking at the molecular gas content of galaxies in two clusters at  $z \sim 0.2$ , based on a program I am leading with the Large Millimeter Telescope that has obtained CO spectroscopy for  $\sim 70$  galaxies with a range of stellar masses, atomic gas masses, and different parts of projected phase space around the two clusters. This molecular gas study provides a detailed statistical look at how the molecular and atomic gas contents of galaxies are affected by the environmental processes in their host clusters. I will summarize all of my results in these various aspects of my dissertation, with the overall theme of how galaxies are affected by their environment.

**Author(s):** Ryan Cybulski<sup>1</sup>, Min Su Yun<sup>1</sup>

**Institution(s):** 1. University of Massachusetts, Amherst

##### 408.03 – Demographics of Isolated Galaxies along the Hubble Sequence

Isolated galaxies in low-density environments are considered not to be perturbed by other galaxies at least for the last few Gyr, and thus they are important in the sense that they are least affected by the hierarchical mergers and interactions. To figure out the properties of isolated galaxies and their star-formation histories, we select isolated galaxies and their comparison sample in relatively denser environments from the Sloan Digital Sky Survey Data Release 7. The samples in the redshift range of  $0.025 < z < 0.044$  are volume-limited. The galaxies are classified based on the Hubble morphology classification scheme through a visual inspection. The catalog of Oh et al. (2011) is used for the spectroscopic study. Although we have found most of the photometric and spectroscopic properties are similar between the isolated and comparison sample galaxies, there are some differences between the samples. The most remarkable results are as follows. Late-type galaxies are dominant in isolated galaxies with the morphology distribution (E:So:S:Irr) = (9.9:11.3:77.6:1.2)%. The percentage of elliptical galaxies among isolated galaxies is only a third of that of the comparison sample (E:So:S:Irr) = (28.6:18.1:52.7:0.6)%. Isolated elliptical galaxies are less massive by 50% and younger by 20% in luminosity-weighted age than their counterparts, while spiral galaxies in isolated and comparison samples do not show any significant differences. This can be explained as a result of different merger and star-formation histories for differing environments in the hierarchical merger paradigm. We provide an online catalog for the list and properties of our sample galaxies.

**Author(s):** Honggeun Khim<sup>1</sup>, Suyoung Yi<sup>1</sup>, Jongwon Park<sup>1</sup>, Seong-woo Seo<sup>1</sup>, Jaehyun Lee<sup>1</sup>, Rory Smith<sup>1</sup>

**Institution(s):** 1. Yonsei University

##### 408.04D – Toward the Distribution of Orbital Parameters of Nearby Major Galaxy Mergers

In this thesis project our goal is to measure the initial conditions of a sample of  $\sim 20$  local disk-disk major galaxy mergers. Measuring the orbital parameters is possible by finding the most similar galaxy merger simulation to the morphology and kinematics of the data. We have developed an automated modeling method based on the Identikit software package, which also estimates the uncertainty of the measured initial conditions. We tested our modeling method using an independent set of GADGET simulations, and we acquired reliable results on prograde merger systems. We observed the H $\alpha$  kinematics of our sample using SparsePak IFU on the WIYN telescope at KPNO, and DIS on the 3.5m telescope at APO. For the few merger systems in our sample with archival HI data available, we compare the use of HI vs H $\alpha$  as the kinematic tracer. This work lays the ground-work for the analysis of larger statistical samples of mergers from on-going IFU galaxy survey such as MaNGA.

**Author(s):** Seyed Alireza Mortazavi Karvani<sup>1</sup>

**Institution(s):** 1. Johns Hopkins University

##### 408.05 – Why do the HighMass Galaxies Have so Much Gas?: Studying Massive, Gas-Rich Galaxies at

## **z~0 with Resolved HI and H<sub>2</sub>**

In the standard  $\Lambda$ CDM cosmology, galaxies form via mergers of many smaller dark matter halos. Because mergers drive star formation, the most massive galaxies should also be the ones which have been the most efficient at converting their gas reservoirs into stars. This trend is seen observationally: in general, as stellar mass increases, gas fraction ( $GF = M_{\text{HI}}/M_*$ ) decreases. Galaxies which have large reservoirs of atomic hydrogen (HI) are thus expected to be extremely rare, which was seemingly supported by earlier blind HI surveys.

In seeming contradiction, ALFALFA, the Arecibo Legacy Fast ALFA Survey has observed a sample of 34 galaxies which are both massive ( $M_{\text{HI}} > 10^{10} M_{\odot}$ ) and have unusually high gas fractions (all  $\geq 0.3$ ; half are  $> 1$ ). We call this sample HighMass. Unlike other extremely HI-massive samples, such galaxies are neither low surface brightness galaxies nor are they simply “scaled up” spirals. Could this gas be recently acquired, either from accreting small companions or directly from the cosmic web? Or is it primordial, and has been kept from forming stars, possibly because of an unusually high dark matter halo spin parameter?

We present resolved HI, H<sub>2</sub>, and star formation properties of three of these HighMass galaxies, and compare them with two HighMass galaxies previously discussed in Hallenbeck *et al.* (2014). One of these galaxies, UGC 6168, appears in the process of transitioning from a quiescent to star-forming phase, as indicated by its bar and potential non-circular flows. A second, UGC 7899, has a clear warp, which could be evidence of recently accreted gas—but the presence of a warp is far from conclusive evidence. Both have moderately high dark matter halo spin parameters ( $\lambda' = 0.09$ ), similar to the previously studied UGC 9037. The third, NGC 5230, looks undisturbed both optically and in its radio emission, but is in a group full of extragalactic gas. A neighboring galaxy has been significantly disrupted, and NGC 5230 may be in the process of acquiring some of its neighbor's removed gas.

This work has been supported by NSF-AST-0606007, AST-1107390, and AST-1211005, grants from the Brinson Foundation, and a Student Observing Support award from NRAO.

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**Institution(s):** 1. Union College

**Contributing team(s):** the HighMass Team

## **409 – Molecular Clouds, HII Regions, Interstellar Medium I**

### **409.01 – Mapping Magnetic Fields in Star Forming Regions with BLASTPol**

A key outstanding question in our understanding of star formation is whether magnetic fields provide support against the gravitational collapse of their parent molecular clouds and cores. Direct measurement of magnetic field strength is observationally challenging, however observations of polarized thermal emission from dust grains aligned with respect to the local cloud magnetic field can be used to map out the magnetic field orientation in molecular clouds. Statistical comparisons between these submillimeter polarization maps and three-dimensional numerical simulations of magnetized star-forming clouds provide a promising method for constraining magnetic field strength. We present early results from a BLASTPol study of the nearby giant molecular cloud (GMC) Vela C, using data collected during a 2012 Antarctic flight. This sensitive balloon-borne polarimeter observed Vela C for 57 hours, yielding the most detailed submillimeter polarization map ever made of a GMC forming high mass stars. We find that most of the structure in p can be modeled by a power-law dependence on two quantities: the hydrogen column density and the local dispersion in magnetic field orientation. Our power-law model for p(N,S) provides new constraints for models of magnetized star-forming clouds and an important first step in the interpretation of the BLASTPol 2012 data set.

**Author(s):** Laura M. Fissel<sup>4</sup>, Peter Ade<sup>3</sup>, Francesco E Angilè<sup>15</sup>, Peter Ashton<sup>4</sup>, Steven J Benton<sup>11</sup>, Mark J. Devlin<sup>15</sup>, Bradley Dober<sup>15</sup>, Yasuo Fukui<sup>8</sup>, Nicholas B Galitzki<sup>15</sup>, Natalie Gandilo<sup>16</sup>, J.R. Klein<sup>15</sup>, Zhi-Yun Li<sup>17</sup>, Andrei Korotkov<sup>1</sup>, Peter G. Martin<sup>5</sup>, Tristan Matthews<sup>4</sup>, Lorenzo Moncelsi<sup>2</sup>, fumitaka nakamura<sup>9</sup>, Calvin Barth Netherfield<sup>16</sup>, Giles Novak<sup>4</sup>, Enzo Pascale<sup>3</sup>, Frédéric Poidevin<sup>7</sup>, Fábio Pereira Santos<sup>4</sup>, Giorgio Savini<sup>12</sup>, Douglas Scott<sup>13</sup>, Jamil Shariff<sup>16</sup>, Juan D. Soler<sup>6</sup>, Nicholas Thomas<sup>10</sup>, carole tucker<sup>3</sup>, Gregory S. Tucker<sup>1</sup>, Derek Ward-Thompson<sup>14</sup>

**Institution(s):** 1. Brown University, 2. California Institute of Technology, 3. Cardiff University, 4. CIERA - Northwestern University, 5. CITA, 6. Institute d'Astrophysique Spatiale, 7. Instituto de Astrofísica de Canarias, 8. Nagoya University, 9. NAOJ, 10. NASA Goddard, 11. Princeton University, 12. University College London, 13. University of British Columbia, 14. University of Central Lancashire, 15. University of Pennsylvania, 16. University of Toronto, 17. University of Virginia

### **409.02D – Mid Infrared H<sub>2</sub> lines- a new direct tracer for total molecular gas content in galaxies**

Robust knowledge of the molecular hydrogen (H<sub>2</sub>) gas distribution is necessary to understand star formation in galaxies. Since H<sub>2</sub> is not readily observable in the cold interstellar medium (ISM), the molecular gas content has traditionally been inferred using indirect tracers like carbon-monoxide (CO), dust emission, gamma ray interactions, and star formation efficiency. Physical processes resulting in enhancement and reduction of these indirect tracers can result in misleading estimates of molecular gas masses. My dissertation work is based on devising a new temperature power law distribution model for warm H<sub>2</sub>, a direct tracer, to calculate the total molecular gas mass in galaxies. The model parameters are estimated using mid infrared (MIR) H<sub>2</sub> rotational line fluxes, obtained from IRS- Spitzer (InfraRed Spectrograph- Spitzer) instrument, and the model can be extrapolated to a suitable lower temperature to recover the total molecular gas mass. The power law model is able to recover the dark molecular gas, undetected by CO, in low metallicity galaxies. Using the power law model in the coming era of James Webb Space Telescope (JWST) with the high sensitivity MIR Instrument (MIRI) spectrograph we will be able to understand the properties of molecular gas at low and high redshifts.

**Author(s):** Aditya Togi<sup>1</sup>, John-David T. Smith<sup>1</sup>

**Institution(s):** 1. University of Toledo

### **409.03 – Helium Ionization in the Diffuse Ionized Gas surrounding Ultra-compact HII regions**

We observed radio recombination lines (RRLs) from regions surrounding three Ultra-compact HII (UCHII) regions at frequencies near 5 GHz. The observations were made with the Green Bank Telescope (GBT). From existing observations we know that helium in the diffuse ionized gas (DIR), located far from the ionizing source, is not fully ionized. The objectives of our observations are to determine (a) the distance from the ionizing stars where helium is under ionized for a variety of physical conditions and (b) whether the helium ionization depends on the age of the ionizing star. With these objectives, we observed RRLs towards 16 positions in the envelopes of UCHII regions G10.15-0.34, G23.46-0.20 and G29.96-0.02. Helium lines were detected toward 10 of the observed positions and hydrogen RRLs were detected toward all the observed positions. The observed ratio of ionized helium to ionized hydrogen ( $\text{He}^+/\text{H}^+$ ) at the positions where helium lines are detected range between 0.03 and 0.09. At positions where helium lines are not detected the upper limit on the ratio is  $\sim 0.05$ . We discuss the dependence of  $\text{He}^+/\text{H}^+$  ratio on the distance from and age of the ionizing star clusters in the observed sources.

**Author(s):** D. Anish Rosh<sup>1</sup>, Edward B. Churchwell<sup>2</sup>

**Institution(s):** 1. National Radio Astronomy Observatory, 2. University of Wisconsin-Madison

### **409.04 – A New Mass Conversion Law for CO Observations**

We describe a new conversion law, from CO molecular line data to

inferred mass column, based on observations of the three main CO isotopologues in the ThrUMMS project, which covers a  $60^\circ \times 2^\circ$  portion of the Milky Way's fourth quadrant. The new conversion law replaces the use of the single "X-factor" in widespread use, with a more physically-based relationship between the CO line's optical depth, excitation, and column density. The new law is based on a simple yet robust radiative transfer analysis of the  $12\text{CO}$ ,  $13\text{CO}$ , and  $\text{C}18\text{O}$  line ratios across this area of the Galactic Plane, and also incorporates a temperature-dependent term from a similar study of the California Cloud by Kong et al (2015). It is  $N = 1.8 \times 10^{24} \text{ H}_2 \text{ molecules m}^{-2} (I(\text{CO})/\text{K km s}^{-1})^{1.4} (\text{Tex}/10 \text{ K})^{-0.7}$ . It has the effect of increasing the inferred mass column, over the single X-factor, by typically a factor of 2–3. This means that the molecular mass of the Milky Way may have been substantially underestimated in previous studies, and suggests that scaling laws like the Kennicutt-Schmidt relations may also need to be recalibrated. This new law may also find applications in studies of other Milky-Way-analog spiral galaxies.

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**Institution(s):** 1. National Astronomical Observatory of Japan, 2. University of Florida

#### 409.05 – The Tilt of the Galactic Mid-Plane

The Sun has long been known to lie above the Galactic mid-plane. Most studies of the Sun's height, however, have used objects very local to the Sun, or objects that have ambiguous distances. Furthermore, the discovery that Sgr A\* lies below the mid-plane suggests that the current definition of the mid-plane itself is in error. Using the WISE Catalog of Galactic HII regions, we estimate the tilt of the "true" Galactic mid-plane from the current definition. We assume that the sample of HII regions define the true mid-plane. This sample contains ~1500 regions with known distances spanning the entire Galaxy. We also compute the Sun's height above the "true" mid-plane and discuss Galactic structure implications.

**Author(s):** Loren D. Anderson<sup>1</sup>

**Institution(s):** 1. West Virginia University

#### 409.06 – An X-ray and Infrared Hunt for New Candidate Galactic OB Stars

Most young, massive OB stars produce X-ray emission through a variety of wind-driven shock processes, and individual massive stars are detectable out to several kpc distances in the Galactic plane using high-resolution imaging observations from the *Chandra X-ray Observatory*. We have developed a technique to identify known and new candidate OB stars by fitting model stellar atmospheres to the broadband infrared spectral energy distributions of X-ray-identified stars. Using this technique, we identified 94 candidate O- and early B-type stars in the Carina Nebula and an additional 98 candidates in 11 other Galactic Massive Star-Forming Regions. Visible-light and near-infrared follow-up spectroscopy of these candidates is ongoing, and initial results indicate that a majority of candidate massive stars will be spectroscopically confirmed as OB stars.

**Author(s):** Matthew S. Povich<sup>1</sup>, Michael J Alexander<sup>2</sup>, Heather Busk<sup>4</sup>, Richard J Hanes<sup>3</sup>, Eric Feigelson<sup>4</sup>, M. Virginia McSwain<sup>3</sup>, Leisa K. Townsley<sup>4</sup>

**Institution(s):** 1. Cal Poly Pomona, 2. Lafayette College, 3. Lehigh University, 4. The Pennsylvania State University

#### 409.07 – High-Mass Star Formation in the Outer Scutum-Centaurus Arm

The HII Region Discovery Survey (HRDS; Bania et al., 2010) has discovered nearly 1000 HII regions by detecting their radio recombination line (RRL) emission using the Green Bank Telescope (GBT) and the Arecibo Observatory. Observations of RRLs allow us to measure source velocities and determine positions within the Galaxy using a rotation curve model, but until recently our sample in the far outer Galaxy was incomplete. Using HI and CO data, Dame & Thaddeus (2011) identified an extension of the Scutum-Centaurus spiral arm, deemed the Outer Scutum-Centaurus arm, or OSC. This arm offers a new laboratory for the study of Galactic structure, high-mass star formation, and chemistry of the outer Galaxy. We

searched for new Galactic HII regions in the OSC by targeting infrared-identified candidates that have an (l,b) location consistent with this arm. We have discovered 10 OSC HII regions thus far, using observations of: (1) VLA 9 GHz continuum to identify thermally emitting sources, (2) GBT RRLs to detect evolved HII regions, and (3) GBT  $\text{NH}_3$  to detect younger HII regions. Detected regions lie at an average Heliocentric distance of  $20.0 \pm 1.4$  kpc and an average Galactocentric distance of  $14.5 \pm 1.4$  kpc. The most distant region detected has a Heliocentric distance of 23.5 kpc and a Galactocentric distance of 17.0 kpc. These are the most distant known Galactic high-mass star formation regions. We will present the results of ongoing  $\text{NH}_3$  observations with the GBT, which will likely increase the sample of OSC HII regions further.

**Author(s):** William P. Armentrout<sup>5</sup>, Loren D. Anderson<sup>5</sup>, Dana S. Balser<sup>3</sup>, Thomas M. Bania<sup>1</sup>, Thomas M. Dame<sup>2</sup>, Trey Wenger<sup>4</sup>

**Institution(s):** 1. Boston University, 2. Harvard University, 3. National Radio Astronomy Observatory, 4. University of Virginia, 5. West Virginia University

#### 409.08 – The Bane of Column Density Analysis and What Good It Can Do for Us

Despite the fact that astronomers are inclined to apply statistical tools, from least-square fitting to machine learning, on the big, high-dimensional data, not enough care is often spent on examining the biases that could be introduced by sample selection and observation. The talk focuses on investigating arguably one of the most often applied statistical analyses in clouds and filaments recently--**the probability distribution function (PDF) analysis of column density**. We look at the correlation between column density PDF and various physical processes including turbulence and star formation as traced by young stellar objects and star forming cores, in both observation and simulation; as well as potential problems in statistically consistent fitting of column density distribution, validating correlation, biased sample selection, and projection effects. Our results show that 1) even though on large scale, the "width" of the column density PDF seems to correlate with turbulence, *no clear correlation is found between column density PDF and turbulence in both simulation and observation*, and 2) even previous works show that the index of the "power-law tail" correlates with the star formation activity, *there is statistical ambiguity in the sampling of column density structures and associating point sources with any of these structures*. We further analyze the hierarchical structures of column density in molecular clouds and filaments, using the structure extraction algorithm, the dendrogram.

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**Institution(s):** 1. Florida State University, 2. Harvard-Smithsonian Center for Astrophysics, 3. University of California, Berkeley

#### 410 – The Milky Way, Galactic Center

##### 410.01 – Modeling Diffuse X-ray Emission around the Galactic Center from Colliding Stellar Winds

The Galactic center is a hotbed of astrophysical phenomena. The ~30 evolved massive stars orbiting the super massive black hole (SMBH) on scales  $< 10''$  inject a large fraction of the matter that accretes onto the SMBH, and their wind-wind collisions create large swaths of shocked, hot, X-ray emitting material around Sgr A\*. The 3Ms Chandra X-ray Visionary Program of the Galactic center provided unprecedented detail of this region by resolving the diffuse thermal emission around the SMBH, and also revealed the presence of SMBH feedback into its immediate surroundings. With the original intent of computing the accretion onto the SMBH, smoothed particle hydrodynamics (SPH) simulations with various feedback prescriptions modeled the 30 Wolf-Rayet (WR) stars orbiting the SMBH over 1100 years while ejecting their stellar winds, thus providing various descriptions of the hot shocked gas around Sgr A\*. In this work, we perform 3D X-ray radiative transfer calculations on these hydrodynamic simulations with the goal of reproducing the

Chandra observations in the central  $\pm 6''$  around Sgr A\*. The model spectral shape from the 2"-5" ring agrees very well with the observations for all feedback models, and the X-ray flux levels of the no or weak feedback models agree with the observation for  $r < \sim 3''$ . The model flux is too low beyond this radius, while the strong feedback models produce too low a flux throughout the entire simulation region. This is because the strong outflow emanating from the SMBH clears out much of the hot, X-ray emitting gas from its vicinity. These strong feedback simulations are thus excluded from describing Sgr A\*. We will conclude by discussing ways to improve the no and weak feedback models, such as by including the O stars and their winds, which should cause the WR-wind X-ray emission to increase as these adiabatic shocks (whose strength is inversely proportional to the distance to the shock) will occur closer to their WR stars.

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#### 410.02D – Investigating the Physics of Hard X-ray Outbursts from the Galactic Center Supermassive Black Hole Sagittarius A\* with NuSTAR

The Galactic center supermassive black hole (SMBH) Sagittarius A\* (Sgr A\*) is remarkably underluminous with a bolometric luminosity about  $10^{-9}$  times its Eddington luminosity. It is the closest SMBH and thus an ideal target for investigation of galactic nuclei and their activity cycles. This goal can be fulfilled by studying its current, past and possible future outbursts. Its current X-ray quiescent state, with a luminosity of  $L_X \sim 10^{33} \text{ erg s}^{-1}$ , is punctuated by X-ray flares up to a few times  $10^{35} \text{ erg s}^{-1}$ , whose origin is poorly understood. With 638.6 ks NuSTAR observation of Sgr A\*, I collected nine X-ray flares which are detected up to 79 keV, and studied their timing behavior using the Bayesian block analysis. The broadband (3-79 keV) spectroscopic studies show that the X-ray flares can have a range of photon indexes, which can be explained by the magnetic reconnection scenario. During the flares, Sgr A\* is still orders of magnitudes lower than its Eddington luminosity. Whether it has ever experienced more substantial increases in activity as observed in low-luminosity Active Galactic Nuclei is still under discussion. Indication of such past activity of Sgr A\* has come from the Galactic center molecular clouds (GCMCs). I use the hard X-ray emission from Sgr B2, the densest GCMC, to constrain the past Sgr A\* X-ray outburst, resulting in  $L_X \sim 5 \times 10^{38} \text{ erg s}^{-1}$  with a photon index of  $\Gamma = 2.2 \pm 0.4$ . I also discovered different timing variability from different cloud substructures, which can further constrain the past Sgr A\* outburst and the cloud structure. Future giant outburst from Sgr A\* could be triggered by dust/gas infall. Although the G2 infall event has not caused any increased X-ray activity from Sgr A\*, there has been evidence that it caused flare behavior changes. Ongoing hard X-ray monitoring of Sgr A\* will address this remaining puzzle.

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**Contributing team(s):** NuSTAR Galactic Plane Survey Working Group

#### 410.03 – Evidence for Intermediate Polars as the origin of the Galactic Center hard X-ray emission

Recently, NuSTAR has discovered an unresolved hard (20-40 keV) X-ray emission within the central 10 pc of the Galaxy, possibly indicating a large population of intermediate polars (IPs). Chandra and XMM-Newton measurements of both point sources and diffuse emission in the surrounding  $\sim 50$  pc imply a population of magnetic CVs with white dwarf mass  $\sim 0.5 M_\odot$ . We present NuSTAR broad-band (3-79 keV) spectroscopy of two nearby IPs (TV Columbae and IGR J17303-0601) as well as our investigation of various spectral models and previous X-ray observations. We argue that the observations of both the inner 10 pc and the surrounding 50 pc can be accounted for by IPs with mean white dwarf mass  $\sim 0.9 M_\odot$ . We find that the lower mass derived by Chandra and XMM-Newton is an artifact of narrow energy band fitting, and the spectral features associated with these measurements naturally arise in a heavier IP population. We also discuss implications for the X-ray

emission and source population in the Galactic ridge and bulge.

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**Contributing team(s):** NuSTAR Galactic Plane Survey Working Group

#### 410.04 – The Kinematics of the Milky Way's Biconical Nuclear Wind

Like other spiral galaxies, the Milky Way drives a biconical nuclear wind. Outflowing gas is visible in enhanced emission across the electromagnetic spectrum, including the Fermi gamma-ray bubbles and radio lobes extending above and below the Galactic Center. Last year we presented the first results from a Hubble Space Telescope program to detect and characterize the nuclear wind using UV absorption-line spectroscopy of background AGN. Here we extend those results using several other sight lines in the northern Fermi Bubble region, allowing us to reconstruct, for the first time, the wind velocity profile, and constrain the physical mechanism driving the outflow.

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#### 410.05 – Constraining the Fraction of Dense Gas in the Galactic Center

The central 500 parsecs of the Milky Way-- the Central Molecular Zone or CMZ-- is one of the most extreme environments for molecular gas in our Galaxy. Recent studies have suggested that the star formation relations in this region are anomalous, with less star formation per unit dense ( $n > 10^4 \text{ cm}^{-3}$ ) gas than is seen elsewhere in the universe. While this would be an exciting result indicating that star formation may proceed differently as a function of environment, it must be verified that it is not an effect of either undercounting the amount of star formation, or overestimating the bulk gas density in this region. CMZ gas densities in particular have not been revisited in several decades, and have only been measured accurately for a small handful of clouds in this region. We address this deficiency by presenting updated gas densities for a sample of 10 of the most massive molecular clouds in the CMZ. We use the Robert C. Byrd Green Bank Telescope, MOPRA, and APEX to measure lines of HC<sub>3</sub>N from  $J = 3-2$  to  $J = 30-29$ , and then perform radiative transfer analysis to constrain gas densities. We find that typical gas densities are somewhat lower than previously indicated, and present the first constraints on the fraction of gas with  $n > 10^5 \text{ cm}^{-3}$  for multiple clouds in this region.

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#### 410.06D – Determining the Origins and Impact of Hot Gas in the Milky Way

The Milky Way's circumgalactic medium contains million degree gas that is volume-filling on  $\geq 10$  kpc scales based on X-ray emission from the ROSAT All-Sky Survey, detections of OVII K $\alpha$  ( $\lambda = 21.602 \text{ \AA}$ ) absorption lines at  $z \sim 0$  in AGN spectra, ubiquitous detections of OVII-OVIII emission lines in  $\sim 1,000$  blank-sky spectra, and the discovery of the  $\sim 10$  kpc outflow from the Galactic center known as the Fermi bubbles. Analyses on the line strengths in individual or small samples of sight lines ( $< 30$ ) imply plasma densities between  $10^{-5}$ - $10^{-2} \text{ cm}^{-3}$ , but the dominant hot gas structure is argued to be either a disk morphology ( $\sim 10^8 M_\odot$  of material) or a spherical morphology ( $10^{10}$ - $10^{11} M_\odot$  of material). This is a crucial distinction since these morphologies arise from significantly different galaxy evolution processes, and the Fermi bubbles are recently discovered objects that are interacting with the ambient CGM. In this dissertation, I constrain the global hot gas density structure by comparing the largest samples of OVII equivalent width

measurements and OVII-OVIII line intensities with model line strengths from parametric density models. I find that a spherical profile with  $n \propto r^{-3/2}$  extending to the Milky Way's virial radius results in model line strengths that are most consistent with how the observed line strengths vary across the sky. These results imply a hot gas mass between  $2.5 \times 10^{10} M_{\odot}$  within 250 kpc ( $\leq 50\%$  of the Galactic missing baryons), a hot gas metallicity of  $Z \geq .3 Z_{\odot}$ , and that most of the hot gas formed as shock-heated material during the Milky Way's formation. For the Fermi bubbles, the line intensities and ratios suggest they contain hotter gas than the surrounding medium ( $> 2 \times 10^6$  K) and densities between  $10^{-4}$ - $10^{-3} \text{ cm}^{-3}$ . This implies the bubbles are over-pressurized and expanding into the surrounding halo, potentially heating and displacing the ambient CGM.

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**Institution(s):** 1. *University of Michigan*

#### 410.07 – Evidence for a Large Scale Outflow of Hot Gas from the Scutum-Centaurus Spiral Arm

The Scutum-Centaurus Spiral Arm, sometimes referred to as the "Molecular Ring", is one of the most prominent star-forming structures in the Milky Way Galaxy. The arm extends from a Galactic longitude of  $L=+30$  degrees to  $L=-50$  (310) degrees, and then behind Galactic center to become the Outer Scutum-Centaurus Arm. It is characterized by long, filamentary dark clouds, concentrated star formation, and numerous supernova remnants and bubbles. Previous models have shown that the energy input of supernova explosions can drive a "hybrid" thermal pressure/cosmic-ray pressure wind out of the Galaxy from this region and that such a wind can explain both the  $3/4$  keV X-ray emission observed by ROSAT as well as the high-latitude 408 MHz radio synchrotron emission. Here the effects of Galactic rotation on this wind are demonstrated. The morphology of the X-ray and synchrotron emission as well as the behavior of the Ophiuchus superbubble (which is part of this flow) are shown to be consistent with a launching, rotating wind. Predictions for the velocity structure of this gas are provided that can be tested with future emission and absorption line studies. The importance of understanding this wind as a foreground in studies of the "Fermi Bubble" is also discussed.

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### 411 – Gamma Ray and X-ray Binary Systems

#### 411.01 – A Unified View of X-ray Absorbers in AGNs and XRBs with MHD Winds

The presence of UV and X-ray absorbers (aka. warm absorbers or WAs) has been long known for decades from extensive spectroscopic studies across diverse AGN populations such as nearby Seyfert galaxies and distant quasars. Furthermore, another class of seemingly distinct type of absorbers, ultra-fast outflows or UFOs, is becoming increasingly known today. Nonetheless, a physical identification of such absorbers, such as geometrical property and physical conditions, is very elusive to date despite the recent state-of-the-art observations. We develop a coherent scenario in which the detected absorbers are driven primarily (if not exclusively) by the action of global magnetic fields originating from a black hole accretion disk. In the context of MHD disk-wind of density profile of  $n \sim 1/r$ , it is found that the properties of the observed WAs/UFOs are successfully described assuming a characteristic SED. As a case study, we analyze PG1211+143 and GRO J1655-40 to demonstrate that our wind model can systematically unify apparently diverse absorbers in both AGNs and XRBs in terms of explaining their global behavior as well as individual spectral lines.

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#### 411.02 – Giant Rapid X-ray Flares in Extragalactic

### Globular Clusters

There is only one known class of non-destructive, highly energetic astrophysical object in the Universe whose energy emission varies by more than a factor of 100 on time scales of less than a minute -- soft gamma repeaters/anomalous X-ray pulsars, whose flares are believed to be caused by the energy release from the cracking of a neutron star's surface by very strong magnetic fields. All other known violent, rapid explosions, including gamma-ray bursts and supernovae, are believed to destroy the object in the process. Here, we report the discovery of a second class of non-destructive, highly energetic rapidly flaring X-ray object located within two nearby galaxies with fundamentally different properties than soft gamma repeaters/anomalous X-ray pulsars. One source is located within a suspected globular cluster of the host galaxy and flared one time, while the other source is located in either a globular cluster of the host galaxy or the core of a stripped dwarf companion galaxy that flared on five occasions over a seven year time span. When not flaring, the sources appear as normal accreting neutron star or black hole X-ray binaries, indicating that the flare event does not significantly disrupt the host system. While the nature of these sources is still unclear, the discovery of these sources in decade-old archival *Chandra X-ray Observatory* data illustrates the under-utilization of X-ray timing as a means to discover new classes of explosive events in the Universe.

**Author(s):** Jimmy Irwin<sup>4</sup>, W. Peter Maksym<sup>1</sup>, Aaron J. Romanowsky<sup>3</sup>, Jay Strader<sup>2</sup>, Dacheng Lin<sup>5</sup>

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#### 411.03D – X-ray Emission from Early Universe Analog Galaxies

Around 300,000 years after the Big Bang, the Universe had cooled enough to combine and form neutral atoms. This signified the beginning of a time known as the Dark Ages. Neutral matter began to fall into the dark matter gravitational wells that were seeded after the initial moments of the Big Bang. As the first stars and galaxies formed within these gravitational wells, the surrounding baryonic matter was heated and started to ionize. The source of energetic photons that heated and reionized the early Universe remains uncertain. Early galaxies had low metallicity and recent population synthesis calculations suggest that the number and luminosity of high-mass X-ray binaries are enhanced in star-forming galaxies with low metallicity, offering a potentially important and previously overlooked source of heating and reionization. Here we examine two types of local galaxies that have been shown to be good analogs to the early galaxies in the Universe: Blue compact dwarf galaxies (BCDs) and Lyman Break Analogs (LBAs).

A BCD is defined by its blue optical colors, low metallicities, and physically small size. This makes BCDs the best available local analogs for early star formation. We analyzed data from a sample of 25 metal-poor BCDs and compared our results with those of near-solar metallicity galaxies. Using a Bayesian approach, we showed that the X-ray luminosity function for the low-metallicity BCDs is significantly elevated relative to the XLF for near-solar metallicity galaxies.

Larger, gas-rich galaxies may have formed shortly after these first galaxies. These larger galaxies would be similar in their properties to the high-redshift Lyman break galaxies (LBGs). LBAs provide the best local comparison to the LBGs. We studied a sample of 10 LBAs in order to measure the relation between star formation rate and X-ray luminosity for these galaxies. We found that for LBAs with intermediate sub-solar metallicities, there is enhanced X-ray emission relative to the expected value from near-solar metallicity galaxies.

By incorporating our results into simulations used to predict the redshifted 21cm signal from the early Universe, unique and observable predictions could be made for future 21cm observations.

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#### 411.04 – The Fermi Gamma-ray Burst Monitor as a Transient Monitor

The Gamma-ray Burst Monitor (GBM) performs well as a transient monitor in the 8 keV to 1 MeV range using the publicly available continuous data products. With GBM, we use the Earth occultation technique successfully monitor long-term hard X-ray variations in the Crab Nebula, bright transients such as the black hole binary V404 Cyg, which flared brightly in Jun 2015, and a catalog of 200+ sources. The catalog includes X-ray binaries, active galaxies, and the Sun which we monitor for variations on timescales from days to years, supporting multi wavelength campaigns and triggering other instruments. We monitor the pulse frequency and pulsed flux for 37 accreting pulsars with a high (~50% duty cycle), including Be/X-ray binaries such as V0332+53, which underwent a giant outburst in summer 2015. Through daily searches, we detect X-ray bursts from neutron stars in low-mass X-ray binaries. I will present highlights of these transient monitoring efforts, demonstrating significant science gains using GBM continuous data products.

**Author(s):** Colleen A. Wilson-Hodge<sup>1</sup>  
**Institution(s):** 1. NASA's MSFC  
**Contributing team(s):** Fermi GBM team

#### 411.05D – Revelations of X-ray spectral analysis of the enigmatic black hole binary GRS 1915+105

Of the black hole binaries discovered thus far, GRS 1915+105 stands out as an exceptional source primarily due to its wild X-ray variability, the diversity of which has not been replicated in any other stellar-mass black hole. Although extreme variability is commonplace in its light-curve, about half of the observations of GRS1915+105 show fairly steady X-ray intensity. We report on the X-ray spectral behavior within these steady observations. Our work is based on a vast RXTE/PCA data set obtained on GRS 1915+105 during the course of its entire mission and 10 years of radio data from the Ryle Telescope, which overlap the X-ray data. We find that the steady observations within the X-ray data set naturally separate into two regions in a color-color diagram, which we refer to as steady-soft and steady-hard. GRS 1915+105 displays significant curvature in the Comptonization component within the PCA band pass suggesting significantly heating from a hot disk present in all states. A new Comptonization model 'simpleut' was developed in order to model this curvature to best effect. A majority of the steady-soft observations display a roughly constant inner radius; remarkably reminiscent of canonical soft state black hole binaries. In contrast, the steady-hard observations display a growing disk truncation that is correlated to the mass accretion rate through the disk, which suggests a magnetically truncated disk. A comparison of X-ray model parameters to the canonical state definitions show that almost all steady-soft observations match the criteria of either thermal or steep power law state, while the thermal state observations dominate the constant radius branch. A large portion (80%) of the steady-hard observations matches the hard state criteria when the disk fraction constraint is neglected. These results suggest that within the complexity of this source is a simpler underlying basis of states, which map to those observed in canonical black hole binaries. When represented in a color-color diagram, state assignments appear to map to 'A, B and C' (Belloni et al. 2000) regions that govern fast variability cycles in GRS 1915+105 demonstrating a compelling link between short and long time scales in its phenomenology.

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#### 411.06 – Analysis of the iron Ka line from 4U 1728-34

#### with NuSTAR and Swift

We report on a simultaneous *NuSTAR* and *Swift* observation of the neutron star low-mass X-ray binary 4U 1728-34. We detected and removed four Type 1 X-ray bursts during the observation in order to study the persistent emission. The continuum spectrum is hard and well described by a black body and cutoff power law. Residuals between 6-8 keV indicate strong evidence of a broad Fe Ka line. By modeling the spectrum with a relativistically blurred reflection model, we find an upper limit for the inner disk radius  $R_{in} \leq 1.77$  ISCO. From this upper limit, we find that  $R_{NS} \leq 20$  km, assuming  $M=1.4M_{\odot}$  and  $a=0.15$  (where  $a=cJ/GM^2$  is calculated from the previously measured burst oscillation frequency). We discuss how this limit could be improved for neutron star LMXBs in the future.

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#### 411.07 – The energy dependence of quasi periodic oscillations in GRS 1915+105

Accreting stellar-mass black holes display quasi-periodic oscillations (QPOs) in their X-ray flux with a period that drifts from approximately 0.05 to 10 seconds. Since the oscillatory signal originates from the close proximity of the black hole, QPOs provide a diagnostic of the motion of matter in this region of extreme gravitational curvature. Here I present an analysis of the energy dependence of QPOs in the black hole binary GRS 1915+105. The QPO period in this black hole binary is known to be correlated with the observed energy band. To investigate this further, we extract light curves in two broad energy bands using archival data from the Rossi X-ray Timing Explorer, and apply a filter that separates the QPO from the coincident noise. The filtered light curves reveal that, in both energy bands, the modulation repeatedly rises and falls in amplitude in an envelope that typically lasts about five to ten QPO cycles. We find that, during each of these so-called coherence timescales, the phase difference between the two QPO light curves increases before resetting at the start of the next coherence time scale. This indicates that the oscillation in one energy band is genuinely faster than that in the other band, and puts interesting constraints on current QPO models. If the QPO originates from vertical general relativistic precession of the inner accretion flow, our result indicates that the inner regions of this flow precess slightly quicker than the outer regions, with the precession phase resetting after five to ten QPO cycles.

**Author(s):** Jakob Van Den Eijnden<sup>1</sup>, Adam Ingram<sup>1</sup>, Phil Uttley<sup>1</sup>  
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#### 416 – Gamma Ray Bursts

##### 416.01 – Features of >130 Gamma-Ray Bursts at high energy: towards the 2nd Fermi LAT GRB catalog

The high-energy emission from Gamma-Ray Bursts is a formidable probe for extreme physics, calling for highly relativistic sources with very large Lorentz factors. Despite the advancements prompted by observations from the Fermi Large Area Telescope and the Fermi Gamma-Ray Burst Monitor, as well as other observatories, many questions remain open, especially on radiative processes and mechanisms. We present here the most extensive search for GRBs at high energies performed so far, featuring a detection efficiency more than 50% better than previous works, and returning more than 130 detections. With this sample size, much larger than the 35 detections presented in the first Fermi/LAT GRB catalog, we are able to assess the characteristics of the population of GRBs at high energy with unprecedented sensitivity. We will review the preliminary results of this work, as well as their interpretation.

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**Institution(s):** 1. Stanford University  
**Contributing team(s):** Fermi LAT collaboration

## 416.02 – Fermi GBM Counterparts to LIGO Gravitational-Wave Candidates

As the advanced configuration of the Laser Interferometer Gravitational-wave Observatory (LIGO) begins operations, we eagerly anticipate the detection of gravitational waves (GW) with LIGO in coincidence with a gamma-ray signal from the Fermi Gamma-ray Burst Monitor (GBM). The most likely source is a short Gamma-Ray Burst (GRB) arising from the merger of two compact objects. With its broad sky coverage, GBM triggers and localizes more short GRBs than other active space missions, ~45 each year, with an estimate of <1-5 within the LIGO detection horizon. Combining GBM and LIGO localization uncertainty regions may provide a smaller target to look for the GW host. A joint GBM-LIGO detection increases the confidence in the GW detection and helps characterize the parameters of the merger. Offline searches for weak GRBs that fail to trigger onboard Fermi indicate that additional short GRBs can be detected in the GBM data. I will discuss the implementation and expected benefits of joint searches to detect and localize GW candidates. I will also explore how the non-detection in the GBM data of a signal consistent with GW candidates in the LIGO data can affect follow-up strategies for counterpart searches by other observers.

**Author(s):** Valerie Connaughton<sup>6</sup>, Lindy Blackburn<sup>3</sup>, Michael Stephen Briggs<sup>7</sup>, Eric Burns<sup>7</sup>, Jordan Camp<sup>4</sup>, Tito Dal Canton<sup>1</sup>, Nelson Christensen<sup>2</sup>, Adam Goldstein<sup>5</sup>, Peter Jenke<sup>7</sup>, Tyson Littenberg<sup>6</sup>, Judith L. Racusin<sup>4</sup>, Peter S. Shawhan<sup>9</sup>, Leo Singer<sup>4</sup>, John Veitch<sup>8</sup>, Colleen Wilson-Hodge<sup>5</sup>, Binbin Zhang<sup>7</sup>  
**Institution(s):** 1. AEI, 2. Carleton College, 3. CfA, 4. NASA/GSFC, 5. NASA/MSFC, 6. Universities Space Research Association, 7. University of Alabama in Huntsville, 8. University of Birmingham, 9. University of Maryland

## 416.03D – Jet or Shock Breakout? The Low-Luminosity GRB 060218

We consider a model for the long-duration, low-luminosity gamma-ray burst GRB 060218 that plausibly accounts for multiwavelength observations to day 20. The components of our model are: (1) a long-lived ( $t_j \sim 3000$  s) central engine and accompanying low-luminosity ( $L_j \sim 10^{45}$  erg s<sup>-1</sup>), mildly relativistic jet; (2) a low-mass ( $\sim 10^{-2} M_{\text{sun}}$ ) envelope surrounding the progenitor star; and (3) a modest amount of dust ( $A_V \sim 0.1$ ) in the circumstellar or interstellar environment. Blackbody emission from the transparency radius in a low-power jet outflow can fit the prompt thermal X-ray emission, and the prompt nonthermal X-rays and  $\gamma$ -rays may be produced via Compton scattering of thermal photons from hot leptons in the jet interior or the external shocks. The later mildly relativistic phase of this outflow can produce the radio emission via synchrotron radiation from the forward shock. Meanwhile, interaction of the associated SN 2006aj with a circumstellar envelope extending to  $\sim 10^{13}$  cm can explain the early optical peak. The X-ray afterglow can be interpreted as a light echo of the prompt emission from dust at  $\sim 30$  pc. Our model is a plausible alternative to that of Nakar, who recently proposed shock breakout of a jet smothered by an extended envelope as the source of prompt emission. Both our results and Nakar's suggest that ultra-long bursts such as GRB 060218 and GRB 100316D may originate from unusual progenitors with extended circumstellar envelopes, and that a jet is necessary to decouple the prompt high-energy emission from the supernova.

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## 416.04 – Environments of Gamma-Ray Bursts

The death of some of the most massive stars are manifest as long gamma-ray bursts (GRBs). Studying their light curves and spectra are uncovering some of the properties of the “central engine” that remains after the progenitor star collapses, as well as the environment in which they reside. Much of our current understanding comes from data obtained in the gamma-ray to X-ray. Despite this progress in the high-energy regime, our understanding of the soft-energy component (UV/optical) is lacking, particularly with regards to UV/optical flaring from the central engine and

distinguishing between interstellar material and wind environments. Although these questions have been addressed for individual bursts, no systematic study in the UV/optical has been done due to the lack of a large homogenous sample. The *Swift* Ultra-Violet/Optical Telescope (UVOT) has observed more GRBs in the UV/optical than any other telescope. From these observations we have generated a homogenous UV/optical GRB afterglow catalog. From this catalog and coupled with archival *Swift* X-Ray Telescope (XRT) data, we examine the spectral evolution of GRBs in order to probe the circumburst environment and to test current progenitor models.

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**Institution(s):** 1. Southwest Research Institute, 2. University of North Dakota

## 416.05 – Explaining the Relative and Absolute LGRB Rate with Metallicity

There is now strong evidence that Long-duration Gamma-Ray Bursts (LGRBs) have an intrinsic preference for low-metallicity environments despite the existence of some exceptions to this trend (Graham & Fruchter 2013). Here I will present a pair of results expanding on this work. First, a detailed effort to quantize magnitude of this effect, and characterized its change as a function of metallicity. Thus we directly address a fundamental question of this subfield: how much more likely is an LGRB to form at one metallicity as compared with another? Then, employing these results, we relate the LGRB rate as a function of redshift to the cosmic star-formation rate and provide a detailed breakdown of the intervening steps and their rate of occurrence. This provides interesting implications for radio search efforts to detect off axis LGRB events which will be discussed.

**Author(s):** John Graham<sup>1</sup>  
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## 416.06 – Non-Bohm Diffusion in Relativistic Shock Acceleration

We have modeled nonlinear Fermi shock acceleration in relativistic shocks with a parameterized momentum-dependent particle diffusion coefficient. In short-scale magnetic turbulence, likely to be self-generated in relativistic shocks, a scattering mean free path (mfp) with a momentum dependence  $mfp \propto p^2$  is expected. We show that, in addition to changing the scale of the shock precursor, nonlinear effects from efficient Fermi acceleration can increase the cosmic ray injection and acceleration efficiency, over that expected from Bohm diffusion, by significant factors. These effects are absent in parallel, non-relativistic shocks and do not appear in relativistic shocks unless nonlinear effects are self-consistently described. The changes in Fermi acceleration from a strong momentum dependent diffusion coefficient will translate to changes in the intensity and spectral shape of subsequent radiation and may have important applications to gamma-ray bursts and other phenomena involving relativistic shocks.

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## 417 – AGN, QSO, Blazars: Broad lines, Narrow Lines, and Flows

### 417.01 – Do QSOs have Narrow Line Region Outflows? Implications for quasar-mode feedback. Spectroscopic Results

We present an HST/STIS spectroscopic analysis of an intermediate-redshift, radio-quiet QSO2 sample, in order to determine the ubiquity of massive outflows through their narrow-line regions (NLRs). A recent study of QSO2 NLRs via ground-based observations found their kinematics to be chaotic, with little evidence for large-scale outflows. Our previous study of low-redshift Seyfert galaxies show that roughly 1/3 of the AGN possess kinematics with distinct signatures of outflows, therefore a lack of outflows within a

similar population of AGN at higher redshifts strongly questions the importance of quasar-mode feedback on galaxy evolution. Using space-based, high resolution spectroscopic observations, we determine if a lack of outflows in QSOs is truly intrinsic or due to spatial resolution limitations in previous observations.

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#### 417.02 – Do QSO2s have Narrow Line Region Outflows? Implications for quasar-mode feedback. Imaging Results

We present HST/ACS narrow-band [O III] images 11 radio-quiet QSO2s, selected from the Reyes et al. (2008) sample. The purpose of the study is to determine whether massive outflows through the Narrow Line Region (NLR) are present in QSO2s, testing a recent claim from ground-based observations that the NLR of QSO2s show little evidence for grand-scale outflows, which are important for quasar-mode feedback. We have measured the size and structure of the NLRs in the sample and determined that they follow the same luminosity/size relationship determined for Seyfert galaxies by Schmitt et al. (2003). We find two distinct types of [O III] morphologies: 1. extended (~ several kpc) roughly symmetric structures and 2. extremely compact emission. We explore possible reasons for the different morphologies. The detailed kinematic structure will be discussed in an accompanying presentation at this meeting (Fischer et al).

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#### 417.03D – Quasar Outflow Constraints using Broad Absorption Line Variability Studies

Quasar outflows are plausible candidates for AGN feedback processes influencing the host galaxy and may explain the established correlations between the supermassive black hole (SMBH) and the surrounding bulge. In order to better understand feedback and the physical conditions of the outflowing gas, observational constraints on absorber kinematics and energetics are needed. We are utilizing multiple epoch, rest frame UV quasar spectra to establish limits on outflow locations and total column densities for the purpose of estimating wind kinetic energies and momenta. We are also investigating the variability patterns of broad absorption lines (BALs) and mini-BALs across a range of ionization states to probe underlying connections between the various classes of absorbers. This work employs observations from the Sloan Digital Sky Survey, Hobby Eberly Telescope, and MDM observatory. We detect BAL variability in 3 out of 12 FeLoBAL quasars over multiple year timescales and conclude that the variable absorbers lie within tens of parsecs of the SMBH based on interpretations of the Fe II and Mg II BALS. We also measure significant BAL changes across daily to yearly timescales in a sample of 71 quasars with plausible detections of the P V 1117,1128 BAL. Detecting phosphorus in absorption is notable because it traces high column density outflows and is therefore relevant for studying AGN feedback. Constraints on outflow energetics and other selected results will be presented.

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#### 417.04 – Toward a Complete Picture of Quasar Outflows: from BALs to mini-BALs

Accretion disk outflows are important for galaxy evolution and an integral part of the quasar phenomenon, but they remain poorly understood. In order to construct a more complete picture of the quasar phenomenon, we need to understand the full range of different types of quasar outflows and how they correlate with one another. We examine seven SDSS quasars with CIV 1548,1551 Å outflow lines that span a range from strong BALs to weak mini-BALs. They have moderate redshifts ( $1.68 < z < 1.91$ ) to minimize contamination from the Ly $\alpha$  forest while still allowing measurements of CIV from the ground and other important lines like OVI 1031,1038 Å and PV 1118,1128 Å with HST. We use archival SDSS and BOSS spectra in combination with HST COS G230L observations and multi-epoch ground-based spectra obtained at the MDM and Kitt Peak observatories to measure a variety of ions across the rest UV wavelength range. Our preliminary analysis shows OVI is present and stronger than CIV in all seven quasars. In one case, we detect an OVI mini-BAL with no accompanying CIV, requiring a highly-ionized outflow. In the strongest BAL quasar, we detect resolved PV doublet absorption that requires PV optical depths  $> 3$  and in outflow gas with a line-of-sight covering fraction of only 0.27. Thus, the total column density in this outflow component might exceed  $N_{\text{H}} > 10^{23} \text{ cm}^{-2}$  which has important consequences for the outflow kinetic energies and feedback. The multi-epoch CIV data reveal CIV outflow variability in all seven quasars; four become weaker, one becomes stronger, and two become both stronger and weaker over the different epochs. This variability happens across time scales of ~1-12 years in the quasar rest frames which is consistent with outflow locations close to the central quasar engines. We use these and other results to constrain the ionization, column density, and location of the absorbers with the broader goals of understanding accretion physics, the integrated structure of quasar outflows, and the impact a quasar has on its host galaxy.

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#### 417.05 – Still Raining in Quasars: An Origin for the Broad Emission Line Region

The strong broad emission lines (BELs) characteristic of quasars do not have an agreed-upon physical explanation. Why is there dense gas at hundreds to thousands of Schwarzschild radii around all\* accreting super-massive black holes? I propose that dense cool clouds naturally form (Krolik et al. 1981) in the accretion disk winds of quasars and AGNs (Murray et al. 1995) before the wind reaches escape velocity. X-ray variability causes the gas to accumulate in the stable regions on the thermal equilibrium curve. These clouds have the density and temperature of BEL clouds. The narrow range of density at which the BEL clouds form in pressure equilibrium with the warm wind may explain the simple  $L^{1/2}$  scaling of BEL region radius. The clouds are self-shielding and can no longer accelerate; so they rain back on elliptical orbits. They are then destroyed by Kelvin-Helmholtz instabilities as they move at Mach ~ 30 through the warm disk wind. The timescales for all these processes fit with this picture. Observationally this “quasar rain” model agrees with the Pancoast et al. (2014) kinematics of the BEL region, with the cool phase of the warm absorber wind seen in X-rays (e.g. Krongold et al. 2005), and with the “cometary” tails seen in a few AGN X-ray eclipses (Maiolino et al. 2010).  
 [\* unobscured, non-jet-dominated.]

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#### 417.06 – Giant Broad Line Regions in Dwarf Seyferts

High angular resolution spectroscopy obtained with the Hubble Space Telescope has revealed a remarkable population of galaxies hosting dwarf Seyfert nuclei with an unusually large broad-line region (BLR). These objects are remarkable for two reasons. Firstly, the size of the BLR can, in some cases, rival those seen in the most luminous quasars. Secondly, the size of the BLR is not correlated with the central continuum luminosity, an observation that

distinguishes them from their reverberating counterparts. Collectively, these early results suggest that non-reverberating dwarf Seyferts are a heterogeneous group and not simply scaled versions of each other. Careful inspection reveals broad H Balmer emission lines with single peaks, double peaks, and a combination of the two, suggesting that the broad emission lines are produced in kinematically distinct regions centered on the black hole (BH). Because the gravitational field strength is already known for these objects, by virtue of knowing their BH mass, the relationship between velocity and radius may be established, given a kinematic model for the BLR gas. In this way, one can determine the inner and outer radii of the BLRs by modeling the shape of their broad emission line profiles. In the present contribution, high quality spectra obtained with the Space Telescope Imaging Spectrograph are used to constrain the size of the BLR in the dwarf Seyfert nuclei of M81, NGC 3998, NGC 4203, NGC 3227, NGC 4051, and NGC 3516.

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#### 417.07D – Studying AGN Feedback with Galactic Outflows in Luminous Obscured Quasar

Feedback from Active galactic nuclei (AGN) has been proposed as an important quenching mechanism to suppress star formation in massive galaxies. We investigate the most direct form of AGN feedback - galactic outflows - in the most luminous obscured AGN ( $L > 10^{45}$  erg/s) from the SDSS sample in the nearby universe ( $z < 0.2$ ). Using ALMA and Magellan observations to target molecular and ionized outflows, we find that luminous AGN can impact the dynamics and phase of the galactic medium, and confirm the complex multi-phase and multi-scaled nature of the feedback phenomenon. In particular, we found that most of these luminous AGN hosts ionized outflows. The outflow size, velocity, and energetics correlate with the AGN luminosity, and can be very extended ( $r > 10$  kpc) and fast ( $v > 1000$  km/s) for the most luminous ones. I end with presenting a new technique to find extended ionized outflows using broadband imaging surveys, and to characterize their occurrence rate, morphology, size distribution, and their dependence on the AGN luminosity. This technique will open a new window for feedback studies in the era of large-scale optical imaging surveys, e.g., HSC and then LSST.

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### 418 – Star Forming Regions: Observations

#### 418.01 – Studying the outflow-core interaction with ALMA Cycle 1 observations of the HH 46/47 molecular outflow

We present ALMA Cycle 1 observations of the HH 46/47 molecular outflow which is driven by a low-mass Class 0/I protostar. Previous ALMA Cycle 0 12CO observation showed outflow cavities produced by the entrainment of ambient gas by the protostellar jet and wide-angle wind. Here we present analysis of observation of 12CO, 13CO, C18O and other species using combined 12m array and ACA observations. The improved angular resolution and sensitivity allow us to detect details of the outflow structure. Specially, we see that the outflow cavity wall is composed of two or more layers of outflowing gas, which separately connect to different shocked regions along the outflow axis inside the cavity, suggesting the outflow cavity wall is composed of multiple shells entrained by a series of jet bow-shock events. The new 13CO and C18O data also allow us to trace relatively denser and slower outflow material than that traced by the 12CO. These species are only detected within about 1 to 2 km/s from the cloud velocity, tracing the outflow to lower velocities than what is possible using only the 12CO emission. Interestingly, the cavity wall of the red lobe appears at very low outflow velocities (as low as  $\sim 0.2$  km/s). In addition, 13CO and C18O allow us to correct for the CO optical depth, allowing us to obtain more accurate estimates of the outflow mass, momentum and kinetic energy. Applying the optical depth correction significantly increases the previous mass estimate by a factor of 14. The outflow kinetic energy distribution shows that even though the red lobe is mainly entrained by jet bow-shocks, most

of the outflow energy is being deposited into the cloud at the base of the outflow cavity rather than around the heads of the bow shocks. The estimated total mass, momentum, and energy of the outflow indicate that the outflow has the ability to disperse the parent core. We found possible evidence for a slowly moving rotating outflow in CS. Our 13CO and C18O observations also trace a circumstellar envelope with both rotation and infall motions.

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#### 418.02D – The L1495-B218 filaments in Taurus seen in NH<sub>3</sub> & CCS and Dynamical Stability of Filaments and Dense Cores

We present deep NH<sub>3</sub> map of L1495-B218 filaments and the dense cores embedded within the filaments in Taurus. The L1495-B218 filaments form an interconnected, nearby, large complex extending 8 pc. We observed the filaments in NH<sub>3</sub> (1,1) & (2,2) and CCS 2<sub>1-10</sub> with spectral resolution of 0.038 km/s and spatial resolution of 31". The CSAR algorithm, which is a hybrid of seeded-watershed and binary dendrogram algorithm, identifies 39 leaves and 16 branches in NH<sub>3</sub> (1,1). Applying a virial analysis for the 39 NH<sub>3</sub> leaves, we find only 9 out of 39 leaves are gravitationally bound, and 12 out of 30 gravitationally unbound leaves are pressure-confined. Our analysis suggests that a dense core may form as a pressure-confined structure, evolve to a gravitationally bound core, and then undergo collapse to form a protostar (Seo et al. 2015).

We also present more realistic dynamic stability conditions for dense cores with converging motions and under the influence of radiation pressure. The critical Bonnor-Ebert sphere and the isothermal cylinder have been widely used to test stability of dense cores and filaments; however, these assume a quiescent environment while actual star forming regions are turbulent and illuminated by radiation. In a new analysis of stability conditions we account for converging motions which have been modeled toward starless cores (Seo et al. 2011) and the effect of radiation fields into account. We find that the critical size of a dense core having a homologous converging motion with its peak speed being the sound speed is roughly half of the critical size of the Bonnor-Ebert sphere (Seo et al. 2013). We also find that the critical mass/line density of a dense core/filament irradiated by radiation are considerably smaller than that of the Bonnor-Ebert sphere/isothermal cylinder when the radiation pressure is stronger than the central gas pressure of dense core/isothermal cylinder. For inner Galactic regions and regions near OB associations, the critical mass/line density of dense structure may be less than 20% of the critical mass/line density of Bonnor-Ebert sphere/isothermal cylinder (Seo et al., in prep.).

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#### 418.03 – Formation of proto-multiple systems in a magnetized, fragmenting filament

In just the past few years, it has become clear that filamentary structure is present in the star-formation process across many orders of magnitude in spatial scale, from the galactic scales probed by Planck and Herschel all the way down to the AU-scale structures that ALMA has revealed within protoplanetary disks. A similar story can be told of magnetic fields, which play a role in star formation across the same vast range of size scales. Here I will show filamentary structure near three protostars in the Serpens Main star-forming region, as seen with both CARMA (at 1000 AU scales) and ALMA (at 150 AU scales!). Even at such high resolution, these sources have a number of nearby, filamentary blobs/condensations/companions, which may be the beginnings of multiple star systems. Additionally, the filamentary structures along which these companions lie coincide in a tantalizing way with the magnetic fields we mapped with CARMA.

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#### **418.04 – Observing the Depth of Star-Forming Regions: Sheets within Perseus and Serpens**

We will show that dense gas in regions of nearby molecular clouds where young stars are forming is flattened (sheet-like) at parsec scales. We find that the regions observed with the CARMA Large Area Star Formation Survey (CLASSy) with significant young stellar content (e.g., Serpens Main and Barnard 1) have line-of-sight  $N_2H^+$  depths  $\sim 0.15$  pc while their projected sizes are  $\sim 1$  pc across the sky. We observe filamentary substructure in these sheet-like structures, which is commonly found in numerical simulations of supersonic turbulence. We find that the dense gas in the CLASSy region with the fewest young sources (the L1451 region of Perseus) is better characterized as a collection of distinct ellipsoidal structures than a contiguous region of flattened gas and dust. The lack of flattened, high-density structure in L1451 may indicate that this region of Perseus has not been strongly compressed by turbulent flows to create a sheet-like geometry and the strong density enhancement needed to efficiently form stars.

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**Contributing team(s):** CLASSy

#### **418.05D – The Physics and Chemistry of Massive Starless Cores**

Better characterization of the initial conditions is crucial to understanding massive star formation. Whether or not high-mass stars form in a similar way as low-mass stars can be tested by massive starless cores (MSCs), which are invoked as the initial condition in the Core Accretion model, but not in the Competitive Accretion model. We first searched for MSC candidates in the densest regions of Infrared Dark Clouds with the deuterated species  $N_2D^+$ , which has been found to be one of the best tracers of the cold, dense conditions of low-mass pre-stellar cores. Two candidates (C1-N & S) were revealed by our ALMA Cycle 0 observation. In particular, C1-S has  $\sim 60 M_\odot$ . Our dynamical study found that  $\sim mG$  magnetic fields need to be present if the cores are virialized. Next we developed astrochemical modeling to understand how high levels of deuteration arise in these cores, especially tracking the deuteration fraction  $D_{\text{frac}}^{N_2H^+} (= [N_2D^+]/[N_2H^+])$ , which can rise by several orders of magnitude above the cosmic  $[D]/[H]$  ratio. Our models show that high levels of  $D_{\text{frac}}^{N_2H^+} \geq 0.1$  generally require at least several local free-fall times to be established under typical core conditions and this is the basis of a “deuteration clock” that can measure the chemical age and thus collapse rates of MSCs. We have begun work to implement the astrochemical network into full (M)HD simulations of these structures. A detailed observational study to measure  $[N_2D^+]$ ,  $[N_2H^+]$  and thus  $D_{\text{frac}}^{N_2H^+}$  in the C1-N and C1-S cores have been carried out, utilizing multi-transition data observed with ALMA, CARMA, SMA, JCMT, IRAM 30m and NRO 45m telescopes. We find high levels of  $D_{\text{frac}}^{N_2H^+} \approx 0.2 - 0.7$ . Comparing with the theoretical chemical dynamical models indicates that C1-N and C1-S have been contracting at rates  $\sim 10$  times slower than free-fall, which may be consistent with the presence of strong magnetic fields in the cores. Using ALMA, we have also extended our search for more MSCs, using  $N_2D^+(3-2)$  emission as our primary tracer. At least several promising candidates have been found that appear to be similar in their properties to C1-S, which may indicate massive starless cores are commonly involved in the massive star formation process.

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#### **418.06 – The Green Bank Ammonia Survey: Initial results**

The past several years have seen a tremendous advancement in our ability to characterize the structure of nearby molecular clouds and the substructures in which dense star-forming cores are born. These advances include identifying and classifying the young protostellar population (Spitzer c2d and Gould Belt surveys) and the dense cores and larger filaments and clumps which form the cores and YSOs (Herschel and JCMT Gould Belt Legacy Surveys). The power of these legacy surveys lies in the large areal coverage and consistency in observing strategies between nearby molecular clouds. A major gap in the present data is a comparable survey to characterize the dense gas properties. Kinematics and gas temperatures are key to understanding the history and future fate of star-forming material, and these are not accessible from the primarily continuum-based measurements in the legacy surveys described above. We have begun an ambitious legacy survey for the GBT, the Green Bank Ammonia Survey (GAS), to map  $NH_3$  emission toward all the northern Gould Belt star forming regions where  $A_V > 7$ . The Gould Belt is a ring of young stars and star-forming regions that contains nearly all the ongoing, predominantly low-mass star formation within 500 pc of the Sun. Here we present the initial results from the survey.

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### **419 – Cosmology**

#### **419.01 – A Spectroscopic Survey of the Fields of 28 Strong Gravitational Lenses: Lens Environments and Line-of-Sight Structures**

Galaxy-scale strong gravitational lensing has long been used to measure cosmological parameters such as the Hubble constant as well as the dark matter properties of galaxy halos. Additional mass around the lens galaxy or projected in the line-of-sight affects the light bending and needs to be incorporated into lensing analyses. We present new results from a spectroscopic survey to characterize the environmental and line-of-sight mass for 28 galaxy-scale lens fields. We show how the external convergence, number of lensed images, and lensed image separation are altered by groups at the lens and along the sightline.

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#### **419.02 – Weak Lensing Analysis of Massive Galaxy Cluster IDCS J1426.5+3508 at $z=1.75$**

We present a weak lensing study of the galaxy cluster IDCS J1426.5+3508 at  $z=1.75$ , which is the highest redshift strong lensing cluster known and the most distant cluster for which a weak lensing analysis has been undertaken. Using F160W, F814W, and F606W observations with the *Hubble Space Telescope*, we detect tangential shear at  $2\sigma$  significance. Fitting a Navarro-Frenk-White mass profile to the shear with a theoretical median mass-concentration relation, we derive a mass consistent with previous mass estimates from the Sunyaev-Zel'dovich (SZ) effect, X-ray, and strong lensing. The cluster lies on the local SZ-weak lensing mass scaling relation observed at low redshift, indicative of minimal evolution in this relation.

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#### **419.03 – The Swift AGN and Cluster Survey**

The Swift active galactic nucleus (AGN) and Cluster Survey (SACS)

uses  $125 \text{ deg}^2$  of Swift X-ray Telescope serendipitous fields with variable depths surrounding X-ray bursts to provide a medium depth ( $4 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1}$ ) and area survey filling the gap between deep, narrow Chandra/XMM-Newton surveys and wide, shallow ROSAT surveys. Here, we present the first two papers in a series of publications for SACS. In the first paper, we introduce our method and catalog of 22,563 point sources and 442 extended sources. We examine the number counts of the AGN and galaxy cluster populations. SACS provides excellent constraints on the AGN number counts at the bright end with negligible uncertainties due to cosmic variance, and these constraints are consistent with previous measurements. The depth and areal coverage of SACS is well suited for galaxy cluster surveys outside the local universe, reaching  $z \sim 1$  for massive clusters. In the second paper, we use Sloan Digital Sky Survey (SDSS) DR8 data to study the 203 extended SACS sources that are located within the SDSS footprint. We search for galaxy over-densities in 3-D space using SDSS galaxies and their photometric redshifts near the Swift galaxy cluster candidates. We find 103 Swift clusters with a  $> 3\sigma$  over-density. The remaining targets are potentially located at higher redshifts and require deeper optical follow-up observations for confirmations as galaxy clusters. We present a series of cluster properties including the redshift, BCG magnitude, BCG-to-X-ray center offset, optical richness, X-ray luminosity and red sequences. We compare the observed redshift distribution of the sample with a theoretical model, and find that our sample is complete for  $z \leq 0.3$  and 80% complete for  $z \leq 0.4$ , consistent with the survey depth of SDSS. We also match our SDSS confirmed Swift clusters to existing cluster catalogs, and find 42, 2 and 1 matches in optical, X-ray and SZ catalogs, respectively, so the majority of these clusters are new detections. These analysis results suggest that our Swift cluster selection algorithm presented in our first paper has yielded a statistically well-defined cluster sample for further studying cluster evolution and cosmology.

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#### 419.04 – Highlights of the Merging Cluster Collaboration's Analysis of 26 Radio Relic Galaxy Cluster Mergers

Merging galaxy clusters are now recognized as multifaceted probes providing unique insight into the properties of dark matter, the environmental impact of plasma shocks on galaxy evolution, and the physics of high energy particle acceleration. The Merging Cluster Collaboration has used the diffuse radio emission associated with the synchrotron radiation of relativistic particles accelerated by shocks generated during major cluster mergers (i.e. radio relics) to identify a homogenous sample of 26 galaxy cluster mergers. We have confirmed theoretical expectations that radio relics are predominantly associated with mergers occurring near the plane of the sky and at a relatively common merger phase; making them ideal probes of self-interacting dark matter, and eliminating much of the dominant uncertainty when relating the observed star formation rates to the event of the major cluster merger. We will highlight a number of the discovered common traits of this sample as well as detailed measurements of individual mergers.

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**Contributing team(s):** Merging Cluster Collaboration

#### 419.05 – Dynamical Mass Measurements of Contaminated Galaxy Clusters Using Machine Learning

Galaxy clusters are a rich source of information for examining fundamental astrophysical processes and cosmological parameters, however, employing clusters as cosmological probes requires accurate mass measurements derived from cluster observables. We study dynamical mass measurements of galaxy clusters contaminated by interlopers, and show that a modern machine learning (ML) algorithm can predict masses by better than a factor of two compared to a standard scaling relation approach. We create a mock catalog from Multidark's publicly-available N-body MDPL1 simulation where a simple cylindrical cut around the cluster center allows interlopers to contaminate the clusters. In the standard approach, we use a power law scaling relation to infer cluster mass from galaxy line of sight (LOS) velocity dispersion. The presence of interlopers in the catalog produces a wide, flat fractional mass error distribution, with width = 2.13. We employ the Support Distribution Machine (SDM) class of algorithms to learn from distributions of data to predict single values. Applied to distributions of galaxy observables such as LOS velocity and projected distance from the cluster center, SDM yields better than a factor-of-two improvement (width = 0.67). Remarkably, SDM applied to contaminated clusters is better able to recover masses than even a scaling relation approach applied to uncontaminated clusters. We show that the SDM method more accurately reproduces the cluster mass function, making it a valuable tool for employing cluster observations to evaluate cosmological models.

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#### 419.06 – Galaxy Cluster Studies with the Hobby Eberly Telescope Dark Energy Experiment

The study of clusters of galaxies has been argued to be a very effective way to measure cosmological parameters, including measuring dark energy and testing models of gravity. The Hobby Eberly Telescope Dark Energy Experiment (HETDEX) will observe many hundreds of square degrees, covering a large sample of galaxy clusters out to  $z = 0.5$  based on their optical spectra (3500-5500 Å). The spectra will provide important measures of the clusters dynamics and may enable constraints on cosmological parameters, but only if the measurements provide accurate estimates of the total cluster masses. We have carried out a study to investigate the ability of HETDEX to recover accurate galaxy cluster masses over a wide range of masses and redshifts. We used a detailed mock galaxy catalog and present mock observations of two different scenarios: (1) We targeted individual galaxy clusters to investigate the recovery of parameters with such observations. (2) We created and evaluated a HETDEX-like selection "function" of galaxies over a similarly sized portion of the sky and use well adopted techniques to recover the dynamical properties, such as velocity dispersion and mass. Using both observing strategies, we produce cluster mass probability density functions  $P(X|M,z)$ , which can be used to determine the probability that a galaxy cluster of given mass ( $M$ ), located at redshift ( $z$ ) determined using observable parameter ( $X$ ). We then applied these probability functions to ten galaxy clusters selected from the Sloan Digital Sky Survey DR8 and the Chandra-XMM X-ray Cluster Survey at  $z=0.2-0.3$ , and observed by the HETDEX spectrograph prototype instrument (VIRUS-p). We measured spectroscopic redshifts and line-of-sight velocities of the galaxies in and around each cluster, derived a line-of-sight velocity dispersion, and inferred a dynamical mass for each cluster which ranges from  $(0.4-24) \times 10^{14} M_{\odot}$  ( $M_{200c}$ ). Using the mass probability density functions described above, we updated these masses and compared them to existing literature estimates, or to the masses estimated from other observables such as X-ray temperature or richness.

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**Institution(s):** 1. Kavli Institute for Particle Astrophysics and Cosmology, 2. Texas A&M University, 3. University of Texas

#### 419.07 – Mapping matter jointly with CMB lensing and Large Scale Structure

In the near future, Stage III and Stage IV Cosmic Microwave Background experiments will measure to high precision the lensing

distortions that trace matter fluctuations in the universe. On a similar timescale DES, HSC, WFIRST, EUCLID, DESI, LSST, and other surveys will provide galaxy redshift information, imaging, and cosmic shear data over large regions of the sky. Taking a holistic, Bayesian approach to combine datasets, we seek to understand the statistical properties of joint estimates of the matter distribution and its correlations, including their non-Gaussian likelihoods.

**Author(s):** Kevin Huffenberger<sup>1</sup>, Aditya Rotti<sup>1</sup>, Felipe Maldonado<sup>1</sup>

**Institution(s):** 1. Florida State University

#### **419.08 – GTC observations of Lyman-Alpha Emitters at $z=6.5$ : A Search for a Highest Redshift Proto-Cluster**

We present the results of our search for one of the first proto-clusters near the end of the Reionization Epoch using very deep OSIRIS images obtained at the Gran Telescopio Canarias (GTC). Our observations focus around two close, massive, Lyman Alpha Emitters (LAEs) at redshift 6.5 discovered in the SXDS field within a large-scale over-dense region (Ouchi et al. 2010). The total GTC observing time in three medium band filters (F883w35, F913w25 and F941w33) is over 34 hours covering 8x8 square-arcminute (or  $\sim 30,000$  Mpc<sup>3</sup> at  $z=6.5$ ). In addition to the two confirmed brightest LAEs in the field, we have identified 45 fainter LAE candidates. The preliminary luminosity function derived from our observations, assuming a spectroscopic confirmation success rate of 67% as in previous surveys, suggests this area is at least three times denser than the general field galaxy population at  $z=6.5$ . If confirmed spectroscopically, our results will imply the discovery of one of the first proto-clusters in the universe, which will evolve to resemble the most massive galaxy clusters today.

**Author(s):** Krittapas Chanchaiworawit<sup>1</sup>, Rafael Guzman<sup>1</sup>

**Institution(s):** 1. University of Florida

#### **419.09 – Precision distances with spiral galaxy apparent diameters**

Spiral galaxy diameters offer the oldest extragalactic distance indicator known. Although outdated and hitherto imprecise, two spiral diameter-based distance indicators applied in the 1980s can be tested, calibrated, and re-established for precision era use, based on abundant redshift-independent distances data available in NED-D. Indicator one employs the largest Giant Spiral Galaxies, which have an absolute isophotal major diameter of  $\sim 70 \pm 10$  kpc, offering standard ruler-based distances with  $<10\%$  precision. Indicator two employs the diameter-magnitude relation for spirals in general, as a secondary indicator, offering  $\sim 20\%$  precision. The ruler-based indicator is the only indicator with  $<10\%$  precision able to independently calibrate type Ia supernovae-based distances at cosmological distances. The secondary-based indicator is the only indicator with 20% precision applicable to more galaxies than in current Tully-Fisher surveys. The primary indicator gives researchers a new tool to confirm or refute if, as currently believed, universal expansion is accelerating. The secondary indicator gives researchers a new path toward acquiring a more complete 3D picture of the local universe and potentially, because the majority of galaxies in the universe are spirals, the distant universe.

**Author(s):** Ian Steer<sup>1</sup>

**Institution(s):** 1. NED

### **420 – Extrasolar Planets: Populations and Demographics**

#### **420.01 – A Probabilistic Mass-Radius Relationship for Sub-Neptune-Sized Planets: Implications for Missions Post-Kepler**

The Kepler Mission has discovered thousands of planets with radii between 1 and 4  $R_{\text{Earth}}$ , paving the way for the first statistical studies of the dynamics, formation, and evolution of planets in a size range where there are no Solar System analogs. Masses are an

important physical property for these theoretical studies, and yet the vast majority of Kepler planet candidates do not have their mass measured. Therefore, a key practical concern is how to most accurately map a measured sub-Neptune radius to a mass estimate given the existing observations. This issue is also highly relevant to devising the most efficient follow-up programs of future transiting exoplanet detection missions such as TESS. Here we present a probabilistic mass-radius relationship (M-R relation) evaluated within a hierarchical Bayesian framework, which both accounts for the anticipated intrinsic dispersion in these planets' compositions and quantifies the uncertainties on the M-R relation parameters. Assuming that the M-R relation can be described as a power law with a dispersion that is constant and normally distributed, we find that  $M/M_{\text{Earth}} = 2.7 (R/R_{\text{Earth}})^{1.3}$  and a scatter in mass of 1.9  $M_{\text{Earth}}$  is the "best-fit" probabilistic M-R relation for the sample of RV-measured transiting sub-Neptunes ( $R_{\text{pl}} < 4 R_{\text{Earth}}$ ; Wolfgang, Rogers, & Ford, in review). The probabilistic nature of this M-R relation has several advantages: not only does its use automatically account for a significant source of uncertainty in the comparison between planet formation theory and observation, but it can predict the yield of future transit missions' follow-up programs under the observed range of planet compositions at a given radius. We demonstrate the latter with TESS as a case study, building on Sullivan et al. 2015 to provide the RV semi-amplitude distribution predicted by this more general M-R relation and a more detailed treatment of the underlying planet population as derived from Kepler. The uncertainties in the predicted K distribution, which are driven by our derived spread of masses at a given radius, provide an additional consideration for choosing the best RV follow-up target selection strategy.

**Author(s):** Angie Wolfgang<sup>1</sup>, Leslie Rogers<sup>2</sup>, Eric B Ford<sup>1</sup>, Gregory P. Laughlin<sup>3</sup>

**Institution(s):** 1. The Pennsylvania State University, 2. University of California, Berkeley, 3. University of California, Santa Cruz

#### **420.02 – The Dependence of the Kepler Planet Population on Host Star Properties**

The Kepler main field contains stars with a wide range of masses and metallicities. These properties correlate with the amount of building blocks available for planet formation, and leave an imprint on the planet population. We derive planet occurrence rates as a function of stellar mass and metallicity. In contrast to giant planets, whose occurrence scales positively with both quantities, the occurrence of smaller planets is anti-correlated with stellar mass and shows complex behavior as a function of metallicity depending on planet radius and orbital period.

The higher average mass of planetary systems around low-mass stars compared to sun-like stars indicates migration of planetary building blocks is stellar-mass dependent and plays a prominent role in the planet formation process. The trends with stellar metallicity provide new constraints for planet formation and population synthesis models.

**Author(s):** Gijb Mulders<sup>1</sup>, Ilaria Pascucci<sup>1</sup>, Daniel Apai<sup>1</sup>

**Institution(s):** 1. University of Arizona

#### **420.03D – Synthesizing Exoplanet Demographics**

The discovery of thousands of exoplanets has revealed a large diversity of systems, the majority of which look nothing like our own. On the theoretical side, we are able to make ab initio calculations that make predictions about the properties of exoplanets. However, in order to link these predictions with observations, we must construct a statistical census of exoplanet demographics over as broad a range of parameters as possible. Current constraints on exoplanet demographics are typically constructed using the results of individual surveys using a single detection technique, and thus are incomplete. The only way to derive a statistically-complete census that samples a wide region of exoplanet parameter space is to synthesize the results from surveys employing all of the different discovery methods at our disposal. I present the first studies to demonstrate that this is actually possible, and describe a (mostly) de-biased exoplanet census that is constructed from the synthesis of results from microlensing, radial velocity, and direct imaging surveys. I will also discuss future work that will include the results of

transit surveys (in particular, Kepler discoveries) to complete the census of exoplanets in our Galaxy, and describe the application of this census to develop the most comprehensive, observationally-constrained models of planet formation and evolution that have been derived to date.

**Author(s):** Christian Clanton<sup>1</sup>

**Institution(s):** 1. *The Ohio State University*

#### **420.04 – Connections among spacing, composition, and flatness in super-Earth systems**

The collection of thousands of super-Earths discovered by the Kepler Mission contains a wealth of information about the process of planet formation. Their spacing distribution is an archaeological artifact of the final stages of planet formation, when planets grow from embryos to super-Earths. We explore how the interplay between stirring and mergers establishes the spacing distribution and links it to the composition and flatness of planets in the system, with the latter influenced by damping by residual gas. We show how these links manifest in Kepler observables such as period ratio, number of transiting planets, and transit duration ratios. Our study theoretically motivates connections between architectures and compositions that reflect conditions during the end stages of planet formation and are not merely the result of selection effects.

**Author(s):** Rebekah Ilene Dawson<sup>1</sup>, Eve Lee<sup>1</sup>, Eugene Chiang<sup>1</sup>

**Institution(s):** 1. *University of California, Berkeley*

#### **420.05 – The Robo-AO KOI Survey: Laser Adaptive Optics Imaging of Every Kepler Exoplanet Candidate**

The Robo-AO *Kepler* Planetary Candidate Survey is observing every *Kepler* planet candidate host star (KOI) with laser adaptive optics imaging to hunt for blended nearby stars which may be physically associated companions. With the unparalleled efficiency provided by the first fully robotic adaptive optics system, we perform the critical search for nearby stars (0.15" to 4.0" separation with contrasts up to 6 magnitudes) that pollute the observed planetary transit signal, contributing to inaccurate planetary characteristics or astrophysical false positives. We present approximately 3300 high resolution observations of *Kepler* planetary hosts from 2012-2015, with ~500 observed nearby stars. We measure an overall nearby star probability rate of  $16.2 \pm 0.8\%$ . With this large dataset, we are uniquely able to explore broad correlations between multiple star systems and the properties of the planets which they host. We then use these clues for insight into the formation and evolution of these exotic systems. Several KOIs of particular interest will be discussed, including possible quadruple star systems hosting planets and updated properties for possible rocky planets orbiting in the habitable zone.

**Author(s):** Carl Ziegler<sup>4</sup>, Nicholas M. Law<sup>4</sup>, Christoph Baranec<sup>3</sup>, Tim Morton<sup>2</sup>, Reed L. Riddle<sup>1</sup>

**Institution(s):** 1. *California Institute of Technology*, 2. *Princeton University*, 3. *University of Hawaii at Manoa*, 4. *University of North Carolina - Chapel Hill*

#### **420.06 – Exploring the Diversity of Super-Earths**

The discovery of planets with masses and radii intermediate between Earth and Neptune was one of the biggest surprises in the brief history of exoplanet science. These "super-Earths" are an order of magnitude more abundant than close-in giant planets. Despite this ubiquity, we know little about their typical compositions and formation histories. Spectroscopic transit observations can shed new light on these mysterious worlds by probing their atmospheric compositions. In this talk, we will give an overview of our ongoing 124-orbit (200-hour) Hubble Space Telescope program to reveal the chemical diversity and formation histories of super-Earths. This unprecedented survey will provide the first comprehensive look at this intriguing new class of planets ranging from 1 Neptune mass and temperatures close to 2000K to a 1 Earth mass planet near the habitable zone of its host star. We will discuss the scope of the program, demonstrate observational techniques to observe extremely bright exoplanet targets with HST WFC3 and STIS, and present early results.

**Author(s):** Björn Benneke<sup>1</sup>, Ian Crossfield<sup>6</sup>, Heather Knutson<sup>1</sup>, Joshua Lothringer<sup>6</sup>, Diana Dragomir<sup>3</sup>, Jonathan J. Fortney<sup>5</sup>, Andrew Howard<sup>7</sup>, Peter R. McCullough<sup>4</sup>, Ronald L. Gilliland<sup>4</sup>, Eliza Kempton<sup>2</sup>, Caroline Morley<sup>5</sup>

**Institution(s):** 1. *Caltech*, 2. *Grinnell College*, 3. *LCOGT*, 4. *STScI*, 5. *UC Santa Cruz*, 6. *University of Arizona*, 7. *University of Hawaii*

#### **420.08 – Five Years of SETI with the Allen Telescope Array: Lessons Learned**

We discuss recent observations at the Allen Telescope Array (ATA) supporting a wide ranging Search for Extraterrestrial Intelligence (SETI). The ATA supports observations over the frequency range 1-10 GHz with three simultaneous phased array beams used in an anticoincidence detector for false positive rejection. Here we summarize observational results over the years 2011-2015 covering multiple campaigns of exoplanet stars, the galactic plane, infrared excess targets, etc. Approximately  $2 \times 10^8$  signals were identified and classified over more than 5000 hours of observation. From these results we consider various approaches to the rapid identification of human generated interference in the process of the search for a signal with origins outside the radius of the Moon's orbit. We conclude that the multi-beam technique is superb tool for answering the very difficult question of the direction of origin of signals. Data-based simulations of future instruments with more than 3 beams are compared.

**Author(s):** Gerald Harp<sup>1</sup>

**Institution(s):** 1. *SETI Institute*

### **421 – Catalogs, Surveys, Data: The Variable Sky**

#### **421.01 – The Promise of Domain Adaptation**

Most new surveys spend an appreciable time in collecting data on which to train classifiers before they can be used on future observations from the same dataset. The result generating phase can start much earlier if the training could incorporate data accumulated from older surveys enhanced with a small set from the new survey. This is exactly what Domain Adaptation (DA) allows us to do. The main idea behind DAs can be summarized thus: if we have two classes of separable objects in some feature space of a Source survey (S), we can define a hyperplane to separate the two types. In a second Target survey (T), for the same features the hyperplane would be inclined differently. DA methods get the mapping between the two hyperplanes using a small fraction of data from the Target (T) survey and can then be used to predict the classes of the remaining majority of data in T. We discuss the parameters that need to be tuned, the difficulties involved, and ways to improve the results.

As we move towards bigger, and deeper surveys, being able to use existing labelled information to conduct classification in future surveys will be more cost-effective and promote time efficiency as well. Starting with the light curve data of 50,000 periodic objects from Catalina Real-Time Transient Survey (CRTS), we have applied domain adaptation techniques such as Geodesic Flow Kernel (GFK) with Random forest classifier and Co-training for domain adaptation (CODA) to the CRTS data which has 35,000 points overlapping with Palomar Transient Factory (PTF), and 12,000 with Lincoln Near-Earth Asteroid Research (LINEAR). The results suggest that domain adaptation is an area worth exploring as the knowledge between these surveys is transferable and the approaches to find the mappings between these surveys can be applied to the remaining data as well as for near future surveys such as CRTS-II, Zwicky Transient Facility (ZTF) and the Large Synoptic Survey Telescope (LSST) to name a few at the optical wavelengths.

**Author(s):** Ashish A. Mahabal<sup>2</sup>, Jingling Li<sup>1</sup>, Samarth Vajjanapurkar<sup>3</sup>, Brian Bue<sup>4</sup>, Adam Miller<sup>2</sup>, Ciro Donalek<sup>2</sup>, Stanislav G. Djorgovski<sup>2</sup>, Andrew J. Drake<sup>2</sup>, Matthew Graham<sup>2</sup>

**Institution(s):** 1. *Bryn Mawr College*, 2. *Caltech*, 3. *IIT*, 4. *JPL*  
**Contributing team(s):** CRTS, iPTF

#### **421.02 – The Solar System Survey by NASA's K2**

## Mission

The K2 mission is using the unique assets of the repurposed Kepler space telescope to perform long-baseline, high-cadence, high-precision photometry of targets selected by the community. Unlike the original Kepler mission, the loss of two reaction wheels requires K2 to point near the ecliptic plane. As a result, thousands of faint asteroids can be seen to pass through the target pixel masks that are downlinked to earth after each ~75-day observing campaign. I will show how these serendipitous observations of asteroids can be used to obtain lightcurves for faint ( $V > 18$ ) objects which are otherwise challenging to target from the ground. In particular, I will demonstrate that the data are well-suited to identify small asteroids with rotation periods near or below the ~2 hour "spin barrier". I will also highlight the K2 data of other solar system bodies for which dedicated pixel masks have been (or will be) downlinked, including Neptune, Uranus, Pluto, Jupiter trojans, trans-Neptunian objects, and multiple comets including Siding Spring and Chiron. Owing to its ecliptic pointing and 1.4-meter diameter mirror, K2 is offering unique time-series photometry of solar system objects at a precision which is unlikely to be rivaled by the future, smaller-aperture photometric missions such as TESS and PLATO.

**Author(s):** Geert Barentsen<sup>1</sup>

**Institution(s):** 1. NASA Ames

**Contributing team(s):** Kepler team

### 421.03D – Exploring the transient sky: from surveys to simulations

The transient sky is very important to study the dynamics of the Universe on human timescales. Transient sources are seen in every band of the electromagnetic spectrum, from low radio frequencies to gamma-ray energies, and produced by nearby flare stars to cosmological gamma-ray bursts.

We have performed a transient survey of four different fields with the Low Frequency Array (LOFAR) at 150 MHz. LOFAR is a new generation radio interferometer which is observing at very low radio frequencies, a so far relatively unexplored frequency domain for transient searches. No credible transients were detected in our survey, but we were able to set stringent upper limits on the transient surface density using three new statistical methods. We also calculated the transient surface density as a function of the timescale of the transients, and established that the upper limits we can set vary up to two orders of magnitude for different timescales.

We have explored the complex relation between flux density, timescale and transient surface density, and developed a simulation method to calculate the transient rate as a function of both the flux and the duration of transients for different shapes of their lightcurves and for a given observing strategy. This method is independent of the nature of transient sources, and the instrument or the frequency of the observations. Therefore, this provides a tool for transient surveys carried out by current and future observatories across the electromagnetic spectrum.

**Author(s):** Dario Carbone<sup>1</sup>

**Institution(s):** 1. University of Amsterdam

### 421.04 – Searching for Variability in the Gamma-ray Sky using the Fermi All-sky Variability Analysis (FAVA)

We present the results of the second Fermi All-sky Variability Analysis (FAVA) catalog, consisting of a search for week long variability above 100 MeV using the new Pass 8 data selection. The catalog includes over 2000 flares, spanning 6 years of the Fermi mission, with hundreds of flares that are not associated with any known catalog source. FAVA was designed to efficiently search for variable sources over a wide range of energies and timescales. Unlike a traditional likelihood analysis, the analysis performed by FAVA uses the mission averaged emission as a background, and is as such independent of any model for the diffuse gamma-ray emission. This makes the FAVA analysis especially sensitive to variable sources in the Galactic plane. This analysis is also computationally inexpensive, allowing for blind searches for flux variations over the entire sky. We will present some of the interesting flares identified through this

analysis, and highlight those that are typically missed through traditional analysis methods. We will also present the new public FAVA webpage, which is designed to alert the community of new gamma-ray flares in real time and allow users to create relative flux light curves for any position on the sky; a task that is currently computationally intensive to perform over long intervals using traditional analysis tools.

**Author(s):** Daniel Kocevski<sup>3</sup>, Rolf Buehler<sup>2</sup>, Marco Ajello<sup>1</sup>, Matteo Giomi<sup>2</sup>

**Institution(s):** 1. Clemson University, 2. DESY Zeuthen, 3. NASA Goddard Space Flight Center

**Contributing team(s):** Fermi LAT Collaboration

### 421.05 – Automated Transient Recovery Algorithm using Discrete Zernike Polynomials on Image-Subtracted Data

We present an unsupervised algorithm for the automated identification of astrophysical transients recovered through image subtraction techniques. We use a set of discrete Zernike polynomials to decompose and characterize residual energy discovered in the final subtracted image, identifying candidate sources which appear point-like in nature. This work is motivated for use in collaboration with Advanced gravitational wave (GW) interferometers, such as Advanced LIGO and Virgo, where multiwavelength electromagnetic (EM) emission is expected in parallel with gravitational radiation from compact binary object mergers of neutron stars (NS-NS) and stellar-mass black holes (NS-BH). Imaging an EM counterpart coincident with a GW trigger will help to constrain the multi-dimensional GW parameter space as well as aid in the resolution of long-standing astrophysical mysteries, such as the true nature of the progenitor relationship between short-duration GRBs and massive compact binary mergers. We are working on making our method an open-source package optimized for low-latency response for community use during the upcoming era of GW astronomy.

**Author(s):** Kendall Ackley<sup>1</sup>, Stephen S. Eikenberry<sup>1</sup>, Sergey Klimenko<sup>1</sup>

**Institution(s):** 1. University of Florida

### 421.06D – Unveiling the Variable Sky with the Time-Domain Spectroscopic Survey

The dawn of large-scale multi-epoch imaging surveys enables systematic exploration of the rich astrophysical information in the time-domain, and serendipitous discovery of new and rare phenomena. Spectroscopic follow-up of variable objects discovered based on their optical light curves provides valuable complementary insight into their physical nature through key spectral parameters. The Time-Domain Spectroscopic Survey (TDSS) is an ongoing SDSS-IV subproject primarily aimed at eventually obtaining initial follow-up spectra of ~200,000 optically-variable objects selected from SDSS/Pan-STARRS1 multi-epoch imaging. We present initial science results from ~15,000 TDSS related spectra (including from the SDSS-III SEQUELS program), focusing on the nature and demographics of quasar and stellar populations selected by variability. We highlight the unique advantages of using our variability-selected sample for various science applications, including studies of broad absorption line quasars, gamma-ray blazars, rare eclipsing binaries, and magnetically active M dwarfs. We also highlight emerging physical insights on the recently-discovered 'changing-look' quasar phenomenon, based on new serendipitous discoveries of these rare objects.

**Author(s):** John J. Ruan<sup>4</sup>, Scott F. Anderson<sup>4</sup>, Paul J. Green<sup>2</sup>, Michael Eracleous<sup>3</sup>, Eric Morganson<sup>2</sup>, Jessie C. Runnoe<sup>3</sup>, W. Niel Brandt<sup>3</sup>, Donald P. Schneider<sup>3</sup>, Yue Shen<sup>1</sup>

**Institution(s):** 1. Carnegie Observatories, 2. Harvard Smithsonian CfA, 3. Penn State Univ., 4. University of Washington

**Contributing team(s):** TDSS Team, SDSS and PS1 collaborations

### 421.07 – The iPTF Galactic Plane Survey

Beginning in 2013, the Intermediate Palomar Transient Factory has conducted a survey of the Northern Galactic Plane. The major

science goals of the survey include mapping variable stars throughout the Galaxy; discovering outbursting sources such as Cataclysmic Variables, FU Ori outbursts, and M-dwarf flares; and identifying rare types of compact binaries. Through 2015 the survey has obtained an average of 60 epochs in R-band in the spatial region  $0 < l < 150$  degrees,  $|b| < 20$  degrees, with greatest coverage in the  $|b| < 5$  degree region.

I will describe the performance of the survey and present initial results, with a focus on variability-based identification of X-ray sources. The Zwicky Transient Facility, to begin in 2017, will include an extensive public variability survey of the Galactic Plane.

**Author(s):** Eric Christopher Bellm<sup>1</sup>, Thomas A Prince<sup>1</sup>, Adam Miller<sup>3</sup>, Shrinivas R. Kulkarni<sup>1</sup>, Thomas Kupfer<sup>1</sup>, Russ Laher<sup>2</sup>, Frank J. Masci<sup>2</sup>, Eran Oded Ofek<sup>4</sup>, David L. Shupe<sup>2</sup>, Jason A. Surace<sup>2</sup>

**Institution(s):** 1. Caltech, 2. IPAC, 3. JPL, 4. Weizmann Institute of Science

**Contributing team(s):** Intermediate Palomar Transient Factory Collaboration

## 422 – Star-Forming Galaxies at $z \sim 0.3-1.0$

### 422.01 – Coupling the emission of ionizing radiation and Lyman alpha

The class of objects that reionized the intergalactic hydrogen remains an observational and theoretical challenge. Recently, the shape of the Lyman-alpha (Ly $\alpha$ ) emission line profile has been proposed as a way to pre-select Lyman Continuum (LyC) leaking galaxies. We present results of deep spectroscopic observations obtained with the Cosmic Origin Spectrograph on the HST of a sample of 4 Ly $\alpha$ -emitting galaxies at  $z \sim 0.3$ , chosen to be candidate LyC leaking galaxies, on the grounds of blueshifted peaks of Ly $\alpha$  emission/symmetric extended Ly $\alpha$  wings. We do not detect ionizing radiation escaping from these objects, with upper  $3\sigma$  limits on the absolute escape fraction of LyC photons between 14 and 2%.

**Author(s):** Claudia Scarlata<sup>3</sup>, Matthew Hayes<sup>1</sup>, Brendan P. Miller<sup>2</sup>, Johannes Pushnig<sup>1</sup>, Gustav Jansson<sup>1</sup>

**Institution(s):** 1. Stockholm University, 2. University of Michigan, 3. University of Minnesota

### 422.02 – Spectroscopic Study of Star-forming Galaxies in Filaments and the Field at $z \sim 0.5$ : Evidence for Environmental Dependence of Electron Density

We study the physical properties of a spectroscopic sample of 28 star-forming galaxies in a large filamentary structure in the COSMOS field at  $z \sim 0.53$ , with spectroscopic data taken with the Keck/DEIMOS spectrograph, and compare them with a control sample of 30 field galaxies. We spectroscopically confirm the presence of a large galaxy filament ( $\sim 8$  Mpc), along which five confirmed X-ray groups exist. We show that within the uncertainties, the ionization parameter, equivalent width (EW), EW versus specific star-formation rate (sSFR) relation, EW versus stellar mass relation, line-of-sight velocity dispersion, dynamical mass, and stellar-to-dynamical mass ratio are similar for filament and field star-forming galaxies. However, we show that on average, filament star-forming galaxies are more metal-enriched ( $\sim 0.1-0.15$  dex), possibly due to the inflow of the already enriched intrafilamentary gas into filament galaxies. Moreover, we show that electron densities are significantly lower (a factor of  $\sim 17$ ) in filament star-forming systems compared to those in the field, possibly because of a longer star-formation timescale for filament star-forming galaxies. Our results highlight the potential pre-processing role of galaxy filaments and intermediate-density environments on the evolution of galaxies, which has been highly underestimated.

**Author(s):** Behnam Darvish<sup>3</sup>, Bahram Mobasher<sup>3</sup>, David Sobral<sup>1</sup>, Shoubaneh Hemmati<sup>3</sup>, Hooshang Nayyeri<sup>2</sup>, Irene Shivaie<sup>3</sup>  
**Institution(s):** 1. Lancaster University, 2. University of California, Irvine, 3. University of California, Riverside

### 422.03D – The Evolution of the Tully-Fisher Relation

## Since $z \sim 1$ with KROSS and SAMI

The KMOS Redshift One Spectroscopic Survey (KROSS) aims to study the spatially-resolved dynamics, star formation and chemistry of  $\sim 1000$  star-forming galaxies at  $z \sim 1$ . Here we begin to probe the epoch of peak star formation in the universe, a key era for galaxy mass assembly. The primary causes of this increased star formation are hotly debated, as are the dominant mechanisms for mass growth (e.g. major mergers, secular evolution). It is thus essential to determine how the ratio of stellar, gaseous and dark mass in galaxies has varied over cosmic time, and whether this is related to the global fall of star formation activity over the same period. Using a simple arctan function to model the spatially-resolved H $\alpha$  kinematics of the KROSS galaxies, and SED fitting to retrieve stellar masses, I present the observed and baryonic Tully-Fisher relations (TFRs) for sub-samples of the  $\sim 400$  KROSS galaxies observed. I find a dependence of the KROSS TFRs on the relative importance of rotation and pressure support in galaxies ( $V/\sigma$ ). I explore reasons for the increased intrinsic scatter found in all relations in comparison to  $z \sim 0$ . Considering only rotationally supported galaxies ( $V/\sigma > 2.5$ ), there is an apparent evolution of the zero-point of the TFR ( $-1.8$  mag and  $0.54$  dex for the absolute K-band and stellar mass TFR respectively) since  $z \sim 1$ . For a given dynamical mass, galaxies had less stellar mass at  $z \sim 1$  than today. The implications of this for galaxy evolution theory are discussed.

Further, when comparing the KROSS TFRs to those at  $z \sim 0$  we must consider the systematic bias introduced as a result of the measurement methods used. To make a direct comparison it is essential to use the same observational and analytical methods. In practice, to compare to KROSS we must take IFU observations of  $z \sim 0$  galaxies and degrade the data to the same signal-to-noise ratio, and spatial and spectral resolution as that of the KROSS data. The degraded data must then be analysed in the same manner as with KROSS, at which point a direct comparison may be made. I discuss my work comparing the TFRs of KROSS and the SAMI Galaxy Survey in this manner and its implications on previous measures of the evolution of the TFR since  $z \sim 1$ .

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### 422.04 – An Examination of Strong-line Metallicity Diagnostics with Direct Gas-Phase Metallicities at Higher Redshifts

The [OIII] $\lambda 4363$  nebular emission line, which provides the *most reliable determination of the gas metallicity* by measuring the electron temperature of the gas, is intrinsically weak. As such, most metallicity studies at both low and high redshifts have utilized "strong-line" metallicity calibrations, such as [NII] $\lambda 6583$ /H $\alpha$  or  $R_{23} = ([\text{OII}] + [\text{OIII}])/\text{H}\beta$ . However, there are growing concerns that these diagnostics may not be used for evolutionary studies due to differences in the physical conditions (e.g., density, ionization, abundance ratios) of the interstellar gas in galaxies. A clear demonstration for this concern is the offset on the Baldwin-Phillips-Terlevich diagnostic diagram ([OIII] $\lambda 5007$ /H $\beta$  vs. [NII] $\lambda 6583$ /H $\alpha$ ) for high- $z$  star-forming galaxies from local star-forming galaxies.

To examine this issue, we investigate the accuracy that commonly-used strong-line diagnostics can explain the direct oxygen abundances. Here, we use a sample of  $\sim 100$  low-mass galaxies at  $z = 0.07$  to  $1.0$  with detections of the [OIII] $\lambda 4363$  emission line from Keck and MMT optical spectroscopy. These galaxies are pre-selected for their strong nebular emission lines from the Subaru Deep Field and the DEEP2 Survey. Utilizing the optical emission lines, we argue that " $R_{23}$ " is not a reliable diagnostic and that discrepancies from [OIII] $\lambda 4363$ -based metallicity cannot be explained simply by higher gas densities or higher ionization parameter. We do find that the [NII]-based metallicity diagnostics of Pettini & Pagel (2004) are in agreement with [OIII] $\lambda 4363$ -based metallicity at  $z \sim 0.5$ . There is, however, a sub-population (25%) where [NII]-based estimates are overestimating the oxygen metallicities. We argue that enhanced nitrogen abundances, relative to oxygen, is responsible for this significant ( $\sim 0.5$  dex) offset in metallicity. We present preliminary

results for a revised metallicity calibration that considers the N/O abundance ratio.

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#### **422.05D – Where stars form: inside-out growth and coherent star formation across the main sequence from HST H $\alpha$ maps at $z \sim 1$**

Imaging surveys with HST have demonstrated that many galaxies attained their current forms at  $z \sim 1$ . Key to understanding this process is a direct measurement of the distribution of star formation within galaxies at this crucial epoch. This is now possible with the WFC3 grism capability on HST, as it provides H $\alpha$  maps of all galaxies at  $0.7 < z < 1.5$  in its field of view. Using H $\alpha$  maps for 2727 galaxies, we show where star formation is distributed in galaxies across the star formation - mass plane (the “main sequence”). We find that the disk scale length of H $\alpha$  is larger than that of the stellar continuum emission, consistent with inside-out assembly of galactic disks. Across the main sequence, we find evidence for ‘coherent star formation’: in galaxies with higher than average star formation rates, H $\alpha$  is enhanced throughout the disk; similarly, in galaxies with low star formation rates H $\alpha$  is depressed throughout the disk. I discuss these results in the context of several proposed mechanisms for enhancing and quenching star formation. I also show first results of the spatial distribution of star formation at  $z \sim 2-3$ .

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**Contributing team(s):** 3D-HST Collaboration

#### **422.06 – Investigating the burstiness of the star formation history of low-mass galaxies at intermediate redshifts with KECK/DEIMOS spectroscopy and CANDELS imaging**

The history of gas accretion, expulsion, and recycling, and star formation of low-mass galaxies (with stellar mass below  $10^9 M_{\odot}$ ) is thought to be stochastic and bursty. We combine the deep broad-band images of CANDELS and the high-resolution optical spectroscopy from Keck/DEIMOS surveys --- TKRS, DEEP2, DEEP3, and HALO7D --- to explore the star formation histories of low-mass galaxies at intermediate redshifts ( $0.5 \leq z \leq 1.0$ ). We study (1) the stellar mass ( $M$ )--gas-phase metallicity ( $Z$ ) relation (MZR) and its scatter and (2) the ratio of star formation rates (SFRs) measured through FUV to that through H $\beta$  (FUV--H $\beta$  ratio). Our MZR sample is  $\sim 20$  times larger than those in previous studies beyond the local universe. This huge gain in sample size enables superior constraints on the MZR and its scatter in the low-mass regime. We find that the scatter of the MZR increases as mass decreases. For the FUV--H $\beta$  ratio, we find that it increases with the decrease of mass and SFR. Both results can be explained by low-mass galaxies having a star formation history with more bursts than massive galaxies having. A simple model shows that the star formation occurring in starburst phases in low-mass galaxies is 5x higher than that in a constant star formation phase, while, for massive galaxies, the bursty phases of star formation is negligible. Finally, we find that our median FUV--H $\beta$  ratio for low-mass galaxies is higher than that of local galaxies of the same mass, implying a redshift evolution.

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### **423 – Pulsars and Neutron Stars**

#### **423.01 – High Energy Emission in Pulsar Magnetospheres: Modeling in the FERMI Era**

Our study of pulsar high-energy emission in dissipative pulsar magnetospheres provides meaningful constraints on the macroscopic

parameters of the global pulsar magnetosphere solutions through the extensive comparison of model light curves and their spectra with those provided by multi-wavelength observations of real pulsars. These state-of-the-art solutions, by their nature, provide both the field geometry, and the necessary particle accelerating electric fields. Using these solutions, we generate model gamma-ray light curves by calculating the trajectories and the Lorentz factors of the radiating particles, under the influence of both the accelerating electric components and curvature radiation-reaction. I will show how this study leads to the construction of model magnetospheres that successfully reproduce the observed light-curve phenomenology as depicted in the radio-lag vs peak-separation diagram obtained by Fermi. These models allow the calculation of phase-averaged and phase-resolved spectra and the total gamma-ray luminosities as well. I will show that the corresponding photon cut-off energies and total gamma-ray luminosities are within the observed ranges for both standard and millisecond pulsars. A direct and detailed comparison with the Fermi data reveals the dependence of the macroscopic conductivity parameter on the spin down rate, constraining the physical mechanisms underlying the observed pulsar high-energy emission.

**Author(s):** Constantinos Kalapotharakos<sup>1</sup>, Alice Kust Harding<sup>1</sup>, Demosthenes Kazanas<sup>1</sup>, Gabriele Brambilla<sup>1</sup>

**Institution(s):** 1. NASA, Goddard Space Flight Center

#### **423.02 – Merger of Magnetized Binary Neutron Stars**

We present simulations of the merger of binary neutron star systems calculated with full general relativity and incorporating the global magnetic field structure for the stars evolved with resistive magnetohydrodynamics. We also incorporate the effects of neutrino transport and tabular equations of state to describe the degenerate matter. We gratefully acknowledge the support of NASA through the Astrophysics Theory Program grant NNX13AH01G.

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#### **423.03 – A complete library of X-ray pulsars in the Magellanic Clouds: A new resource for modeling the time evolution of luminosity and pulse profile**

We have collected and analyzed all XMM-Newton and Chandra ( $\sim 300$ ) observations of the known pulsars in the Small & Large Magellanic Clouds (SMC, LMC). We aim to classify various pulsar properties with amplitude  $\log L_X = 33 \sim 38$  erg/s and incorporate the related parameters in theoretical models. With the high time-resolution data from the European Photon Imaging Camera (EPIC) and the latest calibration files and the Science Analysis System (SAS) software from High Energy Astrophysics Science Archive Research Center Software (HEASOFT), our pipeline generates a suite of useful products for each pulsar detection: point-source event lists, pulse profiles, periodograms, and spectra for the broad energy band, the soft band (0.2-2 keV), and the hard band (2-12 keV). Of 59 SMC pulsars in the EPIC field of view, we were able to measure 29 with pulse periods and power spectra. From XMM for example, for 16 of them, we find 12 are spinning up and 4 are spinning down. We also compare the observed pulse profiles to geometric models of the pulsars in order to constrain the magnetospheric parameters of each of these sources. Our motivation is to provide a library for time domain studies and profile modeling.

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**Institution(s):** 1. Harvard-Smithsonian Center for Astrophysics, 2. University of Massachusetts, 3. University of Southampton

#### **423.04 – Discovery of Pulsed Gamma Rays and a New Spin-Down State of the LMC Pulsar B0540-69**

The young pulsar B0540-69 in the nearby Large Magellanic Cloud has the third largest spin-down luminosity of the  $\sim 2500$  known pulsars. Multi-year observations with Fermi/LAT using the ephemerides from RXTE reveal that B0540-69 is the most luminous gamma-ray pulsar ever detected. Its pulsed luminosity above 100 MeV is  $5.7 \times 10^{36}$  erg/s, about 20 times brighter than the Crab Pulsar, the next brightest. The pulse profile in gamma rays is similar to that seen in X-rays and optical light; the giant radio pulses align with the shoulders of the high-energy profiles. The detection of B0540-69 in gamma rays offers a new look at particle acceleration and emission in the magnetospheres of very young pulsars. Unpulsed gamma-ray emission has also been detected from PSR J0537-6910, another young pulsar in the LMC. The two pulsars contribute most of the gamma-ray emission from the 30 Doradus nebula, indicating that cosmic rays contribute only a small part. Recent monitoring of B0540-69 with the Swift/XRT shows a large, sudden, and persistent increase in the spin-down rate of B0540-69. The relative increase in the spin-down rate of 36% is unprecedented for B0540-69. No accompanying change in the spin rate was seen, and no change was seen in the pulsed X-ray emission from B0540-69 following the change in the spin-down rate. Such large relative changes in the spin-down rate are seen in the recently discovered class of "intermittent pulsars", and we compare the properties of B0540-69 to such pulsars. We consider possible changes in the magnetosphere of the pulsar that could cause such a large change in the spin-down rate. These changes are likely to result in a new braking index for the pulsar. We report on continued monitoring with Swift/XRT to determine the new braking index and to detect a new state change, should it occur.

**Author(s):** Francis E. Marshall<sup>4</sup>, Lucas Guillemot<sup>1</sup>, Alice Kust Harding<sup>4</sup>, Pierrick Martin<sup>3</sup>, David A Smith<sup>2</sup>

**Institution(s):** 1. CNRS-Universite d'Orleans, 2. CNRS-Universite de Bordeaux, 3. CNRS/IRAP, Universite Paul Sabatier, 4. NASA's GSFC

#### 423.06 – Arecibo Search for Radio Pulses from M33

All radio pulsars that have been discovered to date are located within the Milky Way and its globular clusters, or in the Magellanic Clouds. The increased sensitivity of the wide-bandwidth Puerto Rico Ultimate Pulsar Processing Instrument (PUPPI) installed at the Arecibo Observatory makes detection of pulsars beyond the Magellanic Clouds a promising possibility. We are using the PUPPI backend and the 327 MHz receiver at Arecibo to try to detect giant radio pulses from neutron stars in the nearby spiral galaxy M33. Pulsars in M33 could be used to probe the local intergalactic medium and would help us study neutron star formation and pulsar evolution in another spiral galaxy. Using the Crab pulsar as a guide, we estimate that giant pulses from every Crab-like pulsar beaming toward us from the M33 optical disk ought to be detectable in our search, with several pulses detected in each hour of integration time. In this presentation I describe this project and provide an update on the status of the search.

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**Institution(s):** 1. Cornell University, 2. Franklin and Marshall College, 3. Max-Planck-Institut für Radioastronomie

#### 423.07 – Timing and Fermi LAT Analysis of Four Millisecond Pulsars Discovered in Parkes Radio Searches of Gamma-ray Sources

We present phase-connected timing solutions for four binary millisecond pulsars discovered in searches of Fermi LAT gamma-ray sources using the Parkes radio telescope. Follow-up timing observations of PSRs J0955-6150, J1012-4235, J1036-8317, and J1946-5403 have yielded timing models with precise orbital and astrometric parameters. For each pulsar, we also did a gamma-ray spectral analysis using LAT Pass 8 data and generated photon probabilities for use in a weighted H-test pulsation test. In all 4 cases, we detect significant gamma-ray pulsations, confirming the identification with the gamma-ray source originally targeted in the discovery observations. We describe the results of the pulse timing and gamma-ray spectral and timing analysis and the characteristics of each of the systems.

The Fermi-LAT Collaboration acknowledges support for LAT development, operation and data analysis from NASA and DOE (United States), CEA/Irfu and IN2P3/CNRS (France), ASI and INFN (Italy), MEXT, KEK, and JAXA (Japan), and the K.A. Wallenberg Foundation, the Swedish Research Council and the National Space Board (Sweden). Science analysis support in the operations phase from INAF (Italy) and CNES (France) is also gratefully acknowledged. NRL participation was funded by NASA.

**Author(s):** Paul S. Ray<sup>5</sup>, Scott M. Ransom<sup>4</sup>, Fernando M. Camilo<sup>2</sup>, Matthew Kerr<sup>1</sup>, John Reynolds<sup>1</sup>, John Sarkissian<sup>1</sup>, Paulo Freire<sup>3</sup>, H. Thankful Cromartie<sup>7</sup>, Ewan D. Barr<sup>6</sup>

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#### 423.08 – Dynamo Activity in Strongly Magnetized Accretion Disks

Strongly magnetized accretion disks around black holes have many attractive features that may explain the enigmatic behavior observed from X-ray binaries. The physics and structure of these disks are governed by a dynamo-like mechanism, which channels the accretion power liberated by the magnetorotational instability into an ordered toroidal magnetic field. To study dynamo activity, we performed three-dimensional, stratified, isothermal, ideal magnetohydrodynamic shearing box simulations. In our simulations, the strength of this self-sustained toroidal magnetic field depends on the net vertical magnetic flux we impose, which allows us to study weak-to-strong magnetization regimes. We find that the entire disk develops into a magnetic pressure-dominated state for a sufficiently strong net vertical magnetic flux. Over the two orders of magnitude in net vertical magnetic flux that we consider, the effective  $\alpha$ -viscosity parameter scales as a power-law. We quantify dynamo properties of toroidal magnetic flux production and its buoyant escape as a function of disk magnetization. Finally, we compare our simulations to an analytic model for the vertical structure of strongly magnetized disks applicable to the high/soft state of X-ray binaries.

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#### 423.09 – FRBs: We are realfast

We present "realfast": a new quasi-real-time system on the Very Large Array to search for and precisely localize fast radio bursts and other millisecond transients. Fast Radio Bursts (FRBs) are dispersed, millisecond-duration radio signals whose origins have remained a mystery since their first discovery in 2007. Circumstantial evidence has been building of an extragalactic origin for FRBs, and real-time systems on single dish telescopes have enabled extensive follow-up of recent discoveries at other wavelengths. However, the single dishes that have discovered FRBs to date cannot sufficiently localize FRBs to tie them to a specific origin; they also are unable to accurately measure a flux density of FRBs. The ability to perform sub-arcsecond localization of an FRB is absolutely critical for both tying its origin to a host (galaxy, star, blank field, etc.), for enabling extensive tracking to identify the FRB progenitor, and for enabling confident intensity measurements.

The realfast system on the VLA has now been implemented to perform imaging at 5ms cadence and has a survey speed comparable to that of the world's most prodigious FRB-finder, Parkes Telescope. In this presentation we will describe the implementation of the realfast system, and demonstrate our unique ability to precisely localize FRBs in quasi-real-time. Our observing system is well-characterized, which also allows us to provide accurate sensitivity limits and flux measurements upon FRB detection.

**Author(s):** Geoffrey C. Bower<sup>1</sup>, Sarah Spolaor<sup>5</sup>, Casey J. Law<sup>6</sup>, Paul Demorest<sup>5</sup>, Bryan J. Butler<sup>5</sup>, Michael P. Rupen<sup>2</sup>, T. Joseph W. Lazio<sup>3</sup>, Scott Vander Wiel<sup>4</sup>, Earl Lawrence<sup>4</sup>

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## 424 – Molecular Clouds, HII Regions, Interstellar Medium II

### 424.01 – The Dense Gas Fraction in Molecular Clouds

Stars form in the densest regions of molecular clouds, which are known to have varying levels of star formation activity. But the origin of the so-called dense-gas fraction – the amount of dense gas in a molecular cloud above a certain critical threshold – is unclear. In this study, we compare the dense gas fractions of two molecular clouds with very different rates of star formation: the Rosette and Maddalena. Using far-infrared *Herschel* observations, we find that ~4% of the molecular mass in the Rosette is contained in gas with extinction  $A_V > 7.3$  mag [ $N(\text{H}_2) > 6.9 \times 10^{21} \text{ cm}^{-2}$ ], while Maddalena has only ~0.7% of its gas above this threshold. Although Maddalena is the more massive cloud, it has fewer young stellar objects (YSOs). In fact, the two clouds follow a power-law relationship described by Lada et al. (2010), in which the number of YSOs,  $N(\text{YSO})$ , increase as a function of mass above 7.3 mag,  $M_{\text{O}}$ , according to  $N(\text{YSO}) \sim (M_{\text{O}})^{0.96}$ .

**Author(s):** Nia Imara<sup>1</sup>

**Institution(s):** 1. *Harvard-Smithsonian Center for Astrophysics*

### 424.02D – Molecular hydrogen emission as a density and temperature indicator

Infrared observations have discovered a variety of objects, including filaments in the Crab Nebula and cool-core clusters of galaxies, where the 1-0 S(1) line is stronger than the infrared H I lines. A variety of processes could be responsible for this emission. Although many complete shock or PDR calculations of emission have been published, we know of no previous simple calculation that shows the emission spectrum and level populations of thermally excited low-density. We present a range of purely thermal collisional simulations, corresponding to constant gas kinetic temperature at different densities. We consider the cases where the collisions affecting  $\text{H}_2$  are predominantly with atomic or molecular hydrogen. The resulting level population (often called “excitation”) diagrams show that excitation temperatures are sometimes lower than the gas kinetic temperature when the density is too low for the level populations to go to LTE. The atomic case goes to LTE at much lower densities than the molecular case due to larger collision rates. At low densities for the  $v=1$  and 2 vibrational manifolds level populations are quasi-thermal, which could be misinterpreted as showing the gas is in LTE at high density. At low densities for the molecular case the level population diagrams are discontinuous between  $v=0$  and 1 vibrational manifolds and between  $v=2$ ,  $J=0$ , 1 and other higher  $J$  levels within the same vibrational manifold. These jumps could be used as density diagnostics. We show how much the  $\text{H}_2$  mass would be underestimated using the 1-0 S(1) line strength if the density is below that required for LTE. We give diagnostic diagrams showing level populations over a range of density and temperature. The density where the level populations are given by a Boltzmann distribution relative to the total molecular abundance (required to get the correct  $\text{H}_2$  mass), is shown for various cases. We discuss the implications of these results for the interpretation of  $\text{H}_2$  observations of the Crab Nebula and filaments in cool-core clusters of galaxies.

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### 424.03 – RAMPS: The Radio Ammonia Mid-Plane Survey

The Radio Ammonia Mid-Plane Survey (RAMPS) is a new 1.3 cm survey of the Galactic plane that will simultaneously image several 23 GHz ammonia lines [ $\text{NH}_3$  (1,1), (2,2), (3,3), (4,4), and (5,5)] and the 22.2 GHz water maser line from  $l = 10^\circ$  to  $40^\circ$  and  $b = -0.5^\circ$  to  $0.5^\circ$ . RAMPS employs the K-band Focal Plane Array receiver on the NRAO Green Bank Telescope. The main goal of RAMPS is to characterize the Galactic population of dense star-forming molecular clumps by measuring the gas temperatures, column densities, radial velocities, and kinematic distances using the ammonia line ratios. I report

results from the survey's first 6.4 square degrees and present large-scale  $\text{NH}_3$  (1,1), (2,2), and (3,3) integrated intensity maps, gas temperature maps, and column density maps. To date over 500 clumps have been identified and characterized. In addition, RAMPS has now detected 619 water maser sites, most of which are detected for the first time. Only 60% of the water masers are associated with detected ammonia emission. We have also discovered a remarkable star forming region with unusually broad  $\text{NH}_3$  lines ( $\Delta V \sim 25 \text{ km/s}$ ) and a very rare  $\text{NH}_3$  (3,3) shock-excited maser. Although located in the Galactic disk, this clump has characteristics usually found in Galactic Center clouds.

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**Institution(s):** 1. *Boston Univ.*

### 424.04 – An HST/COS survey of molecular hydrogen in low-z DLAs/sub-DLAs

Molecular hydrogen ( $\text{H}_2$ ) is the most abundant molecule in the universe. It plays a crucial role in cooling and molecular chemistry of the interstellar medium (ISM). The Lyman- and Werner-bands absorption of  $\text{H}_2$  are detected in 10-20% of high-z Damped Lyman-alpha absorbers (DLAs). Due to the lack of far-UV (FUV) sensitive space based spectrograph in the past,  $\text{H}_2$  has never been studied in low-z DLAs/sub-DLAs systematically. However, the unprecedented FUV sensitivity of the Cosmic Origins Spectrograph (COS) aboard the HST has changed this scenario dramatically. Recently, we have conducted the first survey of  $\text{H}_2$  in low-z DLAs/sub-DLAs in the public HST/COS archive and found that ~50% of them show  $\text{H}_2$  absorption with  $N(\text{H}_2) > 10^{14} \text{ cm}^{-2}$ . The  $\text{H}_2$  incidence rate is, thus, >2 times higher at low-z. We argue that the increase of the cosmic mean metallicity of DLAs/sub-DLAs and the dimming of ambient radiation field due to the decrease of the cosmic star-formation rate density with redshift are responsible for such an enhanced  $\text{H}_2$  detection rate at low-z. Simple photoionization models favor a radiation field much weaker than the mean Galactic ISM field and particle density in the range  $10\text{-}100 \text{ cm}^{-3}$ . The large impact parameters of the identified host-galaxies suggest that the  $\text{H}_2$  bearing gas is not related to star forming disks but stems from self-shielded, tidally stripped or ejected disk-material in the halo or from extended HI disk. Important results of our survey (see 2015MNRAS.448.2840M for details) will be summarized in the talk.

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**Institution(s):** 1. *Inter-University Centre for Astronomy & Astrophysics*, 2. *The Pennsylvania State University*

### 424.05 – Dust grain alignment in IC 63 - $\text{H}_2$ formation enhancement and collisional disalignment

Interstellar dust grain alignment gives rise to polarization from UV to mm wavelengths, allowing the study of the geometry and strength of the magnetic field. Over the last couple of decades observations and theory have led to the establishment of the Radiative Alignment Torque (RAT) mechanism as the leading candidate to explain the effect. With a quantitatively well constrained theory, polarization can be used not only to study the interstellar magnetic field, but also the dust and other environmental parameters. Photo-dissociation Regions (PDRs), with their intense, anisotropic radiation fields, consequent rapid  $\text{H}_2$  formation, and high spatial density-contrast provide a rich environment for such studies. Here we discuss an expanded optical, NIR and mm-wave study (cf. Andersson et al. 2013) of the IC 63 reflection nebula, showing strong  $\text{H}_2$  formation-enhanced alignment and the first direct, empirical, evidence for disalignment due to gas-grain collisions.

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### 424.06 – The Mass Surface Density Distribution of a High-Mass Protocluster forming from an IRDC and

## GMC

We study the probability distribution function (PDF) of mass surface densities of infrared dark cloud (IRDC) G028.36+00.07 and its surrounding giant molecular cloud (GMC). Such PDF analysis has the potential to probe the physical processes that are controlling cloud structure and star formation activity. The chosen IRDC is of particular interest since it has almost 100,000 solar masses within a radius of 8 parsecs, making it one of the most massive, dense molecular structures known and is thus a potential site for the formation of a high-mass, “super star cluster”. We study mass surface densities in two ways. First, we use a combination of NIR, MIR and FIR extinction maps that are able to probe the bulk of the cloud structure that is not yet forming stars. This analysis also shows evidence for flattening of the IR extinction law as mass surface density increases, consistent with increasing grain size and/or growth of ice mantles. Second, we study the FIR and sub-mm dust continuum emission from the cloud, especially utilizing Herschel PACS and SPIRE images. We first subtract off the contribution of the foreground diffuse emission that contaminates these images. Next we examine the effects of background subtraction and choice of dust opacities on the derived mass surface density PDF. The final derived PDFs from both methods are compared, including also with other published studies of this cloud. The implications for theoretical models and simulations of cloud structure, including the role of turbulence and magnetic fields, are discussed.

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## 424.07 – Toward Measuring Galactic Dense Molecular Gas Properties and 3D Distribution with Hi-GAL

The Herschel Space Observatory’s submillimeter dust continuum survey Hi-GAL provides a powerful new dataset for characterizing the structure of the dense interstellar medium of the Milky Way. Hi-GAL observed a 2° wide strip covering the entire 360° of the Galactic plane in broad bands centered at 70, 160, 250, 350, and 500  $\mu\text{m}$ , with angular resolution ranging from 10 to 40 arcseconds. We are adapting a molecular cloud clump-finding algorithm and a distance probability density function distance-determination method developed for the Bolocam Galactic Plane Survey (BGPS) to the Hi-GAL data. Using these methods we expect to generate a database of 105 cloud clumps, derive distance information for roughly half the clumps, and derive precise distances for approximately 20% of them. With five-color photometry and distances, we will measure the cloud clump properties, such as luminosities, physical sizes, and masses, and construct a three-dimensional map of the Milky Way’s dense molecular gas distribution.

The cloud clump properties and the dense gas distribution will provide critical ground truths for comparison to theoretical models of molecular cloud structure formation and galaxy evolution models that seek to emulate spiral galaxies. For example, such models cannot resolve star formation and use prescriptive recipes, such as converting a fixed fraction of interstellar gas to stars at a specified interstellar medium density threshold. The models should be compared to observed dense molecular gas properties and galactic distributions.

As a pilot survey to refine the clump-finding and distance measurement algorithms developed for BGPS, we have identified molecular cloud clumps in six 2° × 2° patches of the Galactic plane, including one in the inner Galaxy along the line of sight through the Molecular Ring and the termination of the Galactic bar and one toward the outer Galaxy. Distances have been derived for the inner Galaxy clumps and compared to Bolocam Galactic Plane Survey results. We present the pilot survey clump catalog, distances, clump properties, and a comparison to BGPS.

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## 424.08 – Hydrogen Sticking on Amorphous

## Water-Ice: A Numerical Study

Gas-grain and gas-phase reactions dominate the formation of molecules in the interstellar medium (ISM). Gas-grain reactions require a substrate on which the reaction is able to occur. The formation of molecular hydrogen ( $\text{H}_2$ ) in the ISM is a prime example of a gas-grain reaction. In these reactions, an atom of hydrogen will strike a surface, adsorb to the surface, interact with the molecular structure of substrate (in this case water), form molecular hydrogen, and then be ejected from the surface. We perform classical molecular dynamics (MD) simulations of hydrogen atoms sticking to an amorphous water-ice surface. This study examines the first step in the process; the sticking of the atom to the substrate. This talk emphasizes the importance of accurately defining a sticking event in calculating sticking probabilities which are used to obtain a reasonable model for  $\text{H}_2$  formation in the ISM. With these sticking probabilities calculated, sticking coefficients are obtained for various ice substrate temperatures and incident H-atom kinetic energies.

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## 425 – The Milky Way, Stellar Populations

### 425.01 – Chronography of the Milky Way’s Halo System with Field Blue Horizontal-Branch Stars

In a pioneering effort, Preston et al. (1991, AJ 375, 121) reported that the colors of blue horizontal-branch (BHB) stars in the halo of the Galaxy shift with distance, from regions near the Galactic center to about 12 kpc away, and interpreted this as a correlated variation in the ages of halo stars, from older to younger, spanning a range of a few Gyrs. We have applied this approach to a sample of some 4700 spectroscopically confirmed BHB stars selected from the Sloan Digital Sky Survey to produce the first “chronographic map” of the halo of the Galaxy.

We demonstrate that the mean de-reddened g-r color increases outward in the Galaxy from -0.22 to -0.08 (over a color window spanning [-0.3:0.0]) from regions close to the Galactic center to ~40 kpc, independent of the metallicity of the stars. Models of the expected shift in the color of the field BHB stars based on modern stellar evolutionary codes confirm that this color gradient can be associated with an age difference of roughly 2-2.5 Gyrs, with the oldest stars concentrated in the central ~15 kpc of the Galaxy. Within this central region, which we refer to as the Ancient Chronographic Sphere (ACS), the age difference spans a mean color range of about 0.05 mag (~0.8 Gyrs). Interestingly, the ACS extends far enough to include the Solar Neighborhood, suggesting that ancient metal-poor stars should be readily detectable in the vicinity of the Sun. Furthermore, we show that chronographic maps can be used to identify individual substructures, such as the Sagittarius Stream, and overdensities in the direction of Virgo and Monoceros, based on the observed contrast in their mean BHB colors with respect to the foreground/background field population.

We acknowledge partial support from the grant PHY 14-30152; Physics Frontier Center/JINA Center for the Evolution of the Elements (JINA-CEE), awarded by the US National Science Foundation.

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### 425.02D – At the interface of the disk and halo: A lesson from APOGEE and other large spectroscopic surveys

One of the primary goals of the large spectroscopic surveys is to

study the chemo-dynamical structure of the Galaxy. In particular, I am interested in exploring the Galactic disc-halo transition region within  $-1.20 < [\text{Fe}/\text{H}] < -0.55$  as a means to study chemical difference (and similarities) between these components. I discuss here a chemical abundance distribution study in 11  $\alpha$ , odd-Z, even-Z, light, and Fe-peak elements of approximately 3200 intermediate-metallicity giant stars from APOGEE survey. Results indicated the following: (1) the  $\alpha$ -poor halo subgroup is chemically distinct from the  $\alpha$ -rich halo; (2) the thick disc and halo are not chemically distinct in all elements indicating a smooth transition in chemical spaces; (3) a subsample of the  $\alpha$ -poor stars at metallicities as low as  $[\text{Fe}/\text{H}] < -0.85$  dex are chemically and dynamically consistent with the thin disc indicating that it may extend to lower metallicities than previously thought; and (4) the locations of the most metal-poor thin disc stars are consistent with a negative radial metallicity gradient. Finally, I discuss previous and ongoing work with other large surveys including Gaia-ESO, RAVE and SEGUE and how they can inform our understanding of Galactic structure in the Gaia era.

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**Institution(s):** 1. Institute of Astronomy, Cambridge

#### 425.03 – Chemodynamics of the Milky Way Disk with Gaia-ESO

The chemodynamic structure of the Milky Way disk provides a window into the evolutionary history of the Galaxy and is a key constraint for models of galaxy formation and evolution. We present results on the chemical and kinematic structure of the Milky Way disk using a sample of more than 20,000 stars from the fourth internal data release (iDR4) of the Gaia-ESO Survey. The Gaia-ESO Survey is a high-resolution spectroscopic survey of the Milky Way disk, bulge, and halo, which provides precision atmospheric parameters ( $T_{\text{eff}}$ ,  $\log g$ ,  $[\text{Fe}/\text{H}]$ ,  $[\alpha/\text{Fe}]$ ) for each star observed. Combined with proper motions from PPMXL, we probe the chemodynamic structure of the Milky Way disk across a range of radii ( $3 < R < 13$  kpc) and heights above the plane ( $0 < |z| < 3$  kpc).

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**Contributing team(s):** Gaia-ESO Survey Consortium

#### 425.04 – Spectroscopic determination of masses (and implied ages) for red giants

The mass of a star is arguably its most fundamental parameter and for red giant stars it implies a stellar evolution age. Stellar masses and ages have never been derived directly from spectra of red giants. However, using the APOGEE Kepler sample of stars, (the APOKASC sample), with high-quality spectra and asteroseismic masses, we can build a data-driven spectral model using THE CANNON (arXiv:1501.07604) to infer stellar mass and therefore age from stellar spectra. We determine stellar masses to 0.07 dex from APOGEE DR12 spectra of red giants; these imply age estimates accurate to 0.2 dex (40 percent). THE CANNON constrains the ages foremost from spectral regions with particular absorption lines, elements whose surface abundances reflect mass-dependent dredge-up. We deliver an unprecedented catalog of 85,000 giants (including 20,000 red-clump stars) with mass and age estimates, spanning the entire disk (from the Galactic center to  $R \sim 20$  kpc). Such stellar age constraints across the Milky Way open up new avenues in Galactic archeology.

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**Institution(s):** 1. MIT, 2. MPA, 3. NYU

#### 425.05D – Determining Ages of APOGEE Giants with Known Distances

We present a sample of 705 local ( $d < 400$  pc) red giant stars observed using the New Mexico State University 1m telescope with the SDSS-III APOGEE spectrograph, for which we estimate stellar

ages and the age distribution from the high-resolution spectroscopic stellar parameters and accurate distance measurements from Hipparcos. The high-resolution ( $R \sim 23,000$ ), near infrared ( $H$ -band,  $1.5\text{--}1.7\ \mu\text{m}$ ) APOGEE spectra provide measurements of the stellar atmospheric parameters (temperature, surface gravity,  $[\text{M}/\text{H}]$ , and  $[\alpha/\text{M}]$ ). Due to the smaller uncertainties in surface gravity possible with high-resolution spectra and accurate Hipparcos distance measurements, we are able to calculate the stellar masses to within 40 %. For red giants, the relatively rapid evolution of stars up the red giant branch allows the age to be constrained based on the mass. We examine methods of estimating age using both the mass-age relation directly and a Bayesian isochrone matching of measured parameters, assuming a constant SFH. To improve the prior on the SFH, we use a hierarchical modeling approach to constrain the parameters of a model SFH from the age probability distribution functions of the data. The results of an  $\alpha$ -dependent Gaussian SFH model shows a clear relation between age and  $[\alpha/\text{M}]$  at all ages. Using this SFH model as the prior for an empirical Bayesian analysis, we construct a full age probability distribution function and determine ages for individual stars. The age-metallicity relation is flat, with a slight decrease in  $[\text{M}/\text{H}]$  at the oldest ages and a  $\sim 0.5$  dex spread in metallicity. For stars with ages  $> 1$  Gyr we find a smaller spread, consistent with radial migration having a smaller effect on these young stars than on the older stars. This method of estimating ages of red giants is developed with the intent of estimating ages for the much larger sample of APOGEE survey giants that will have parallax measurements from Gaia.

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**Contributing team(s):** The APOGEE Team

#### 425.06 – Chemo-dynamics in the Heart of the Galactic Bulge

Galactic bulges contain dense, information-rich fossil records of star formation and galaxy assembly, encoded in the chemo-dynamical patterns of the stellar populations. The Milky Way's bulge is the only one in which we can resolve the chemistry and kinematics of individual stars in those populations, but we still do not fully understand the formation and subsequent evolution of the bulge. The SDSS APOGEE survey affords the opportunity to characterize in detail large numbers of stars throughout the Milky Way's entire bulge. We present an analysis of the chemo-dynamical patterns observed in the full set of  $\sim 15,000$  inner Galaxy stars from APOGEE-1, and compare these patterns to extragalactic bulges and to evolutionary models that include both chemistry and kinematics for the stellar populations. We discuss implications for disentangling contributions from different bulge formation scenarios.

**Author(s):** Gail Zasowski<sup>2</sup>, Melissa Ness<sup>3</sup>, Ana García Pérez<sup>1</sup>, Jennifer Johnson<sup>4</sup>

**Institution(s):** 1. IAC, 2. Johns Hopkins University, 3. MPA, 4. The Ohio State University

#### 425.07 – Stellar Populations in the Kepler and K2 fields: APOGEE-KASC Collaboration

The age distribution, both absolute and relative, of stars throughout the Milky Way reveals the history of star formation and migration and is a key constraint on galaxy formation models. The combination of spectroscopic and asteroseismic information for stars observed by both the APOGEE survey and the Kepler/K2 missions provides ages for field red giants along many lines of sight through the Galaxy. The fundamental stellar properties derived from these data are used to test theories of the formation of the thin and thick disks, the role of radial migration, and the timescales for nucleosynthesis in our Galaxy. We also explore correlations between asteroseismic mass and spectroscopic abundances, with a view towards age calibrations for large current and future spectroscopic surveys.

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**Contributing team(s):** APOKASC Collaboration

## 427 – Instrumentation: Exoplanets, Adaptive Optics, Transients

### 427.01D – Photonic systems for high precision radial velocity measurements

I will discuss new instrumentation and techniques designed to maximize the Doppler radial velocity (RV) measurement precision of next generation exoplanet discovery instruments. These systems include a novel wavelength calibration device based on an all-fiber fabry-perot interferometer, a compact and efficient optical fiber image scrambler based on a single high-index ball lens, and a unique optical fiber mode mixer. These systems have been developed specifically to overcome three technological hurdles that have classically hindered high precision RV measurements in both the optical and near-infrared (NIR), namely: lack of available wavelength calibration sources, inadequate decoupling of the spectrograph from variable telescope illumination, and speckle-induced noise due to mode interference in optical fibers. The instrumentation presented here will be applied to the Habitable-zone Planet Finder, a NIR RV instrument designed to detect rocky planets orbiting in the habitable zones of nearby M-dwarfs, and represents a critical technological step towards the detection of potentially habitable Earth-like planets. While primarily focused in the NIR, many of these systems will be adapted to future optical RV instruments as well, such as NASA's new Extreme Precision Doppler Spectrometer for the WIYN telescope.

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**Institution(s):** 1. *Pennsylvania State University*

### 427.02 – The CHARA Array Adaptive Optics Program

The CHARA array is an optical/near infrared interferometer consisting of six 1-meter diameter telescopes the longest baseline of which is 331 meters. With sub-millisecond angular resolution, the CHARA array is able to spatially resolve nearby stellar systems to reveal the detailed structures. To improve the sensitivity and scientific throughput, the CHARA array was funded by NSF-ATI in 2011, and by NSF-MRI in 2015, for an upgrade of adaptive optics (AO) systems to all six telescopes. The initial grant covers Phase I of the adaptive optics system, which includes an on-telescope Wavefront Sensor and non-common-path (NCP) error correction. The WFS use a fairly standard Shack-Hartman design and will initially close the tip tilt servo and log wavefront errors for use in data reduction and calibration. The second grant provides the funding for deformable mirrors for each telescope which will be used closed loop to remove atmospheric aberrations from the beams. There are then over twenty reflections after the WFS at the telescopes that bring the light several hundred meters into the beam combining laboratory. Some of these, including the delay line and beam reducing optics, are powered elements, and some of them, in particular the delay lines and telescope Coude optics, are continually moving. This means that the NCP problems in an interferometer are much greater than those found in more standard telescope systems. A second, slow AO system is required in the laboratory to correct for these NCP errors. We will briefly describe the AO system, and it's current status, as well as discuss the new science enabled by the system with a focus on our YSO program.

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**Institution(s):** 1. *Australian National University*, 2. *Georgia State Univ.*, 3. *NOAO*, 4. *University of Michigan*, 5. *University of Nice*, 6. *University of Sydney*

### 427.03 – Robo-AO KP: A new era in robotic adaptive optics

Robo-AO is the first and only fully automated adaptive optics laser guide star AO instrument. It was developed as an instrument for 1-3m robotic telescopes, in order to take advantage of their availability to pursue large survey programs and target of

opportunity observations that aren't possible with other AO systems. Robo-AO is currently the most efficient AO system in existence, and it can achieve an observation rate of 20+ science targets per hour. In more than three years of operations at Palomar Observatory, it has been quite successful, producing technology that is being adapted by other AO systems and robotic telescope projects, as well as several high impact scientific publications. Now, Robo-AO has been selected to take over operation of the Kitt Peak National Observatory 2.1m telescope. This will give Robo-AO KP the opportunity to pursue multiple science programs consisting of several thousand targets each during the three years it will be on the telescope. One-sixth of the observing time will be allocated to the US community through the NOAO TAC process. This presentation will discuss the process adapting Robo-AO to the KPNO 2.1m telescope, the plans for integration and initial operations, and the science operations and programs to be pursued.

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### 427.04D – Fast-response optical and near-infrared GRB science with RATIR and RIMAS

As the Universe's most luminous transient events, long gamma-ray bursts (GRBs) are observed at cosmological distances. The afterglow emission generated by the burst's interaction with the surrounding medium presents the opportunity to study the local environment, as well as intervening systems. The transient nature of these events requires observations starting within minutes of the GRB to maximize the scientific opportunities.

This dissertation work comprises efforts to advance the field with a new instrument, the Rapid Infrared Imager and Spectrograph (RIMAS). The optical design is complicated by the broad band coverage (0.97 to 2.39 microns) and the necessity of transmissive optics due to space and weight limitations on the telescope. Additionally, the entire optical system must be cooled to cryogenic temperatures to decrease the background from thermal emission. The completed instrument will be permanently installed on Lowell Observatory's new 4.3 meter Discovery Channel Telescope (DCT) located in Happy Jack, Arizona. The fast slew time of the telescope, combined with the instrument's ability to image in two bands simultaneously and switch to spectroscopic configurations in under a minute will allow observers to obtain photometric data within minutes and spectra within ~ ten minutes.

In addition to instrumentation work on RIMAS's optics, early time photometric light curves have been studied primarily using data from the Reionization and Transients Infrared/Optical Project (RATIR). Early time photometric data in six optical and near-infrared (NIR) bands has allowed a study of color evolution in the early to late time SEDs. This study probes possible impacts of the GRB on the local medium as well as intrinsic changes in the afterglow emission.

This work is made possible by the RATIR and RIMAS collaborations as well as financial support by the NSF.

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**Contributing team(s):** RIMAS collaboration, RATIR project team

### 427.05 – Algolcam: Low Cost Sky Scanning with Modern Technology

Low cost DSLR cameras running under computer control offer good sensitivity, high resolution, small size, and the convenience of digital image handling. Recent developments in small single board computers have pushed the performance to cost and size ratio to unprecedented values, with the further advantage of very low power consumption. Yet a third technological development is motor control electronics which is easily integrated with the computer to make an automated mount, which in our case is custom built, but with similar

mounts available commercially. Testing of such a system under a clear plastic dome at our auroral observatory was so successful that we have developed a weatherproof housing allowing use during the long, cold, and clear winter nights at northerly latitudes in Canada. The main advantage of this housing should be improved image quality as compared to operation through clear plastic. We have improved the driving software to include the ability to self-calibrate pointing through the web API of astrometry.net, and data can be reduced automatically through command line use of the Muniwin program. The mount offers slew in declination and RA, and tracking at sidereal or other rates in RA. Our previous tests with a Nikon D5100 with standard lenses in the focal length range 50-200 mm, operating at f/4 to f/5, allowed detection of 12<sup>th</sup> magnitude stars with 30 second exposure under very dark skies. At 85 mm focal length, a field of 15° by 10° is imaged with 4928 by 3264 color pixels, and we have adopted an 85 mm fixed focal length f/1.4 lens (as used by Project Panoptes), which we expect will give a limited magnitude approaching 15. With a large field of view, deep limiting magnitude, low cost, and ease of construction and use, we feel that the Algotcam offers great possibilities in monitoring and finding changes in the sky. We have already applied it to variable star light curves, and with a suitable pipeline for detection of moving or varying objects, it offers great potential for analysis and discovery. The use of low cost cutting edge technology makes Algotcam particularly interesting for enhancing the advanced undergraduate learning experience in astronomy.

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**Institution(s):** 1. Athabasca University, 2. University of Alberta

#### 427.06 – The Rapid Transient Surveyor

The next decade of astronomy will be dominated by large area surveys (see the detailed discussion in the Astro-2010 Decadal survey and NRC's recent OIR System Report). Ground-based optical transient surveys, e.g., LSST, ZTF and ATLAS and space-based exoplanet, supernova, and lensing surveys such as TESS and WFIRST will join the Gaia all-sky astrometric survey in producing a flood of data that will enable leaps in our understanding of the universe. There is a critical need for further characterization of these discoveries through high angular resolution images, deeper images, spectra, or observations at different cadences or periods than the main surveys. Such follow-up characterization must be well matched to the particular surveys, and requires sufficient additional observing resources and time to cover the extensive number of targets. We describe plans for the Rapid Transient Surveyor (RTS), a permanently mounted, rapid-response, high-cadence facility for follow-up characterization of transient objects on the U. of Hawai'i 2.2-m telescope on Maunakea. RTS will comprise an improved robotic laser adaptive optics system, based on the prototype Robo-AO system (formerly at the Palomar 1.5-m and now at the Kitt Peak 2.2-m telescope), with simultaneous visible and near-infrared imagers as well as a near-infrared integral field spectrograph (R~100,  $\lambda = 850 - 1830$  nm, 0.15" spaxels, 8.7"×6.0" FoV). RTS will achieve an acuity of ~0.07" in visible wavelengths and < 0.16" in the near infrared leading to an increase of the infrared point-source sensitivity against the sky background by a factor of ~9, crucial for efficient near-infrared spectroscopy. RTS will allow us to map the dark matter distribution in the  $z < 0.1$  local universe with ten times better accuracy and precision than previous experiments. ATLAS will discover several thousand SNIae per year, measuring SNIa peak brightness, and decline rates, while RTS will measure reddening by dust, confirm SN type and confirm redshifts of the host galaxies. This unique combination of automated detection and characterization of astrophysical transients during a sustained observing campaign will yield the necessary statistics to precisely map dark matter in the local universe.

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## 430 – Extrasolar Planets and the Solar System Late Poster Session

### 430.01 – Asteroidal companions in the visible: HST data

We present a reanalysis of HST images of five asteroids with known companions (45 Eugenia, 87 Sylvia, 93 Minerva, 107 Camilla, 121 Hermione). It is remarkable that all of these companion bodies are much redder in the visible region than their primary bodies. Storrs et al. (2009, BAAS vol. 41, no. 4, p 189) attributed this to space weathering, however, all of these bodies belong to dark C- or X-type groups. Current modeling of space weathering effects are limited to bright asteroids (e.g. Cloutis et al., Icarus 252, pp. 39-82, 2015) and show little change on the scale reported here. We suggest that the interaction of dark, possibly organic-rich surfaces with the solar wind produces reddening on a much greater scale than is observed in bright, silica-rich surfaces, and that this effect is easily reset by collisions. Thus, while both the parent and companion object accumulate the effects, the parent is much more likely to be "reset" by small collisions than the companion, due to the differences in their cross-sections.

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**Institution(s):** 1. NASA HQ, 2. Planetary Science Institute, 3. Towson Univ., 4. U. of N. Dakota

### 430.02 – The Albedo Distribution of Near Earth Asteroids

The cryogenic WISE mission in 2010 was extremely sensitive to asteroids and not biased against detecting dark objects. Mainzer et al (2011, ApJ, 743, 156) fit the distribution of albedos of the 428 NEAs observed by WISE with a double Gaussian function with 5 parameters.

This note describes a 3 parameter function that fits as well as the double Gaussian: a sum of two Rayleigh distributions. The Rayleigh distribution is zero for negative values, and follows  $f(x) = x \exp[-x^2/(2\sigma^2)]/\sigma^2$  for positive  $x$ . The peak value is at  $x=\sigma$ , so the position and width are tied together. The three parameters are the fraction of the objects in the dark population, the position of the dark peak, and the position of the normal peak. 25.1% of the NEAs observed by WISE are in a very dark population peaking at  $p_V = 0.03$ , while the other 74.9% of the NEAs seen by WISE are in a moderately dark population peaking at  $p_V = 0.167$ .

A consequence of this bimodal distribution is that the Congressional mandate to find 90% of all NEOs larger than 140 m diameter cannot be satisfied by surveying to  $H=22$  mag, since a 140 m diameter asteroid at the very dark peak has  $H=23.7$  mag, and more than 10% of NEAs are darker than  $p_V = 0.03$ .

**Author(s):** Edward L. Wright<sup>1</sup>  
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### 430.03 – The Las Cumbres Observatory (LCOGT) Network for NEO and Solar System Science

Las Cumbres Observatory Global Telescope Network (LCOGT) has deployed a homogeneous telescope network of nine 1-meter telescopes to four locations in the northern and southern hemispheres, with a planned network size of twelve 1-meter telescopes at 6 locations. This 1-meter network is in addition to the two 2-meter Faulkes Telescopes that have been operating since 2005. This network is very versatile and is designed to respond rapidly to target of opportunity events and also to perform long term monitoring of slowly changing astronomical phenomena. The global coverage of the network and the apertures of telescope available make LCOGT ideal for follow-up and characterization of Solar System objects e.g. Near-Earth Objects (NEOs), comets, asteroids and Kuiper Belt Objects and also for the discovery of new objects.

LCOGT has completed the first phase of the deployment with the installation and commissioning of the nine 1-meter telescopes at

McDonald Observatory (Texas), Cerro Tololo (Chile), SAAO (South Africa) and Siding Spring Observatory (Australia). The telescope network has been fully operational since 2014 May, and observations are being executed remotely and robotically. Future expansion to sites in the Canary Islands and Tibet are planned for 2016-2017.

I will describe the Solar System science research that is being carried out using the LCOGT Network with highlights from the LCOGT NEO Follow-up Network, long-term monitoring of the Rosetta spacecraft target comet 67P and comet C/2013 A1 (Siding Spring) and work on Kuiper Belt Object occultation targets, including Pluto.

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#### 430.04 – Low Order Wavefront Sensing and Control for WFIRST-AFTA Coronagraph

NASA's WFIRST-AFTA Coronagraph will be capable of directly imaging and spectrally characterizing giant exoplanets similar to Neptune and Jupiter, and possibly even super-Earths, around nearby stars. To maintain the required coronagraph performance in a realistic space environment, a Low Order Wavefront Sensing and Control (LOWFS/C) subsystem is necessary. The LOWFS/C will use the rejected stellar light to sense and suppress the telescope pointing drift and jitter as well as low order wavefront errors due to the changes in thermal loading of the telescope and the rest of the observatory. The measured wavefront information will also be used for the coronagraph data post-processing (PSF subtraction) needed to further remove the speckle field and enhance the contrast. The LOWFS/C uses a Zernike phase contrast wavefront sensor with the phase shifting disk combined with the stellar light rejecting occulting mask, a key concept to minimize the non-common path error. Developed as a part of the Dynamic High Contrast Imaging Testbed (DHCIT), the LOWFS/C subsystem also consists of an Optical Telescope Assembly (OTA) simulator to generate the realistic wavefront error and line-of-sight (LoS) drift and jitter from WFIRST-AFTA telescope's vibration and thermal drift. The entire LOWFS/C subsystem have been integrated, calibrated, and tested in a dedicated LOWFS/C testbed. The test results have shown that the Zernike WFS have line-of-sight (LoS) tilt sensitivity better than 0.2 milli-arcsec and LoS post correct residual better than 0.5 milli-arcsec with the presence of the WFIRST-AFTA like LoS drift and jitter (14 milli-arcsec). In this poster we will describe the LOWFS/C subsystem and present the LOWFS/C performance test results as well as the progress of integration of LOWFS/C into the DHCIT.

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#### 430.05 – Kepler AutoRegressive Planet Search

The Kepler AutoRegressive Planet Search (KARPS) project uses statistical methodology associated with autoregressive (AR) processes to model Kepler lightcurves in order to improve exoplanet transit detection in systems with high stellar variability. We also introduce a planet-search algorithm to detect transits in time-series residuals after application of the AR models. One of the main obstacles in detecting faint planetary transits is the intrinsic stellar variability of the host star. The variability displayed by many stars may have autoregressive properties, wherein later flux values are correlated with previous ones in some manner. Our analysis procedure consisting of three steps: pre-processing of the data to remove discontinuities, gaps and outliers; AR-type model selection and fitting; and transit signal search of the residuals using a new Transit Comb Filter (TCF) that replaces traditional box-finding algorithms. The analysis procedures of the project are applied to a portion of the publicly available Kepler light curve data for the full 4-year mission duration. Tests of the methods have been made on a subset of Kepler Objects of Interest (KOI) systems, classified both as planetary 'candidates' and 'false positives' by the Kepler Team, as well as a random sample of unclassified systems. We find that the ARMA-type modeling successfully reduces the stellar variability, by a factor of 10 or more in active stars and by smaller factors in more quiescent stars. A typical quiescent Kepler star has an interquartile

range (IQR) of  $\sim 10$  e-/sec, which may improve slightly after modeling, while those with IQR ranging from 20 to 50 e-/sec, have improvements from 20% up to 70%. High activity stars (IQR exceeding 100) markedly improve. A periodogram based on the TCF is constructed to concentrate the signal of these periodic spikes. When a periodic transit is found, the model is displayed on a standard period-folded averaged light curve. Our findings to date on real-data tests of the KARPS methodology will be discussed including confirmation of some Kepler Team 'candidate' planets. We also present cases of new possible planetary signals.

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**Institution(s):** 1. Pennsylvania State University

#### 430.06 – Imaging exoplanets with the WFIRST Coronagraph: A background check of high priority targets

The WFIRST coronagraph is envisioned to achieve a limiting contrast for exoplanet detection of  $10^{-9}$ . This revolutionary mission will enable the direct detection of known and newly discovered exoplanets amongst the nearest stars, from super-Earths to giants. However, at this contrast the coronagraph will essentially see a Hubble Ultra Deep Field (HUDF) in every image. For targets near the Galactic Plane on the sky, distant stars with varying levels of extinction and reddening will dominate the background. Away from the plane, we then expect extragalactic sources to dominate. What impact will these background sources have on the WFIRST exoplanet imaging program? How can we efficiently distinguish background sources from exoplanet targets in a single image? To have a comprehensive understanding of the distribution of background sources across the sky, we have used the HUDF to model extragalactic faint sources, and "Trilegal" simulations to model galactic background sources. Through some preliminary color and point source analysis, we offer a statistical estimation of expected background contamination and the probability of false positive background sources. In this poster we show plots relating number of extragalactic sources versus magnitude in HUDF and "Trilegal" simulation. We present a table of high priority WFIRST exoplanet imaging targets, with an assessment of the "background threat" due to background stars, galaxies, and binary companions.

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**Institution(s):** 1. JPL, 2. SETI Institute, 3. University of Wisconsin - Madison

#### 430.07 – The Properties of Exomoons Around the Habitable Zone Planets, Kepler 22b and HD160691b

As part of a larger study to understand the formation, evolution, and stability of exoplanet satellites, we have examined the Kepler 22 and HD160691 systems. Habitable zone planets (Kopparapu et al. 2013) are found in each system, with Kepler 22b at 0.85 AU and HD160691b at 1.5 AU. While these planets may be habitable, systems of satellites also hold the potential of supporting life.

A series of N-body simulations were performed to examine the most stable configuration of moons orbiting each planet. A moonlet disk was designed to span 10 – 80% of the planet's Hill sphere (Ksting et al. 1993). The 100 bodies ( $m_{\text{disk}}/m_{\text{planet}} = 2 \times 10^{-4}$ ) within the disk were randomly placed around each planet. Simulations were run for 500 kyrs, with the star, planets, and moonlets allowed to gravitationally evolve.

The Kepler 22b system was able to retain three to four moons in 96% of the simulations, while the HD160691b systems had a stable pair of moons in 73% of the simulations. The remaining simulations produced systems with moons on highly eccentric orbits.

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**Institution(s):** 1. Rollins College

#### 430.08 – Using Brigham Young University's Orson Pratt Observatory 16" telescope to identify possible

## **transiting planets discovered by the Kilodegree Extremely Little Telescope**

We use a 16" telescope on the Brigham Young University (BYU) campus to follow-up on the Kilodegree Extremely Little Telescope (KELT) survey to identify possible transiting planets. KELT is an all sky survey that monitors the same areas of the sky throughout the year to identify stars that exhibit a change in brightness. Objects found to exhibit a variation in brightness similar to predicted models of transiting planets are sent to the ground-based follow-up team where we get high precision differential photometry to determine whether or not a transit is occurring and if the transiting object is a planet or companion star. If a planetary transit is found, the object is forwarded for radial velocity follow-up and could eventually be published as a KELT planet. In this poster we present light curves from possible planets we have identified as well as eclipsing binary systems and non-detections. We will highlight features of our telescope and camera and the basic steps for data reduction and analysis.

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**Contributing team(s):** KELT-North

## **430.09 – The Case for Exoplanet Surveys at Radio Wavelengths**

Motivated by the bright and phenomenologically-rich auroral radio bursts observed in the Solar System, astronomers have been attempting to detect exoplanets at radio wavelengths since before the discovery of 51 Peg b. While the first efforts were admittedly optimistic, long-wavelength radio arrays are finally achieving sensitivities comparable to the expected signal, and the pace of investment has been quickening as groups compete to make the first conclusive detection of radio emission from an exoplanet. I describe current survey efforts and their potential payoff: radio observations can yield measurements of otherwise inaccessible quantities such as rotation periods and magnetic moments, the latter being particularly relevant to habitability and star/planet interactions. I argue that the under-construction Hydrogen Epoch of Reionization Array, HERA, will be a particularly powerful instrument in these studies.

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**Institution(s):** 1. Harvard-Smithsonian Center for Astrophysics

## **430.10 – Dispatch Scheduling to Maximize Exoplanet Detection**

MINERVA is a dedicated exoplanet detection telescope array using radial velocity measurements of nearby stars to detect planets. MINERVA will be a completely robotic facility, with a goal of maximizing the number of exoplanets detected. MINERVA requires a unique application of queue scheduling due to its automated nature and the requirement of high cadence observations. A dispatch scheduling algorithm is employed to create a dynamic and flexible selector of targets to observe, in which stars are chosen by assigning values through a weighting function. I designed and have begun testing a simulation which implements the functions of a dispatch scheduler and records observations based on target selections through the same principles that will be used at the commissioned site. These results will be used in a larger simulation that incorporates weather, planet occurrence statistics, and stellar noise to test the planet detection capabilities of MINERVA. This will be used to heuristically determine an optimal observing strategy for the MINERVA project.

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**Contributing team(s):** MINERVA

## **430.11 – Exploring Hot Exoplanet Atmospheres with JWST/NIRSpec and a Hybrid Version of NEMESIS**

Understanding the formation environments and evolution scenarios of hot Jupiters demands robust measures for constraining their atmospheric physical properties and transit observations at unprecedented resolutions. Here we have utilized a combination of two different approaches, Optimal Estimation (OE) and Markov

Chain Monte Carlo (MCMC), as part of the extensively validated NEMESIS atmospheric retrieval code, to infer pressure-temperature (P-T) profiles & gas mixing ratios (VMR) of H<sub>2</sub>O, CO<sub>2</sub>, CH<sub>4</sub> and CO, from a series of tests conducted on JWST/NIRSpec simulations of the dayside thermal emission spectra (secondary eclipse) of H<sub>2</sub>-dominated hot-Jupiter candidates. To keep the number of parameters low and henceforth retrieve more plausible profile shapes, we have used a parametrized form of the temperature profile based upon the analytic radiative equilibrium derivation in Guillot et al. 2010. For the purpose of testing and validation, we also show some preliminary work on published dataset from the Hubble Space Telescope (HST) and Spitzer missions. Finally, high-temperature (T > 1000K) spectroscopic line lists are slowly but continually being improved by the atmospheric retrieval community. Since this carries the potential of impacting hot Jupiter atmospheric models quite significantly, we compare results from different databases.

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## **430.12 – Characterization of Mid-Type M Dwarfs in the Kepler Field**

The planet occurrence rate has been found to increase with decreasing stellar mass (later spectral types) in the original Kepler field, and one out of four M dwarfs are expected to host Earth-sized planets within their habitable zones. M dwarf systems are, therefore, our most promising targets in the search for exoplanets. Yet the identification and characterization of M dwarfs in the Kepler field was accomplished using photometry alone and unfortunately this method provides large uncertainties for late-type stars. Notably absent from planet occurrence calculations are single planet mid-type M dwarfs (~M<sub>2</sub>-M<sub>6</sub>). In order to make an accurate calculation of the planet occurrence rate around mid-type M dwarfs, we need to constrain stellar radii and masses which depend on other stellar parameters (e.g. temperature and metallicity). We have identified 559 probable mid-type M dwarfs using photometric color selection criteria and have started to gather spectra of these objects in order to better constrain stellar properties and refine planet occurrence rates for this population. Here we outline the methods we are using for stellar classification and characterization and present some results from our initial data.

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## **431 – Star Formation and Young Stars Late Poster Session**

### **431.01 – A survey of 44-GHz Class I methanol masers toward High Mass Protostellar Objects**

We present preliminary results of 44-GHz Class I methanol maser observations made with the Very Large Array toward a sample of 55 High Mass Protostellar Objects. We found a 44% detection rate of methanol maser emission. We present a statistical description of our results, along with a comparison of the location of the 44-GHz masers with respect to shocked gas, traced by Extended Green Objects seen in the Spitzer/IRAC bands.

**Author(s):** Carolina Berenice Rodríguez Garza<sup>1</sup>, Stan Kurtz<sup>1</sup>  
**Institution(s):** 1. Instituto de Radioastronomía y Astrofísica, UNAM

### **431.02 – The origin of the scatter of the star forming main sequence at z=0**

We investigate the origin of the dispersion in the relationship between star formation rate (SFR) and stellar mass, known as the star forming main sequence (SFMS). Our study includes predictions from a state-of-the-art semi-analytic model (SAM) as well as

observations from the COLDGASS, Bluedisk, and GAMA surveys. Using a simple toy model we demonstrate that, in the absence of a correlation between gas fraction and galaxy size, we would expect more compact disks to live 'high' on the SFMS, and vice versa, due to the observational Kennicutt relation. We demonstrate that this correlation is not seen in the observations, nor is it predicted by the SAM. We find in both the model and the observations that extended disks have a higher fraction of their baryonic mass in total cold gas and in HI and  $\text{H}_2$  gas separately, offsetting the dependence of SFR on disk size. We investigate the origin of the gas fraction-size correlation in the SAMs, and find that it is connected with the rate of cosmological accretion of gas from the intergalactic medium.

**Author(s):** Clare Shanahan<sup>2</sup>, Rachel S. Somerville<sup>2</sup>, Amelie Saintonge<sup>3</sup>, Mei-Ling Huang<sup>1</sup>

**Institution(s):** 1. Max-Planck Institute for Astrophysics, 2. Rutgers University, 3. University College London

### 431.03 – Resolved Companions of Cepheids as Seen by HST and XMM

We have conducted a survey of 70 classical Cepheids with the Hubble Wide Field Camera3 (WFC3) to identify possible resolved companions. Data cover the range of 0.3" to 20" which typically corresponds to 200 AU to 0.1 pc. At present only possible companions greater than 5" from the Cepheid are discussed, since closer companions require a sophisticated point spread correction for the light of the much brighter Cepheid. We have followed up a subset of the possible resolved companions with XMM observations to determine whether they are young (X-ray active) enough to be physical companions of the Cepheids. We estimate that 4% of the Cepheids have a physical resolved companion, with the widest having a separation of 4000 AU. The one wider young star is in the field of S Nor, but since it is a cluster member, the companion is not assumed to be gravitationally bound to the Cepheid.

**Author(s):** Nancy Remage Evans<sup>3</sup>, Howard E. Bond<sup>2</sup>, Gail Schaefer<sup>1</sup>, Brian D. Mason<sup>4</sup>, Evan Tingle<sup>3</sup>, Margarita Karovska<sup>3</sup>, Ignazio Pillitteri<sup>3</sup>, Scott J. Wolk<sup>3</sup>, Edward F. Guinan<sup>5</sup>, Scott G. Engle<sup>5</sup>

**Institution(s):** 1. Georgia State University, 2. PSU, 3. SAO, 4. US Naval Obs., 5. Villanova

### 431.04 – Characterizing the thermal distributions of warm molecular hydrogen in protoplanetary disks

Probing the surviving molecular gas within the inner regions of protoplanetary disks (PPDs) around T Tauri stars (1 – 10 Myr) provides insight into the conditions in which planet formation and migration occurs while the gas disk is still present. Recent studies done by Hoadley et al. 2015 and Banzatti & Pontopodan 2015 suggest that gas in the inner disks of PPDs appear to "respond" to the loss of small dust grains with evolving PPD stage, and IR-CO emission may either be thermally or photo-excited by stellar UV radiation, depending on PPD evolutionary stage. Because far-UV H<sub>2</sub> emission lines are dominantly photo-excited by stellar HI-Lyman alpha photons, we observe H<sub>2</sub> absorption features against the stellar Lyman alpha wings in a large sample of PPDs at various evolutionary stages. We aim to characterize whether the inner disk H<sub>2</sub> environment is in thermal equilibrium at various stages of PPD evolution. We use a sophisticated first-principles approach to fitting multiple absorption features along the red- and blue-wings of the observed stellar Lyman alpha profiles to extract column density estimates of H<sub>2</sub> along the line of sight to the target. We find that the high kinetic energy H<sub>2</sub> observed in absorption against the LyA wing may be described as a part of the thermal distribution with high kinetic temperature – a potential indication of an inner disk molecular hazy "envelope" around the cooler bulk disk. Ongoing research may help determine the state of the gas and whether it evolves with disk evolutionary stage.

**Author(s):** Keri Hoadley<sup>1</sup>, Kevin France<sup>1</sup>

**Institution(s):** 1. University of Colorado - Boulder

### 431.05 – Photo-reverberation Mapping of a Protoplanetary Accretion Disk around a T Tauri Star

Theoretical models and spectroscopic observations of newborn stars suggest that protoplanetary disks have an inner "wall" at a distance set by the disk interaction with the star. Around T Tauri stars, the size of this disk hole is expected to be on a 0.1-AU scale that is unresolved by current adaptive optics imaging, though some model-dependent constraints have been obtained by near-infrared interferometry. Here we report the first measurement of the inner disk wall around a solar-mass young stellar object, YLW 16B in the  $\rho$  Ophiuchi star-forming region, by detecting the light travel time of the variable radiation from the stellar surface to the disk. Consistent time lags were detected on two nights, when the time series in H and K bands were synchronized while the 4.5  $\mu\text{m}$  emission lagged by  $74.5 \pm 3.2$  seconds. Considering the nearly edge-on geometry of the disk, the inner rim should be  $0.084 \pm 0.004$  AU from the protostar on average. This size is likely larger than the range of magnetospheric truncations, but consistent with an optically and geometrically thick disk front at the dust sublimation radius at  $\sim 1500$  K. The detection of a definite time lag places new constraints on the geometry of the disk.

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**Institution(s):** 1. IPAC/Caltech, 2. University of Arizona

### 431.06 – Reconstructing the low-mass IMF of the Orion Nebula Cluster through HST photometry in the H<sub>2</sub>O band at 1.4micron

We present a progress report on a 52-orbit Hubble Treasury Program aimed at investigating two key characteristics of the Orion Nebula Cluster: a) the low-mass tail of the IMF, down to a few Jupiter masses; b) the dynamical evolution of clusters, as revealed by stellar proper motions. The program, completed a few weeks ago, uses WFC3 and ACS in coordinated parallel mode to perform a synoptic survey in the 1.345micron H<sub>2</sub>O feature and in the F775W I<sub>c</sub> broad-band. In this contribution we concentrate on the WFC3 photometry; the strength of the H<sub>2</sub>O absorption feature is strongly correlated with the effective temperature of low-mass stars, brown dwarfs and planetary-mass objects, and allows extending the IMF down to lowest masses formed by gravitational collapse. We present the first results on the central and densest part of the cluster.

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**Institution(s):** 1. Space Telescope Science Institute, 2. University of Florida

**Contributing team(s):** HST Treasury Program on the Orion Nebula Team

### 431.07 – Observing the Circumstellar Environment of the Eruptive FUor/EXor Protostar V1647 Ori with ALMA

Fu Ori (FUor) and EXor objects represent a short-lived stage of protostellar evolution characterized by intense mass accretion events which cause extreme variability in the form of outbursts. While it is well demonstrated that these objects exhibit sudden outbursts ( $\Delta V \sim 2-6$ ), the mechanism causing such variability is not well understood. High spatial and spectral resolution observations of the circumstellar environment of these objects are essential to distinguish between different outbursting mechanisms. We present ALMA observations of the FUor/EXor object V1647 Ori as part of an ALMA campaign, which has observed a combined eight FUor and EXor type objects. Deeply embedded in the dark cloud LDN 1630 (L1630), V1647 Ori is one of a few FUor/EXor objects to have been extensively studied at multiple wavelengths before, during and after an outburst. We present preliminary results derived from ALMA <sup>12</sup>CO, <sup>13</sup>CO, C<sup>18</sup>O and continuum observations of the circumstellar environment of V1647 Ori. By measuring gas/dust masses and gas kinematics of the circumstellar disk, we investigate the potential mechanisms producing variability in these eruptive protostars during an essential, yet rarely observed, stage of pre-main sequence stellar evolution.

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**Institution(s):** 1. Leiden Observatory, 2. Princeton University, 3. Universidad Diego Portales

## 432 – Stellar Clusters and the Milky Way Late Poster Session

### 432.02 – A Swift/UVOT Study of Open Clusters

Star clusters, due to being coeval populations of similar stars, provide a convenient snapshot of a stellar population to study and compare to theoretical models of stellar evolution. They also serve as the empirical baseline for studies of distant unresolved stellar populations. However, few studies have been performed of detailed color-magnitude diagrams (CMDs) of young open clusters in the near ultraviolet. We present a sample of 92 open clusters compiled using Swift's Ultra-Violet and Optical Telescope (UVOT). We construct CMDs and perform isochrone fitting for the most luminous clusters to determine how well the theoretical models reproduce the salient features of the CMDs. We find that the isochrones provide excellent fits to the primary color-magnitude loci, lending confidence to models of unresolved stellar populations and providing, in the future, an opportunity to use open clusters to probe the UV properties of foreground dust.

**Author(s):** Samuel LaPorte<sup>1</sup>, Michael Siegel<sup>1</sup>  
**Institution(s):** 1. Pennsylvania State University

### 432.03 – Searching for very late-type members of Hyades

Hyades, a 750 Myr-old open cluster, has actively been examined due to its proximity (~50pc) and the large number of its members. The proximity enables us to identify very low-mass members of the cluster. For the member identification, the candidate star's kinematics, age, and metallicity should match to those of the bona fide members of the cluster. In this research, we searched for candidate members of Hyades cluster using a tool developed for calculating membership probability based on the Bayesian approach. Using two hypotheses, Hyades and field star, this algorithm computed probabilities for stars to be either Hyades members or field stars. In order to check the reliability of this algorithm, we tested it to 250 bona fide Hyades members; the algorithm successfully identified 99% of members at probability of > 95%. We first select kinematic candidates marginalizing over distances and radial velocities. We applied this algorithm to URAT1 catalogue stars in the range of  $3^{\text{h}} 20^{\text{m}} < \text{R.A.} < 5^{\text{h}} 20^{\text{m}}$  and  $0^{\circ} < \text{Dec.} < +30^{\circ}$ . Since most early-type members must have been discovered already, we focused on late-type members with  $m_{\text{R}} > 9.0$ . Because most of these late-type candidate members lack trigonometric distance measurements, using SED fitting and theoretical isochrone models, we computed SED distance for each star. Then, the membership probability was re-calculated including the SED distance. To select the final list of candidate members, stars with high membership probability and SED distance of < 100pc were kept. For reducing false positive, we excluded stars in old sequence using GALEX UV data. To confirm the true membership of the candidate members, we began to obtain high spectral resolution spectra to confirm their radial velocity and metallicity. Here, we present the sequence of candidate selection and its results.

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**Institution(s):** 1. The University of Georgia

## 433 – Evolved Stars and Things That Go Boom in the Night Late Poster Session

### 433.01 – An HST COS and Archival IUE Far UV Analysis of the U Geminorum-Type Dwarf Nova CW Monocerotis During Quiescence

CW Mon is a U Geminorum-type dwarf nova with an orbital period of 0.1766 days, which displays both wide and narrow outbursts with a recurrence time between outbursts of 150 days. Szkody and Mateo (1986) found evidence for a grazing eclipse of the accretion disk, an orbital inclination of 67 degrees and a distance of 280 pc while Kato et al. (2003) obtained = 210 pc. We de-reddened the data with E(B-V)

= 0.06 (Bruch and Engel 1993). We present a synthetic spectral analysis of two archival IUE spectra and our recent HST COS spectrum (Pala et al. 2015) taken during quiescence as part of a study to detect the underlying accreting white dwarfs in dwarf novae and nova-like variables. Our model photosphere grid and optically thick accretion disk model grid were constructed with the latest versions of Tlusty, Synspec and Disksyn. The results of our analysis indicate the presence of a relatively cool white dwarf (~20,000K) and a low accretion rate (~ $10^{-10}$  Msun/yr or lower) to yield a distance in agreement with the observed distance range of 210 to 280 pc. Our findings will be compared with the properties of the hot components during the quiescences of other dwarf novae above the period gap with long recurrence times.

This work was supported by NASA/HST grant GO-12870.01A to Villanova University

**Author(s):** Connor Hause<sup>1</sup>, Edward M. Sion<sup>1</sup>, Patrick Godon<sup>1</sup>  
**Institution(s):** 1. Villanova University

### 433.02 – The Role of Extinction in Spatial Distribution of Novae in M31

Observations of novae in M31 reveal more novae in the bulge as compared to the disk, suggesting that perhaps the bulge population is a more prolific nova producer than the disk, but the theoretical modeling of evolution of the underlying progenitor binary systems by Yungelson et al. 1997 suggests otherwise. This discrepancy has not yet been resolved. In order to understand the intrinsic bulge to disk nova rate in M31, we consider the role of dust in the disk of M31. To model extinction in M31 we construct a three component dust distribution model for the disk, and assume a dust-free bulge. This model is based on the 160  $\mu\text{m}$  image of Gordon et al. 2006, which traces the bulk of the dust mass in M31. The model combines a ring at  $R = 10$  kpc, two spiral arms and a smooth background (uniform disk) with a central hole extending to 3 kpc. We perform Monte Carlo simulations of the extinction effects of the dust on spatial distribution models of novae, and investigate whether the observed bulge/disk ratio can be accomplished for reasonable choices of parameters, or if the population synthesis of nova progenitors requires modifications.

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**Institution(s):** 1. Clemson University

### 433.03 – SPIRITS15c: An Unusual Transient Discovered in the Mid-Infrared

The dynamic infrared (IR) sky is only now beginning to be explored. SPIRITS, the SPitzer InfraRed Intensive Transients Survey, is a systematic search of 194 nearby galaxies (< 20 Mpc), on timescales ranging from one week to few years, for mid-IR transients in the *Spitzer*/IRAC bands at 3.6 and 4.5  $\mu\text{m}$ . The SPIRITS team is discovering over 40 transients and 1200 strong variables annually, some of which lie in the luminosity gap between novae and supernovae. Here, we highlight an especially interesting transient discovered by SPIRITS in IC 2163 in February 2015. SPIRITS15c is one of our most luminous and reddest transients discovered thus far. Its spectrum shows a broad ~8000 km s<sup>-1</sup> He I emission line, but almost no other strong spectral features. We explore a number of possible physical phenomena to explain this event including a massive stellar merger, an electron-capture supernova, and even a more exotic scenario similar to the unusual, He-rich, nova-like outburst of V445 Puppis in 2000.

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**Institution(s):** 1. California Institute of Technology  
**Contributing team(s):** The SPIRITS Team

### 433.04 – An Accelerated Radioactive Decay (ARD) Model for Type Ia Supernovae

In 1975, Leventhal and McCall [*Nature*, **255**, 690-692] presented a radioactive decay model  $^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$  for the post-peak luminosity decay of Type I supernovae light curves, in which the two decay rates are both accelerated by a common factor. In 1976, Rust, Leventhal and McCall [*Nature*, **262**, 118-120] used sums of

exponentials fitting to confirm the acceleration hypothesis, but their result was nevertheless rejected by the astronomical community. Here, we model Type Ia light curves with a system of ODEs (describing the nuclear decays) forced by a Ni-deposition pulse modelled by a 3-parameter Weibull pdf, with all of this occurring in the center of a pre-existing, optically thick, spherical shell which thermalizes the emitted gamma rays. Fitting this model to observed light curves routinely gives fits which account for 99.9+% of the total variance in the observed record. The accelerated decay rates are so stable, for such a long time, that they must occur in an almost unchanging environment -- not in a turbulent expanding atmosphere. The amplitude of the Ni-deposition pulse indicates that its source is the fusion of hydrogen. Carbon and oxygen could not supply the large energy/nucleon that is observed. The secondary peak in the infrared light curve can be easily modelled as a light echo from dust in the back side of the pre-existing shell, and the separation between the peaks indicates a radius of  $\approx 15$  light days for the shell. The long-term stability of the acceleration suggests that it is a kinematic effect arising because the nuclear reactions occur either on the surface of a very rapidly rotating condensed object, or in a very tight orbit around such an object, like the fusion pulse in a tokamak reactor.

**Author(s):** Bert W. Rust<sup>1</sup>, Marvin Leventhal<sup>2</sup>  
**Institution(s):** 1. NIST, 2. University of Maryland

### 433.05 – An Analysis of Supernovae and their Place in their Host Galaxies using *Swift*

Type Ia supernovae (SNe Ia) have been studied in detail across many different wavelength bands, but prior to *Swift* ultraviolet (UV) observations were few and far between. Now with *Swift* there is an extensive SNe repository containing many well-sampled SNe Ia UV light curves. Using Peter Brown's reduction pipeline we present galaxy subtracted photometry for multiple SNe Ia along with UV-optical color evolution. We study the UV emission of the locations of the supernovae (following Anderson et al. 2015) to see if that correlates with the UV colors or other properties of the individual supernovae.

**Author(s):** Ethan Kilgore<sup>1</sup>, Mark D. Leising<sup>1</sup>  
**Institution(s):** 1. Clemson University

### 433.06 – Spectropolarimetry of ASASSN-14lp

Spectropolarimetric observations which capture the degree of polarization as a function of wavelength help us to explore the aspherical nature of supernova explosions. Using the CCD Imaging/Spectropolarimeter (SPOL) at the 6.5-m MMT and 90" Bok telescopes, we obtained multi-epoch observations of the Type Ia supernova ASASSN-14lp from pre-maximum through late times. We confirm a low continuum polarization indicating a nearly spherical explosion and investigate how the evolution of the Si II 6355Å feature compares to other Type Ia supernovae.

**Author(s):** Amber L. Porter<sup>1</sup>, Mark D. Leising<sup>1</sup>, Peter Milne<sup>2</sup>, Grant Williams<sup>2</sup>, Paul S. Smith<sup>2</sup>  
**Institution(s):** 1. Clemson University, 2. University of Arizona

### 433.07 – SN2009ip at Very Late Times

The 2012 eruption of SN 2009ip resembled a Type II<sub>n</sub> supernovae, dominated by emission from interaction of the ejecta with circumstellar material, but the question remains: was the 2012 outburst of SN 2009ip truly the terminal explosion of a massive star? We present time series photometric and spectroscopic data for the transient SN2009ip from 260 to 1026 days after the peak of its 2012 outburst. These data were collected at the Las Cumbres Observatory Global Telescope Network and Keck Observatory. We will show that SN 2009ip continues to decline linearly in brightness at very late epochs, analyze the evolution in flux and asymmetry of the Balmer emission lines, and investigate the geometry of the circumstellar material from the progenitor star system and the true nature of SN 2009ip.

**Author(s):** Andrew Christopher Bigley<sup>1</sup>, Melissa Lynn Graham<sup>1</sup>  
**Institution(s):** 1. University of California -- Berkeley

### 433.08 – UV Properties of High-Z Supernovae Found In Archival CFHTLS Data

Using a novel technique to detect  $z \geq 1.7$  archival supernovae in the CFHT Legacy Survey (CFHTLS) we discuss rest-frame UV comparisons between a local sample comprised of *Swift* (photometric) and HST (spectroscopic) data and a high redshift CFHTLS (photometric) + Keck/LRIS (spectroscopic); as well as observations on the horizon for  $z \geq 2.5$  Superluminous supernovae (SLSN) found through the Search for Superluminous Supernovae using DECam (SUDSS) and its u-band companion program necessary for this technique.

**Author(s):** Tyler A. Pritchard<sup>1</sup>, Jeff Cooke<sup>1</sup>  
**Institution(s):** 1. Swinburne

## 434 – Mellow Stellar Topics Late Poster Session

### 434.01 – The Advanced Spectral Library (ASTRAL): Abundance Analysis of the CP Star HR 465

We present the results of a spectrum analysis of the prototypical A-type magnetic CP star HR465. Synthetic spectra, using a non-LTE atmosphere model, were generated to fit high-resolution ultraviolet spectra (1200-3100 Å) obtained as a part of the "Advanced Spectral Library (ASTRAL) Project: Hot Stars" program (GO-13346: Ayres PI). The ultraviolet data were supplemented by high resolution optical data recorded at the Nordic Optical Telescope with the SOFIN spectrograph. The optical data was used as a complement to the high line density ultraviolet spectrum and primarily used to derive accurate iron-group element abundances.

HR 465 has previously been analyzed using IUE spectra. We revisit the object with this high quality data. Large parts of the spectrum have been synthesized with an ATLAS model ( $T_{\text{eff}}=10750\text{K}$ ,  $\log g=4.0$ ) and we present abundance results for more than 50 elements. We can confirm some of the abundance characteristics previously derived from IUE data, where elements heavier than  $Z=30$  show significant abundance enhancements compared to solar values, while some of the lighter elements show abundance deficiencies. We will place these results in context of other AP stars, and the large number of element abundances will also help us to put some constraint on stellar abundance and evolution theories.

**Author(s):** Kenneth G. Carpenter<sup>2</sup>, Krister E. Nielsen<sup>1</sup>, Gladys V. Kober<sup>1</sup>  
**Institution(s):** 1. Catholic University of America, 2. NASA's GSFC

### 434.02 – Doing Away with Occupation Probability: A New Way to Model Continuum Lowering at White Dwarf Photosphere Conditions

White dwarfs are interesting for a number of applications including studying equations of state, stellar pulsations, and determining the age of the universe.

These interesting applications require accurate determination of surface conditions: temperatures and surface gravity (or mass). The most common technique to estimate the temperature and gravity is to find the model spectrum that best fits the observed spectra of a star (known as the spectroscopic method); however, this model rests on our ability to accurately model the hydrogen spectrum at high densities.

There are currently disagreements between the spectroscopic method and other techniques to determine mass.

We seek to resolve this issue by exploring the continuum lowering (or disappearance of states) of the hydrogen atom.

The current formalism, called "occupation probability," defines some criteria for the isolated atom's bound state to be ionized, then extrapolates the continuous spectrum to the same energy threshold. The two are then combined to create the final cross-section.

I introduce a new way of calculating the atomic spectrum by doing some averaging of the plasma interaction potential energy (previously used in the physics community) and directly integrating the Schrodinger equation.

This technique is a major improvement over the Taylor expansion

used to describe the ion-emitter interaction and removes the need of the occupation probability and treats continuum states and discrete states on the same footing in the spectrum calculation. The resulting energy spectrum is in fact many discrete states that when averaged over the electric field distribution in the plasma appears to be a continuum. In the low density limit, the two methods are in agreement, but show some differences at high densities (above  $10^{17}$  e/cc) including line shifts near the "continuum" edge.

**Author(s):** Thomas A. Gomez<sup>3</sup>, Donald E. Winget<sup>3</sup>, Michael H. Montgomery<sup>3</sup>, Dave Kilcrease<sup>1</sup>, Taisuke Nagayama<sup>2</sup>  
**Institution(s):** 1. Los Alamos National Laboratories, 2. Sandia National Laboratories, 3. University of Texas

#### 434.03 – Probing gas--dust interactions in debris disks

We present 3D global hydrodynamical simulations of debris disks in order to explore the effect photoelectric heating instability on disk structure.

**Author(s):** Alexander J.W. Richert<sup>3</sup>, Marc J. Kuchner<sup>2</sup>, Wladimir Lyra<sup>1</sup>  
**Institution(s):** 1. California State University, Northridge, 2. Goddard Space Flight Center (NASA), 3. The Pennsylvania State University

#### 434.04 – Vertical Structure of Magnetized Accretion Disks Around Young Stars

We model the vertical structure of magnetized accretion disks subject to viscous and resistive heating, and irradiation by the central star. We apply our formalism to the radial structure of magnetized accretion disks threaded by a poloidal magnetic field dragged during the process of star formation developed by Shu and coworkers. We consider disks around low mass protostars, T Tauri, and FU Orionis stars. We consider two levels of disk magnetization,  $\lambda_{\text{sys}} = 4$  (strongly magnetized disks), and  $\lambda_{\text{sys}} = 12$  (weakly magnetized disks). The rotation rates of strongly magnetized disks have large deviations from Keplerian rotation. In these models, resistive heating dominates the thermal structure for the FU Ori disk. The T Tauri disk is very thin and cold because it is strongly compressed by magnetic pressure; it may be too thin compared with observations. Instead, in the weakly magnetized disks, rotation velocities are close to Keplerian, and resistive heating is always less than 7% of the viscous heating. In these models, the T Tauri disk has a larger aspect ratio, consistent with that inferred from observations. All the disks have spatially extended hot atmospheres where the irradiation flux is absorbed, although most of the mass (~ 90 - 95 %) is in the disk midplane.

**Author(s):** Carlos Tapia<sup>1</sup>, Susana Lizano<sup>1</sup>  
**Institution(s):** 1. Instituto de Radioastronomía y Astrofísica

#### 434.05 – Applying a Hydrodynamical Treatment of Stream Flow and Accretion Disk Formation in WASP-12/b Exoplanetary System

WASP-12b is a hot Jupiter orbiting dangerously close to its parent star WASP-12 at a radius 1/44th the distance between the Earth and the Sun, or roughly 16 times closer than Mercury. WASP-12's gravitational influence at this incredibly close proximity generates tidal forces on WASP-12b that distort the planet into an egg-like shape. As a result, the planet's surface overflows its Roche lobe through L1, transferring mass to the host star at a rate of 270 million metric tonnes per second. This mass transferring stream forms an accretion disk that transits the parent star, which aids sensitive instruments, such as the Kepler spacecraft, whose role is to examine the periodic dimming of main sequence stars in order to detect ones with orbiting planets. The quasi-ballistic stream trajectory is approximated by that of a massless point particle released from analogous initial conditions in 2D. The particle dynamics are shown to deviate negligibly across a broad range of initial conditions, indicating applicability of our model to "WASP-like" systems in general. We then apply a comprehensive fluid treatment by way of hydrodynamical code FLASH in order to directly model the behavior

of mass transfer in a non-inertial reference frame and subsequent disk formation. We hope to employ this model to generate virtual spectroscopic signatures and compare them against collected light curve data from the Hubble Space Telescope's Cosmic Origins Spectrograph (COS).

**Author(s):** Ian Weaver<sup>1</sup>, Aaron Lopez<sup>1</sup>, Phil Macias<sup>1</sup>  
**Institution(s):** 1. UC Santa Cruz

#### 434.06 – The T-R diagram: a new empirical tool to reveal disk gaps and investigate exoplanet compositions

I present a diagram of temperature versus emitting radius of CO gas in planet-forming regions at 0.1-20 AU in protoplanetary disks. I describe its construction and properties following the analysis presented in Banzatti & Pontoppidan 2015, based on sensitive high-resolution surveys of rovibrational CO spectra from ~50 disks observed with VLT-CRIRES (4.7 micron, R=100,000 or 3 km/s). In addition to providing an empirical temperature profile for inner disks around solar-mass stars (at 0.03-2 AU), the diagram reveals a sequence that may reflect the onset and development of disk gaps from primordial to debris disks phases. In combination to surveys of H<sub>2</sub>O emission spectra obtained at 3 and 10-30 micron, the CO sequence in the diagram provides a new exceptional dataset to study processes linked to: 1) gap-opening mechanisms as proposed by theoretical models (through photo-evaporation and/or planets), 2) the observed distributions of exoplanets (Hot- and Exo-Jupiters, and Super-Earths), and 3) the water snow line and its effects on exoplanet compositions. I include an outline of current and future directions of research that have been opened by this discovery.

**Author(s):** Andrea Banzatti<sup>1</sup>, Klaus Pontoppidan<sup>1</sup>  
**Institution(s):** 1. Space Telescope Science Institute

#### 434.07 – Spectroscopic Observations of Low-Mass Stars in the GALNYSS Survey

Young, low-mass stars are known to be bright in X-ray and UV due to their high levels of magnetic activity. By cross-correlating the GALEX Catalog with the 2MASS Point Source Catalog, we have identified a list of over 2,000 stars whose UV excesses suggest that they are in the 10-100 Myr age range. We used several medium and high-resolution spectrometers in the Northern and Southern hemisphere to obtain optical spectra of ~500 of these stars. By measuring their lithium equivalent widths and H $\alpha$  emission, we have been able to confirm the youth of many stars in our catalog. Furthermore, we were able to measure radial velocities and UVW galactic space velocities for stars with high-resolution spectra, and were able to place some of these stars in nearby young moving groups.

**Author(s):** Laura Vican<sup>1</sup>, Ben M. Zuckerman<sup>1</sup>, David Rodriguez<sup>1</sup>  
**Institution(s):** 1. UCLA

#### 434.08 – The SpeX Prism Library Analysis Toolkit: Design Considerations and First Results

Various observational and theoretical spectral libraries now exist for galaxies, stars, planets and other objects, which have proven useful for classification, interpretation, simulation and model development. Effective use of these libraries relies on analysis tools, which are often left to users to develop. In this poster, we describe a program to develop a combined spectral data repository and Python-based analysis toolkit for low-resolution spectra of very low mass dwarfs (late M, L and T dwarfs), which enables visualization, spectral index analysis, classification, atmosphere model comparison, and binary modeling for nearly 2000 library spectra and user-submitted data. The SpeX Prism Library Analysis Toolkit (SPLAT) is being constructed as a collaborative, student-centered, learning-through-research model with high school, undergraduate and graduate students and regional science teachers, who populate the database and build the analysis tools through quarterly challenge exercises and summer research projects. In this poster, I describe the design considerations of the toolkit, its current status and development plan, and report the first published results led by undergraduate

students. The combined data and analysis tools are ideal for characterizing cool stellar and exoplanetary atmospheres (including direct exoplanetary spectra observations by Gemini/GPI, VLT/SPHERE, and JWST), and the toolkit design can be readily adapted for other spectral datasets as well.

This material is based upon work supported by the National Aeronautics and Space Administration under Grant No. NNX15AI75G. SPLAT code can be found at <https://github.com/aburgasser/splat>.

**Author(s):** Adam J. Burgasser<sup>3</sup>, Christian Aganze<sup>2</sup>, Ivana Escala<sup>3</sup>, Mike Lopez<sup>3</sup>, Caleb Choban<sup>3</sup>, Yuhui Jin<sup>3</sup>, Aishwarya Iyer<sup>3</sup>, Melisa Tallis<sup>3</sup>, Adrian Suarez<sup>3</sup>, Maitrayee Sahi<sup>1</sup>  
**Institution(s):** 1. Grossmont High School, 2. Morehouse College, 3. UC San Diego

### 434.09 – Go Long! Identifying Distant Brown Dwarfs in HST/WFC3 Parallel Field

The spatial distribution of brown dwarfs beyond the local Solar Neighborhood is crucial for understanding their Galactic formation, dynamical and evolutionary history. Wide-field red optical and infrared surveys (e.g., 2MASS, SDSS, WISE) have enabled measures of the local density of brown dwarfs, but probe a relatively shallow (~100 parsecs) volume; few constraints exist for the scale height or radial distributions of these low mass and low luminosity objects. We have searched ~1400 square arcminutes of WFC3 Infrared Spectroscopic Parallel Survey (WISPS) data to identify distant brown dwarfs ( $d > 300$  pc) with near-infrared grism spectra from the the Hubble Space Telescope (HST) Wide Field Camera 3 (WFC3). Using spectral indices to identify candidates, measure spectral types and estimate distances, and comparing the WFC3 spectra to spectral templates in the SpeX Prism Library, we report our first results from this work, the discovery of ~50 late-M, L and T dwarfs with distances of 30 – 1000+ pc. We compare the distance and spectral type distribution to population simulations, and discuss current selection biases.

The material presented here is based on work supported by the National Aeronautics and Space Administration under Grant No. NNX15AI75G

**Author(s):** Christian Aganze<sup>2</sup>, Adam J. Burgasser<sup>3</sup>, Matthew Arnold Malkan<sup>4</sup>, Daniel C. Masters<sup>1</sup>, Gretel Mercado<sup>3</sup>, Adrian Suarez<sup>3</sup>, Tomoki Tamiya<sup>3</sup>  
**Institution(s):** 1. Caltech/IPAC, 2. Morehouse College, 3. UC San Diego, 4. UCLA

## 435 – Pulsars, Neutron Stars and Black Holes Late Poster Session

### 435.01 – What if a black hole devours too much?

The formation of relativistic jets by an accreting compact object is one of the fundamental mysteries of astrophysics. While the theory is poorly understood, observations of relativistic jets from systems known as microquasars have led to a well-established phenomenology. Relativistic jets are not expected from sources with soft or supersoft X-ray spectra, although two such systems are known to produce relatively low-velocity bipolar outflows. Here we report optical spectra of an ultraluminous supersoft X-ray source (ULS) in the nearby galaxy M81 (M81 ULS-1) showing blueshifted broad H $\alpha$  emission lines, characteristic of baryonic jets with relativistic speeds. The time variable jets have projected velocities ~17 per cent of the speed of light, and seem similar to those in the prototype microquasar SS 433. Such relativistic jets are not expected to be launched from white dwarfs, but an origin from a black hole or neutron star in M81 ULS-1 is hard to reconcile with its constant soft X-rays. The completely unexpected presence of relativistic jets in a ULS challenges the canonical theories for jet formation, but can be explained by a long speculated super-critically accreting black hole with optically thick outflows.

**Author(s):** Jifeng Liu<sup>1</sup>

**Institution(s):** 1. National Astronomical Observatory of China

### 435.02 – Multi-wavelength Monitoring of Lensed Quasars: Deciphering Quasar Structure at Micro-arcseconds Scales

Microlensing in multiply imaged gravitationally lensed quasars provides us with a unique tool to zoom in on the structure of AGN and explore their physics in more detail. Microlensing magnification, caused primarily by stars and white dwarfs close to the line of sight towards the lensed quasar images, is seen as uncorrelated flux variations due to the relative motions of the quasar, the lens, its stars, and the observer, and it depends on the structural and dynamical properties of the source and the lens. Since the magnification depends upon the size of the source, we can use microlensing to measure the size of quasar emission regions. In essence, the amplitude of the microlensing variability encodes the source size, with smaller sources showing larger variability amplitudes. Using state of the art microlensing techniques, our team has performed pioneering research in the field based on multi-wavelength space and ground-based observations. Among the most remarkable results, using Chandra observations we have set the first quantitative constraints on the sizes of the X-ray emission regions of quasars. In this work I briefly describe the methodology, the results from our previous multi-wavelength monitoring programs, and the next frontier of exploring the dependence of the structure of the X-ray emission regions on black hole mass and X-ray energy.

**Author(s):** Ana Mosquera<sup>3</sup>, Christopher W. Morgan<sup>3</sup>, Christopher S. Kochanek<sup>2</sup>, Xinyu Dai<sup>5</sup>, Bin Chen<sup>5</sup>, Chelsea Louise MacLeod<sup>4</sup>, George Chartas<sup>1</sup>

**Institution(s):** 1. College of Charleston, 2. The Ohio State University, 3. United States Naval Academy, 4. University of Edinburgh, 5. University of Oklahoma

### 435.03 – Science highlights from high-sensitivity pulsar observations with the MWA

Pulsars are exquisite probes of the turbulent interstellar medium (ISM), capable of resolving structures down to tens of thousands of kilometres. Understanding the ISM is important for many areas of astrophysics, such as galactic dynamics, the chemical evolution of the galaxy, and the identification of timing noise in the search for gravitational waves using pulsar timing arrays. Low frequency observations of pulsars are key, because the strength of propagation effects scales strongly with frequency.

We present the Murchison Widefield Array (MWA) as a key science tool for making high quality observations of pulsars at low frequencies (~80-300 MHz). Recently commissioned software for making tied-array beams and the MWA's high time resolution voltage capture system (VCS) allow an order of magnitude increase in sensitivity, vital for pulsar and other time-domain science. A pipeline has now been developed for observing the scintillation patterns of important pulsars at low frequencies, including a new computational technique for measuring the curvature of parabolic arcs in noisy secondary spectra. A program of MWA observations is being undertaken to sample a large number of millisecond pulsars. We present recent highlights including PSR J0437-4715, which yielded a new measurement of scattering screen distance of ~120 pc from Earth, consistent with a Parkes observation at ~730 MHz, and matching the predicted perimeter of the Local Bubble.

**Author(s):** Samuel McSweeney<sup>1</sup>, Ramesh Bhat<sup>1</sup>, Steven Tremblay<sup>1</sup>, Stephen Ord<sup>1</sup>

**Institution(s):** 1. Curtin University (ICRAR)

### 435.04 – The NANOGrav Nine-Year Dataset: Interpretation of Dispersion Measure Variations

The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) has the primary goal of detecting gravitational waves using pulsar timing. Free electrons along the line of sight cause dispersion, which results in a frequency dependent time delay that needs to be fit for in the timing model. We analyze the dispersion measure variations of 37 milliseconds pulsars in the nine-year

NANOGrav data release and constrain the sources of these variations. Variations in the DM over time can be caused by a variety of factors, including a increasing or decreasing distance between the pulsar and the Earth, inhomogeneities in the ISM, and solar effects. We fit for these types of trends in the DM measurements with time to measure the scale and periodicity, if any, of the variations. We present the structure functions of these pulsars and compare them to that expected for a Kolmogorov medium.

**Author(s):** Megan Jones<sup>1</sup>, Maura McLaughlin<sup>1</sup>

**Institution(s):** 1. West Virginia University

**Contributing team(s):** NANOGrav Timing Group, NANOGrav IMM Group

### 435.05 – Detection of Hidden Pulsar J0737-3039B

The double pulsar system, PSR J0737-3039, contains companions PSR J0737-3039A & PSR J0737-3039B, which rotate at 23 ms and 2.8 respectively. As of March 2008 pulsar B's radio signal disappeared, with previous decreases in flux density by 0.177 mJy yr<sup>-1</sup> and evolving pulse profile separation of 2fdg6 yr<sup>-1</sup> from a single peak to a double peak. Models using the system's relativistic spin precession have predicted the reappearance of PSR J0737-3039B in approximately 2014 or 2035. Using data from the Green Bank telescope we attempt to redetect pulsar B and explain the mechanics of its disappearance.

**Author(s):** Tessa Maynard<sup>1</sup>

**Institution(s):** 1. West Virginia University

### 435.06 – Arecibo Pulsar Highlights

Here we present some of the recent interesting pulsar research that has been conducted from the Arecibo Observatory (AO). Many of these results are only possible because of the unique capabilities of AO's 305 meter telescope. Along with this, we state several possible improvements to AO's capabilities that would aid pulsar studies in the immediate future.

**Author(s):** Andrew Seymour<sup>1</sup>

**Institution(s):** 1. NAIC

## 436 – The ISM, PNe and SNRs Late Poster Session

### 436.01 – Characterizing the X-ray Emitting Plasma of the Galactic Supernova Remnant Kesteven 69 (G21.8-0.6)

Kesteven 69 (G21.8-0.6) is a remarkable Galactic supernova remnant (SNR) which appears to be strongly interacting with adjacent molecular clouds, as revealed by observations made at infrared and millimeter wavelengths. The observed radio emission is a circular arc with a diameter of 15 arcminutes while the X-ray emission is more diffuse in nature. While the properties of a number of isolated hard X-ray sources have been analysed previously, a thorough investigation of the spectral properties of the diffuse thermal X-ray emission has yet to be conducted. In this work we present a spectral analysis of this diffuse X-ray emission using pointed observations made of Kesteven 69 by *XMM-Newton* and *Suzaku*. Initial results will be presented and discussed.

**Author(s):** Thomas Pannuti<sup>1</sup>

**Institution(s):** 1. Morehead State University

### 436.02 – The supernova remnant 3C 397: distance and evolutionary state.

3C 397 (G1.1-0.3) is a bright supernova remnant recently identified as a Type Ia. We use neutral hydrogen absorption to derive a new distance to 3C 397. The distance allows determination of shock radius and density of the X-ray emitting gas. The harder component X-rays come from the bulk of the gas with low density, and the softer component X-rays come from high density gas with very little volume. Generalized supernova remnant models are then applied to show that 3C 397 is considerably younger (age about 1500 years) than previously thought.

**Author(s):** Denis A. Leahy<sup>1</sup>, Sujith Ranasinghe<sup>1</sup>

**Institution(s):** 1. Univ. of Calgary

### 436.03 – Densities in Diffuse Molecular Clouds as Determined from Observations of CO Absorption

One parameter that is important to interstellar chemistry is the density of H<sub>2</sub>, but direct density measurement is impossible. We must therefore rely on methods of estimation based on the observable effects that H<sub>2</sub> density has on other molecules. One such effect is the excitation of CO through collisions with H<sub>2</sub>, which is imprinted in the relative populations between CO rotational levels. Spectroscopic observations were made along 17 sight lines targeting ro-vibrational transitions out of the 0 ≤ J ≤ 6 levels in the fundamental band of CO. These absorption features were analyzed to determine level-specific CO column densities, allowing us to express the relative populations between adjacent energy levels as excitation temperatures. By utilizing the analysis of Goldsmith (2013), which relates H<sub>2</sub> density to CO excitation temperatures, we inferred upper and lower limits on the H<sub>2</sub> density in several clouds. Many of our results are consistent with those found by Goldsmith (2013) and suggest sight lines probing diffuse molecular clouds (n(H<sub>2</sub>) ≈ 10 – 10<sup>3</sup> cm<sup>-3</sup>), although some likely sample denser material (n(H<sub>2</sub>) ≥ 10<sup>3</sup> cm<sup>-3</sup>). We also see a trend for individual sight lines where the inferred density increases when determined from higher J-level pairs. We discuss these findings and the future applicability of observations of CO in the infrared for constraining interstellar gas densities.

**Author(s):** Trevor Ryder Picard<sup>2</sup>, Nick Indriolo<sup>2</sup>, Paul Goldsmith<sup>1</sup>

**Institution(s):** 1. California Institute of Technology, 2. University of Michigan

### 436.04 – Karl G. Jansky VLA 3.6 cm Continuum and RRL Observations of the Galactic Massive Star Forming Region W49A

We are using the VLA to make a multi-configuration study at 3.6 cm of the massive star forming region W49A. Using new observations from 2015, we have imaged W49A in the A, B, and D configurations in 3.6 cm continuum and H92 $\alpha$  and H93 $\alpha$  recombination line emission. We present initial continuum images, and selected line spectra of individual sources. This study is part of an ongoing campaign to search for variability in ultracompact HII regions, as predicted by models of unsteady accretion flows. Such variability has been detected in systematic searches of sources in the crowded Sgr B2 Main and North regions (De Pree et al., 2014, 2015). Deep VLA continuum and line observations were first made of W49A in 1993-94 in the B, C, and D configurations, and we will discuss preliminary comparisons of the new data with these 1993-94 archival data.

**Author(s):** Christopher G. De Pree<sup>1</sup>, David J. Wilner<sup>3</sup>, Roberto Galvan-Madrid<sup>7</sup>, Miller Goss<sup>6</sup>, Ralf Klessen<sup>4</sup>, Mordecai-Mark Mac Low<sup>2</sup>, Thomas Peters<sup>5</sup>, Charlee Amason<sup>1</sup>

**Institution(s):** 1. Agnes Scott College, 2. AMNH, 3. Center for Astrophysics, 4. ITA, 5. MPIA, 6. NRAO, 7. UNAM

### 436.05 – Si K Edge Measurements of the ISM with Chandra

The Si K edge structure in X-ray spectra of the diffuse ISM is expected to exhibit substructure related to the fact that most absorption is due to silicates in dust. We surveyed high resolution X-ray spectra of a large number of bright low-mass X-ray binaries with column densities significantly larger than 10<sup>22</sup> cm<sup>-2</sup>. Using the to date unprecedented spectral resolution of the high energy transmission gratings onboard the Chandra X-ray observatory we find complex substructure in the Si K edge. The highest resolved spectra show two edges, one at the expected value for atomic, one at the value for most silicate compounds with the dominant contribution of the latter. There is specific substructure from silicate optical depth caused by absorption and scattering. Some is also variable and can be attributed to ionized absorption in the vicinity of the X-ray sources.

**Author(s):** Norbert S. Schulz<sup>1</sup>, Lia Corrales<sup>1</sup>, C. R. Canizares<sup>1</sup>  
**Institution(s):** 1. MIT

### 436.06 – The Gas-Grain Chemistry of Galactic Translucent Clouds

We employ a combination of traditional and modified rate equation approaches to simulate the time-dependent gas-grain chemistry that pertains to molecular species observed in absorption in Galactic translucent clouds towards Sgr B2(N). We solve the kinetic rate laws over a range of relevant physical conditions (gas and grain temperatures, particle density, visual extinction, cosmic ray ionization rate) characteristic of translucent clouds by implementing a new grid module that allows for parallelization of the astrochemical simulations. Gas-phase and grain-surface synthetic pathways, chemical timescales, and associated physical sensitivities are discussed for selected classes of species including the cyanopolynes, complex cyanides, and simple aldehydes.

**Author(s):** Dominique M. Maffucci<sup>1</sup>, Eric Herbst<sup>1</sup>  
**Institution(s):** 1. University of Virginia

### 436.07 – Properties of H II Region Populations in the Whirlpool Galaxy: Hubble Space Telescope Pa-beta Imaging

A photometric analysis of the Pa-beta line of star forming nebulae in M51 is performed. H II regions, or diffuse emission nebula, are ionized plasmas encompassing hot, massive, young stars, which emit radiation that ionizes the surrounding hydrogen. The H II regions emit light in the form of hydrogen lines, one of which is Pa-beta. The Pa-beta line is of interest because it does not suffer from extinction due to dust, unlike H-alpha and other bright, commonly analyzed lines. The Pa-beta line flux is measured for H II regions of the Whirlpool Galaxy, a nearby head-on spiral galaxy about the size of the Milky Way. Using Hubble Space Telescope data, images of this line are obtained, and the luminosities, areas, and surface brightnesses of these H II regions are analyzed and found to be consistent with the literature.

**Author(s):** Elizabeth Grace<sup>1</sup>  
**Institution(s):** 1. Reed College

### 436.08 – Compact Neutral Hydrogen Clouds: Searching for Undiscovered Dwarf Galaxies and Gas Associated with an Algol-type Variable Star

Several interesting compact neutral hydrogen clouds were found in the GALFA-HI (Galactic Arecibo L-Band Feed Array HI) survey which may represent undiscovered dwarf galaxy candidates. The continuation of this search is motivated by successful discoveries of Local Volume dwarfs in the GALFA-HI DR1. We identify additional potential dwarf galaxies from the GALFA-HI DR1 Compact Cloud Catalog which are identified as having unexpected velocities given their other characteristics via the Bayesian analysis software BayesDB. We also present preliminary results of a by-eye search for dwarf galaxies in the GALFA-HI DR2, which provides additional sky coverage. Interestingly, one particularly compact cloud discovered during our dwarf galaxy search is spatially coincident with an Algol-type variable star. Although the association is tentative, Algol-type variables are thought to have undergone significant gas loss and it is possible this gas may be observable in HI.

**Author(s):** Jana Grcevich<sup>1</sup>, Sabrina Berger<sup>4</sup>, Mary E. Putman<sup>2</sup>, Joshua Eli Goldston Peek<sup>3</sup>  
**Institution(s):** 1. American Museum of Natural History, 2. Columbia University, 3. Space Telescope Science Institute, 4. University of California

### 436.09 – The Contribution of Small Body Disruptions to Debris Disks

We have performed detailed dynamical modeling of the structure of a faint dust band observed in coadded InfraRed Astronomical Satellite data at an ecliptic latitude of 17° that convincingly demonstrates that it is the result of a relatively recent (significantly less than 1 Ma) disruption of an asteroid and is still in the process of forming. We show that young dust bands retain information on the size

distribution and cross-sectional area of dust released in the original asteroid disruption, before it is lost to orbital and collisional decay. We find that the Emilkowalski cluster is the source of this partial band and that the dust released in the disruption would correspond to a regolith layer ~3 m deep on the ~10 km diameter source body's surface. The dust in this band is described by a cumulative size-distribution inverse power-law index with a lower bound of 2.1 (implying domination of cross-sectional area by small particles) for dust particles with diameters ranging from a few  $\mu\text{m}$  up to a few cm. The coadded observations show that the thermal emission of the dust band structure is dominated by large (mm–cm size) particles. We find that dust particle ejection velocities need to be a few times the escape velocity of the Emilkowalski cluster source body to provide a good fit to the inclination dispersion of the observations. We discuss the implications that such a significant release of material, during the disruption of an asteroid, has for the temporal evolution of the structure, composition, and magnitude of the zodiacal cloud. Using the highly sensitive Wide-field Infrared Survey Explorer (WISE) dataset, we can now search for more of these faint signatures of very recent small body disruptions. Starting with the constraints on the amount and size distribution of the dust released in an asteroid catastrophic disruption, we can extrapolate to determine how small body disruptions would appear in extra solar debris disk systems.

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**Institution(s):** 1. Florida Space Institute, 2. University of Central Florida

## 437 – Binaries and Variable Stars Late Poster Session

### 437.01 – MARVELS Radial Velocity Solutions to Seven Kepler Eclipsing Binaries

Eclipsing binaries serve momentous purposes to improve the basis of understanding aspects of stellar astrophysics, such as the accurate calculation of the physical parameters of stars and the enigmatic mass-radius relationship of M and K dwarfs. We report the investigation results of 7 eclipsing binary candidates, initially identified by the Kepler mission, overlapped with the radial velocity observations from the SDSS-III Multi-Object APO Radial-Velocity Exoplanet Large-Area Survey (MARVELS). The RV extractions and spectroscopic solutions of these eclipsing binaries were generated by the University of Florida's 1D data pipeline with a median RV precision of ~60-100 m/s, which was utilized for the DR12 data release. We performed the cross-reference fitting of the MARVELS RV data and the Kepler photometric fluxes obtained from the Kepler Eclipsing Binary Catalog (V2) and modelled the 7 eclipsing binaries in the BinaryMaker3 and PHOEBE programs. This analysis accurately determined the absolute physical and orbital parameters of each binary. Most of the companion stars were determined to have masses of K and M dwarf stars (0.3-0.8  $M_{\odot}$ ), and allowed for an investigation into the mass-radius relationship of M and K dwarfs. Among the cases are KIC 9163796, a 122.2 day period "heartbeat star", a recently-discovered class of eccentric binaries known for tidal distortions and pulsations, with a high eccentricity ( $e \sim 0.75$ ) and KIC 11244501, a 0.29 day period, contact binary with a double-lined spectrum and mass ratio ( $q \sim 0.45$ ). We also report on the possible reclassification of 2 Kepler eclipsing binary candidates as background eclipsing binaries based on the analysis of the flux measurements, flux ratios of the spectroscopic and photometric solutions, the differences in the FOVs, the image processing of Kepler, and RV and spectral analysis of MARVELS.

**Author(s):** Michael Francis Heslar<sup>1</sup>, Neil B Thomas<sup>2</sup>, Jian Ge<sup>1</sup>, Bo Ma<sup>1</sup>, Alec Herczeg<sup>1</sup>, Alan Reyes<sup>1</sup>  
**Institution(s):** 1. University of Florida, 2. US Air Force  
**Contributing team(s):** SDSS-III MARVELS Team

### 437.02 – Discovery of 30,000 Periodic Variables in the Southern Sky

We have completed a search for periodic variable stars within the 30,000 square degrees of the sky covered by the Catalina Surveys.

Here we present the results from our analysis of six years of optical photometry taken by the Siding Spring Survey (SSS). This data covers 200 million sources at declinations between  $-20$  and  $-75$  degrees in the magnitude range  $11 < V < 19$ . In addition to the 10,000 RR Lyrae that we previously discovered in this data, we find approximately 30,000 new periodic variable stars. These sources include, eclipsing binaries, RR Lyrae, LPVs, RSCVn stars, delta Scutis and Anomalous Cepheids.

As part of our ongoing search for structure within the Galactic halo we determine the distances to each of the type-ab RR Lyrae. We discover that many of these stars appear to belong to the old stellar halo of the LMC. Our analysis suggests that the stellar halo of the LMC extends far beyond the limits previously observed.

**Author(s):** Andrew J. Drake<sup>2</sup>, Stanislav G. Djorgovski<sup>2</sup>, Matthew Graham<sup>2</sup>, Marcio Catelan<sup>4</sup>, Gabriel Torrealba<sup>3</sup>, Ashish A. Mahabal<sup>2</sup>, Eric J. Christensen<sup>5</sup>, Stephen M. Larson<sup>5</sup>, Robert McNaught<sup>1</sup>, Gordon Garrard<sup>1</sup>

**Institution(s):** 1. Australian National University, 2. Caltech, 3. Cambridge University, 4. Pontificia Universidad Catolica, 5. University of Arizona

**Contributing team(s):** CRTS

### 437.03 – Period and Orbital Separation determination of a Subdwarf B Pulsator, EC 20117-4014

EC 20117-4014 (V4640 Sgr) is believed to be a binary system consisting of a pulsating subdwarf B star and a F5V star, however the binary period and orbital distance has not been firmly determined. So far, the most promising theory for the origin of subdwarf B (sdB) stars is that they result from binary mass transfer near the Helium Flash stage. We attempted to constrain this evolutionary theory by searching for companions and determining periods and orbital separations around sdB pulsators using the Observed-minus-Calculated (O-C) method. A star's position in space will wobble due to the gravitational forces of any companion. If the star is emitting a periodic signal, its orbital motion around the system's center of mass causes periodic changes in the light pulse arrival times. EC 20117-4014 was monitored from 2010-1 using the 0.6m SARA-CT telescope in Cerro Tololo Inter-American Observatory, Chile. After obtaining the O-C diagrams for the star, useful limits on suspected companions' minimum masses and semimajor axes were calculated. In addition, a modeling experiment was performed to investigate the ranges and combinations of possible companion masses and orbits that are consistent with the observational data. Also, the expected radial velocity semi-amplitude for each O-C companion signal was estimated.

**Author(s):** Tomomi Otani<sup>1</sup>, Terry Oswalt<sup>1</sup>

**Institution(s):** 1. Embry Riddle Aeronautical University

### 437.04 – An Observational Study of Pulsations in Proto-Planetary Nebulae

We have been carrying out a long-term monitoring program to study the light variability in proto-planetary nebulae (PPNe). PPNe are post-Asymptotic Giant Branch objects in transition between the AGB and PN phases in the evolution of low and intermediate-mass stars. As such, it is not surprising that they display pulsational variability. We have been carrying out photometric monitoring of 30 of these at the Valparaíso University campus observatory over the last 20 years, with the assistance of undergraduate students. The sample size has been enlarged over the past six years by observations made using telescopes in the SARA consortium at KPNO and CTIO. Periods have been determined for those of F-G spectral types. We have also enlarged the sample with PPNe from outside the Milky Way by determining periods of eight PPNe in the lower metallicity environment of the Magellanic Clouds. Periods for the entire sample range from 35 to 160 days. Some clear patterns have emerged, with those of higher temperature possessing shorter periods and smaller amplitudes, indicating a reduction in period and pulsation amplitude as the objects evolve. Radial velocity monitoring of several of the brightest of these has allowed us to document their changes in brightness, color, and size during a pulsation cycle. The results of this study will be presented. This research is supported by grants from

the National Science Foundation (most recently AST 1413660), with additional student support from the Indiana Space Grant Consortium.

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**Institution(s):** 1. East Tennessee State University, 2. Valparaíso Univ.

### 437.05 – Variability Studies in Two Hypergiants and a Post-AGB Object

In the course of long-term photometric monitoring of post-AGB stars at the Valparaíso University campus observatory, we have also observed some objects of uncertain evolutionary state. This includes two objects that have some of the characteristics of post-AGB stars, such as large IR excesses and F-G spectral types. The weight of recent evidence suggests that two of these, IRAS 19114+0002 (AFGL 2343) and IRAS 19244+1115 (IRC+10 420), are instead hypergiants, objects of very high luminosity arising from evolved high-mass progenitors. A third object, IRAS 20004+2955 (V1027 Cyg), appears to be a cool post-AGB star evolving from a low or intermediate-mass progenitor. We have light and color curves from 1994-2007, along with some radial velocity data from 1991-1995. These three objects display complex light and color curves with evidence of periodicity in the range of 100 to 300 days. We will present the results of these studies. This research is supported by grants from the National Science Foundation (most recently AST 1413660), the Indiana Space Grant Consortium, and Valparaíso University.

**Author(s):** Stephen Freund<sup>1</sup>, Bruce J. Hrivnak<sup>1</sup>, Wenxian Lu<sup>1</sup>

**Institution(s):** 1. Valparaíso University

### 437.06 – Extending the capability of GYRE to calculate tidally forced stellar oscillations

Tidally forced oscillations have been observed in many eccentric binary systems, such as KOI-54 and many other 'heart beat stars'. The tidal response of the star can be calculated by solving a revised stellar oscillations equations.

The open-source stellar oscillation code GYRE (Townsend & Teitler 2013) can be used to solve the free stellar oscillation equations in both adiabatic and non-adiabatic cases. It uses a novel matrix exponential method which avoids many difficulties of the classical shooting and relaxation method. The new version also includes the effect of rotation in traditional approximation.

After showing the code flow of GYRE, we revise its subroutines and extend its capability to calculate tidally forced oscillations in both adiabatic and non-adiabatic cases following the procedure in the CAFein code (Valsecchi et al. 2013). In the end, we compare the tidal eigenfunctions with those calculated from CAFein.

More details of the revision and a simple version of the code in MATLAB can be obtained upon request.

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**Institution(s):** 1. Georgia State University

### 437.07 – SARA South Observations and Analysis of the Solar Type, Totally Eclipsing, Shallow Contact Binary, CW Sculptoris

CW Scl is a Solar Type ( $T_1 \sim 6000\text{K}$ ) solar type eclipsing binary. It was observed in October and November, 2014 at Cerro Tololo in remote mode with the 0.6-m SARA South reflector. Three times of minimum light were calculated from our present observations, two primary and one secondary eclipses: HJD Min I = 2456939.60799 $\pm$ 0.0002, 2456976.62450 $\pm$ 0.0002, HJD Min II = 2456940.57227 $\pm$ 0.0006.

In addition, six observations at minima were determined from archived All Sky Automated Survey Data:

HJD Min I = 2452177.603, 2452466.793, 2454404.752, HJD Min II = 2453647.652, 2454669.843, 2455101.701.

The following quadratic ephemerides was determined from all available times of minimum light:  
JD Hel Min I =  $2452940.67733 \pm 0.0003d + 0.3855865917 \pm 0.00031 X$   
E +  $0.000000000114 \pm 0.00000000002 X E^2$

A BVRcIc simultaneous Wilson-Devinney Program (W-D) solution reveals that the system has a mass ratio of  $\sim 0.39$ , and a component temperature difference of  $\sim 200$  K. A Binary Maker fitted cool spot was eliminated by WD Synthetic Light Curve Computations. The Roche Lobe fill-out is only 7%. The inclination is  $\sim 86^\circ$ . An eclipse duration of 19.5 minutes was determined for the primary eclipse. Additional and more detailed information is given in this report.

**Author(s):** Ronald G. Samec<sup>2</sup>, Cody Norris<sup>2</sup>, Walter V. Van Hamme<sup>3</sup>, Danny R Faulkner<sup>4</sup>, Robert L. Hill<sup>1</sup>  
**Institution(s):** 1. Bob Jones Univ., 2. Emmanuel College, 3. Florida International University, 4. University of South Carolina

#### 437.08 – BVRI Photometric Study of the Short Period Solar Type Near-Contact W UMa Binary, FF Vulpeculae

High precision BVRcIc light curves of FF Vul were observed during the Fall, 2015 season at the Dark Sky Observatory 0.81-m reflector of Appalachian State University, and the SARA North 0.91-m reflector at KPNO. It is an eclipsing binary with a period of only 0.444983 (2) d. This is the shortest period of our recently studied Pre Contact W UMa Binary (PCWB's), V2421 Cyg, V1043 Cas, ZZ Eri, V500 Peg, and Mis V1287. Our Binary Maker fits and our Wilson-Devinney solution show that the binary is a near-contact, semidetached binary, i.e., a V1010 Oph type configuration (the more massive component has filled its critical lobe while the secondary component is under-filling). Five times of minimum light were calculated, 3 primary and 2 secondary eclipses from our present observations:  
HJD I =  $2457285.7262 \pm 0.0002$ ,  $2457306.6425 \pm 0.0002$ ,  
 $2457310.6469 \pm 0.0002$   
HJD II =  $2457279.7222 \pm 0.0006$ ,  $2457280.6124 \pm 0.0017$ .

The following quadratic ephemerides was determined from all available times of minimum light:  
JDHelMinI =  $2457310.6473 \pm 0.0007d + 0.4449758 \pm 0.0000002 X E$   
-  $0.00000000006 \pm 0.00000000001 X E^2$   
The continuous 20 year period study reveals a period decrease in the orbital period at about the 6 sigma level. Our modeling shows a near-equatorial hot spot on the following side of the secondary component. This is probably due to a matter transfer onto the secondary component. The light curve has a large difference in primary and secondary amplitudes and the light curve solution gives a component temperature difference of more than 1500 K. The solution shows a total secondary eclipse of 23 minutes duration. As expected in binaries of this type, it has a cool spot region on its primary component.

**Author(s):** Daniel B. Caton<sup>1</sup>, Ronald G. Samec<sup>2</sup>, Ropafadzo Nyaude<sup>2</sup>, Walter V. Van Hamme<sup>3</sup>  
**Institution(s):** 1. Appalachian State Univ., 2. Emmanuel College, 3. Florida Institute of Technology

#### 437.09 – Two Small Instrumental Artifacts from Chandra ACIS Data

We report two instrumental artifacts detected in the Chandra ACIS data. One is a periodic signal from an ultraluminous X-ray source candidate, which should be caused by the dither of the telescope. The other is from an X-ray source with irregular trembles apparently. We are still studying its cause.

**Author(s):** Hang Gong<sup>1</sup>  
**Institution(s):** 1. National Astronomical Observatory of China

#### 437.10 – Polars Observed with SDSS, CRTS, and McDonald Observatory 2.1-m

We present first results of a program to characterize magnetic CVs, mostly polars, using the Sloan Digital Sky Survey (SDSS) and the

Catalina Real-Time Transient Survey (CRTS). We find that while it is difficult to predict what state a particular binary will be in, the duty cycle between optical high and low states of polars remains stable over multi-year time-scales. We suggest that polars lie along a sequence of long-term light curve behavior, from rarely high to rarely low. High speed photometry of polars from the 2.1-m telescope of McDonald Observatory is also presented.

**Author(s):** Joshua Santana<sup>1</sup>, Paul A. Mason<sup>1</sup>  
**Institution(s):** 1. New Mexico State University

#### 437.11 – Designing Information Measures for Real-time Lightcurve Classification

Since telescope time is limited, real-time lightcurve classification involves carefully selecting future time points at which sources must be observed in order to maximize the information that will be gained for classification. We propose a framework for constructing measures of information for testing/classification/model-selection and demonstrate their use in experimental design. Degroot (1962) developed a general framework for constructing Bayesian measures of the expected information that an experiment will provide for estimation, and our framework analogously constructs measures of information for hypothesis testing. Such test information measures are most useful for model selection and classification problems. Indeed, our framework suggests a probability based measure of test information, which in decision problems has more appealing properties than variance based measures. In the case of lightcurve classification, we adapt our designs to penalize long waits until the next observation time. Lastly, we consider ways to address other aspects of the problem, such as uncertainty estimation arising due to contamination from nearby contaminating sources or background diffuse emission. We acknowledge support from Smithsonian Competitive Grants Fund 40488100HH0043 and NSF grant DMS 1208791.

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### 438 – AGN and QSOs Late Poster Session

#### 438.01 – Time Variability of VHE Gamma-Ray Induced Pair Cascades in AGN Environments

In a series of previous papers, we had investigated the three-dimensional development of pair cascades initiated by very-high-energy gamma-rays from the relativistic jets of blazars, especially in the case of low-frequency peaked blazars which are expected to host dense radiation environments. Gamma-gamma absorption and pair production leads to the development of pair cascades which will be deflected and partially isotropised by magnetic fields in the nuclear environment. This has been suggested to make a significant contribution to the Fermi gamma-ray emission of radio galaxies. In this work, we present the study of the time dependence of these cascades, demonstrating that they can be variable on time scales much shorter than the light-crossing time through the characteristic extent of the circumnuclear radiation field. Thus, this interpretation is still consistent with the Fermi gamma-ray emission of radio galaxies such as NGC 1275, even considering the recently observed short-term variability.

**Author(s):** Parisa Roustazadeh<sup>2</sup>, Samantha Elaine Thrush<sup>2</sup>, Markus Boettcher<sup>1</sup>  
**Institution(s):** 1. Centre for Space Research, North-West University, 2. Ohio University

#### 438.02 – Spline-based Study of the Extragalactic Background Light Spectrum using Gamma-Ray Observations

The extragalactic background light (EBL) is made of all the light emitted by stars and galaxies throughout cosmic history. Expanding on the work of Biteau & Williams 2015, we develop a novel natural cubic spline model of the local EBL spectrum and constrain its

parameters using the gamma-ray spectra of 38 blazars measured in the high-energy (HE, 0.1 to 100 GeV) and very-high-energy (VHE, 0.1 to 20 TeV) bands. Starting from this best-fit model, we then study the so-called “delta gamma” ( $\Delta\Gamma$ ) observable, defined as the difference between the VHE and HE photon indices. This second study is focused on a subset of nine BL Lac objects. The application of a scaling factor to the cosmic optical background (0.1 - 10 nm) significantly impacts the predicted  $\Delta\Gamma$  as a function of redshift, whereas a similar modification of the cosmic infrared background (10 - 1000 nm) has no impact. We conclude that the simple delta gamma approach can only constrain part of the EBL spectrum, while a detailed study of the spectra, such as presented in the first part of this research, is needed to constrain the cosmic infrared background.

**Author(s):** Anoushka Bose<sup>1</sup>, Julia Rathmann-Bloch<sup>1</sup>, Jonathan Biteau<sup>1</sup>, David A. Williams<sup>1</sup>

**Institution(s):** 1. Santa Cruz Institute of Particle Physics, University of California Santa Cruz

### 438.03 – Inflow Generated X-ray Corona Around Supermassive Black Holes and Unified Model for X-ray Emission

Three-dimensional hydrodynamic simulations, covering the spatial domain from hundreds of Schwarzschild radii to 2 pc around the central supermassive black hole of mass  $10^8 M_\odot$ , with detailed radiative cooling processes, are performed. Generically found is the existence of a significant amount of shock heated, high temperature ( $\geq 10^8$  K) coronal gas in the inner ( $\leq 10^4 r_{\text{Sch}}$ ) region. It is shown that the composite bremsstrahlung emission spectrum due to coronal gas of various temperatures are in reasonable agreement with the overall ensemble spectrum of AGNs and hard X-ray background. Taking into account inverse Compton processes, in the context of the simulation-produced coronal gas, our model can readily account for the wide variety of AGN spectral shape, which can now be understood physically. The distinguishing feature of our model is that X-ray coronal gas is, for the first time, an integral part of the inflow gas and its observable characteristics are physically coupled to the concomitant inflow gas. One natural prediction of our model is the anti-correlation between accretion disk luminosity and spectral hardness: as the luminosity of SMBH accretion disk decreases, the hard X-ray luminosity increases relative to the UV/optical luminosity.

**Author(s):** Lile Wang<sup>1</sup>, Renyue Cen<sup>1</sup>

**Institution(s):** 1. Princeton University

### 438.04 – The pattern of extreme star formation events in SDSS quasar hosts in *Herschel* fields

Using a sample of ~500 quasars up to redshifts of ~4 detected by the Sloan Digital Sky Survey (SDSS) and the Spectral and Photometric Imaging Receiver (SPIRE) instrument of *Herschel*, we describe the behavior of intense starbursts in luminous quasars and how it correlates with the properties of the active galactic nuclei (AGN). We select our objects in the *Herschel* Stripe 82 Survey (HerS) and in the largest fields of the *Herschel* Multi-tiered Extragalactic Survey (HerMES), including the HerMES Large Mode Survey (HeLMS).

The far-infrared (FIR) emission of our objects is quantified using a spectral energy distribution (SED) fitting technique. As our sources are individually detected in the SPIRE bands, they are bright in the FIR, exhibiting typical star formation rates (SFRs) of order of  $1000 M_\odot \text{yr}^{-1}$ . We find the SFR to increase by a factor of nearly ten from  $z \sim 0.5$  to  $z \sim 3$ , in line with the increasing comoving SFR density over a similar redshift range. The SFR, however, is shown to remain constant with increasing quasar luminosity for quasars with IR luminosities above  $10^{12} L_\odot$ , indicating a self-regulating star formation process rather than a suppression effect due to the presence of powerful AGN. We find no further proof of a causal relation between star formation and accretion onto the central black hole, as the SFR and the Eddington ratio,  $\lambda_{\text{Edd}}$ , are found to be uncorrelated.

We then compare the broad absorption line (BAL) quasars to the rest of the quasar population, as they are candidates for outflows in action from which shorter-term feedback effects could be sought. We

find the accretion luminosities and  $\lambda_{\text{Edd}}$  values of BAL quasars to be drawn from the same population as those of the non-BAL quasars; further, the host SFRs are statistically similar among the two populations, all of which argue against feedback effects. These similarities also oppose an evolutionary scenario, as a different evolutionary stage would imply differences in either the accretion state, the star formation, or both. Thus, to explain the presence of BALs in the spectra of a random fraction of the quasar population, our results favor an orientation effect.

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**Institution(s):** 1. SRON Netherlands Institute for Space Research, 2. CNRS, Institut d'Astrophysique de Paris, 3. European Southern Observatory, 4. University College London, Space and Climate Physics, Mullard Space Science Laboratory, 5. University of Sussex, 6. Virginia Polytechnic Institute and State University

### 438.05 – Determining Orientation in Radio-Quiet Quasars

We present further steps developing an orientation indicator based on optical parameters that can be used for radio-quiet quasars. We recently demonstrated that the ratio of orientation-biased black hole mass calculated using the velocity width of H $\beta$  to the orientation-unbiased black hole mass calculated using the stellar velocity dispersion correlates with radio-loud orientation indicators, albeit with significant scatter. Our new work eliminates or reduces some sources of scatter to improve the significance of the correlation and to produce a better predictive prescription. Beyond biasing some mass measurements, orientation also affects luminosity determinations, and in turn estimates of the Eddington fraction, as well as luminosity functions, and other quasar properties. A practical radio-quiet orientation indicator for quasars is overdue.

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**Institution(s):** 1. Penn State, 2. Univ. of Wyoming

### 438.06 – Evaluating and Improving Redshift Determinations in High-z Quasars

Accuracy and precision in quasar redshifts are required to set the best velocity scale for spectral features like absorption, indicating outflows, as well as for applications like small-scale clustering and the transverse proximity effect. Different emission lines, however, can be shifted significantly relative to each other, usually with higher ionization species being significantly blueshifted on average. The low-ionization species Mg II, which has a small shift relative to systemic, can be used to about  $z = 2.2$  for optical quasar spectra. At higher redshifts, the more problematic C III] and C IV lines are the strongest emission lines. We compare several ultraviolet-based redshifts to [O III] redshifts from the near-infrared spectra of 40 quasars with  $z > 2.2$ , and find the UV-based measurements less than ideal. Empirically, the velocity shifts relative to the [O III] redshift correlate with several properties of the C IV profile and can be significantly improved with correction factors that we derive.

**Author(s):** Michelle Mason<sup>1</sup>, Michael S. Brotherton<sup>1</sup>, Adam D. Myers<sup>1</sup>

**Institution(s):** 1. University of Wyoming

### 438.07 – The Host Galaxies of Nearby, Optically Luminous, AGN

Coevolution of galaxies and their central black holes (BH) has been the central theme of much of recent extragalactic astronomical research. Observations of the dynamics of stars and gas in the nuclear regions of nearby galaxies suggest that the majority of spheroidal galaxies in the local Universe contain massive BHs and that the masses of those central BH correlate with the velocity dispersions of the stars in the spheroid and the bulge luminosity. Cold ISM is the basic fuel for star-formation and BH growth so its study is essential to understanding how galaxies evolve.

I will present high sensitivity observations taken with the Herschel Space Observatory to measure the cold dust content in a sample of 85 nearby ( $z \leq 0.5$ ) QSOs chosen from the optically luminous broad-line PG QSOs sample (QSO1s) and in a complementary sample of 85 narrow-line QSOs (QSO2s) chosen to match the redshift and optical luminosity distribution of the broad-line targets. The FIR data are combined with NIR and MIR measurements from the Two Micron All Sky Survey and the Wide-Field Infrared Survey Explorer to determine their IR spectral energy distributions which we use to assess and compare the aggregate dust properties of QSO1s and QSO2s. I will also present NIR spectroscopy obtained with Gemini's Near-Infrared Spectrograph of a sub-sample of QSO2s and QSO1s which I use to compare the ratio of cold to warm H<sub>2</sub> gas that emits in the NIR in the hosts of QSO1s and QSO2s.

Finally I will present a comparison of star-formation in QSO1s and QSO2s. For both QSO1s and QSO2s estimates of star-formation rates that are based on the total IR continuum emission correlate with those based on the 11.3 micron PAH feature. However, for the QSO1s, star-formation rates estimated from the FIR continuum are higher than those estimated from the 11.3 micron PAH emission. This result can be attributed to a variety of factors including the possible destruction of the PAHs and that, in some sources, a fraction of the FIR originates from dust heated by the active galactic nucleus and by old stars. For QSO2s the SFR derived from the 11.3 micron PAH feature match those derived from the 160micron emission.

**Author(s): Andreea Petric<sup>1</sup>**

**Institution(s):** 1. Gemini Observatories

#### **438.08 – Formation of Continuous and Episodic Relativistic Outflows in Regions of Stability and Instability in Advection-Dominated Accretion Flows**

Previously, we have demonstrated that particle acceleration in the vicinity of a shock in an advection-dominated accretion disk can extract enough energy to power a relativistic jet from a supermassive black hole at the center of a radio-loud active galaxy. However, to maintain a steady jet, a stable shock location is required. By employing the Chevalier & Imamura linearization method and the Nakayama instability boundary conditions, we have also shown that there is a region of the energy and angular momentum parameter space in which disk/shocks with outflows can be either stable or unstable. In a region of instability, the velocity profiles that exhibit pre-shock deceleration and pre-shock acceleration are always unstable to the zeroth mode with zero frequency of oscillation. However, in a region of stability, the zeroth mode, the fundamental, and the overtones are all stable for both pre-shock deceleration as well as pre-shock acceleration. Building on this new insight, in this paper, we explore new parameter values in the regions of stability and instability to explain the production of the observed continuous and episodic relativistic outflows (jets) in M87 and Sgr A\*, respectively.

**Author(s): Truong V. Le<sup>1</sup>, Kent S. Wood<sup>3</sup>, Michael Thomas Wolff<sup>3</sup>, Peter A. Becker<sup>2</sup>, Joy Putney<sup>4</sup>, Elizabeth Edge<sup>1</sup>**

**Institution(s):** 1. Berry College, 2. George Mason University, 3. Naval Research Laboratory, 4. Washington and Lee University

#### **438.09 – Searching for Outflows from the central kpc of nearby ULIRGs with OSIRIS**

We present integral field spectroscopy of the central kiloparsec of 4 nearby ultra-luminous infrared-galaxies which are known to have high velocity ( $v \leq 100$  km/s) molecular outflows. These observations were performed with the OH-Suppressing Infra-red Imaging Spectrograph (OSIRIS) assisted by the Keck I and II Adaptive Optics systems, which enables spatial resolutions of a few 10s of parsecs. We present the preliminary results of a survey designed to explore the relationship between AGN luminosity fraction ( $\alpha_{\text{AGN}}$ ) and outflow properties among lower-redshift ( $z \leq 0.15$ ) systems that we know host high velocity outflows. Our data allow us to examine the opening angle and launching point of the outflow, excitation and temperature of outflowing components (through H<sub>2</sub> lines and high-excitation lines such as [SiIV] and [AlIX]), and molecular outflow mass in these systems. This work provides a nearby, spatially resolved analogue to higher-redshift outflows, allowing us to study the physical processes

which launch outflows on their smallest scales, and relate that to the outflows which must govern the evolution of the most massive galaxies.

**Author(s): Alexander R. Rudy<sup>2</sup>, Claire E. Max<sup>1</sup>, Srikar Srinath<sup>2</sup>**

**Institution(s):** 1. UC Observatories, 2. UC Santa Cruz

### **439 – Galaxy Clusters and Large Scale Structure Late Poster Session**

#### **439.01 – SDSS-IV: The Clustering of eBOSS LRGs using photometric redshifts**

SDSS-IV/eBOSS is producing an exciting data set for cosmology which will add to our understanding of the large-scale structure of the Universe. The Luminous Red Galaxy (LRG) component of this survey will cover a redshift regime barely explored by SDSS-III/BOSS and will allow a  $\sim 1\%$  measurement of the Baryon Acoustic Oscillation (BAO) scale and a 4.0% Redshift Space Distortion (RSD) measurement using a relatively uniform set of luminous, early-type galaxies in the redshift range  $0.6 < z < 1$ . We briefly review a new technique of selecting high- $z$  LRGs utilizing SDSS and WISE (infrared) photometry in combination. These galaxies are old, elliptical systems with strong 4000 Å breaks. Old stellar populations exhibit a global maximum in their spectral energy distributions (SEDs) at a wavelength of 1.6 μm, commonly referred to as the '1.6 μm bump'. Since LRGs possess very few young stars, this feature generally dominates their overall SEDs which makes them extremely bright in infrared. SDSS-IV/eBOSS LRGs range from redshift  $z = 0.6$  to 1.0 over 10,000 square degrees of the sky. Here we briefly present the results of the 3D real space clustering power spectrum of a sample of 600,000 luminous red galaxies (LRGs) measured by the Sloan Digital Sky Survey (SDSS), using photometric redshifts. Although spectroscopic redshifts provide stronger constraints on large scale measurements, these results demonstrate the ability to make precise clustering measurements with photometric surveys.

**Author(s): Abhishek Prakash<sup>1</sup>**

**Institution(s):** 1. University of Pittsburgh

**Contributing team(s):** SDSS-IV/eBOSS

#### **439.02 – A First Calibration of SBF using Multi-Conjugate Adaptive Optics**

We measured Surface Brightness Fluctuations (SBF) in three galaxies, ESO137-G006, NGC 3309, and NGC 5128, using the GeMS Multi-Conjugate Adaptive Optics (MCAO) system on the Gemini South telescope. ESO137-G006 is located in the Norma Cluster, NGC 3309 is located in the Hydra Cluster, while NGC 5128, also known as Centaurus A, is a nearby galaxy with numerous other distance measurements, including Cepheids. These galaxies were observed as a pathfinder to establish the SBF technique using the MCAO system. The J and K-band images taken with MCAO were astrometrically corrected and combined using the THELI software. This method allowed us to accurately account for the distortions of the focal plane when combining the images. The foreground stars as well as the globular clusters were measured to account for their contribution to the SBF. J-K color measurements were made to calibrate SBF and determine the stellar populations of the galaxies.

The results of these measurements give us an SBF calibration that we can use to measure the distances to much more distant galaxies. Accurate distances are needed to determine the true spatial motions of galaxies and measure the mass distribution and density of the Universe. We now live in the era of "precision cosmology" in which distance measurements have transformed our understanding of the composition of the Universe and revealed the presence of Dark Matter and Dark Energy, the two dominant (but still unidentified) components of the Universe. The origins and nature of Dark Matter and Dark Energy are among the most important unsolved mysteries in physics.

**Author(s):** Zachary Gibson<sup>3</sup>, Joseph B. Jensen<sup>3</sup>, John Blakeslee<sup>2</sup>, Mischa Schirmer<sup>1</sup>  
**Institution(s):** 1. *Gemini Observatory*, 2. *Herzberg Institute of Astrophysics*, 3. *Utah Valley University*

### 439.03 – Characterizing the Cosmic Infrared Background Fluctuations

A salient feature of the Cosmic Infrared Background (CIB) fluctuations is that their spatial power spectrum rises a factor of  $\sim 10$  above the expected contribution from all known sources at angular scales  $> 20''$ . A tantalizing large-scale correlation signal between the residual Cosmic X-ray Background (CXB) and CIB found in the Extended Groth Strip (EGS) further suggests that at least 20% of the CIB fluctuations are associated with accreting X-ray sources, with efficient energy production similar to black holes. However, there is still a controversy about the sources that produce the excess flux. They could be faint, local populations with different spatial distribution from other known galaxies, or high- $z$  populations at the epoch of reionization that we know little of. Constraining the origin of the CIB fluctuations will help to establish our understanding of the overall cosmic energy budget. We will combine the archival Spitzer/IRAC and the Chandra data of the Cosmic Evolution Survey (COSMOS), to accurately measure the source-subtracted CIB and CXB fluctuations to the largest angular scale ( $\sim 1-2$  deg) to date. The newly discovered link between CIB and CXB fluctuations found in the EGS will be revisited in the COSMOS, which provides better photon statistics. We will present current state of data collection and analysis progress.

**Author(s):** Yanxia Li<sup>1</sup>, Guenther Hasinger<sup>1</sup>, Nico Cappelluti<sup>2</sup>, Nico Cappelluti, Richard G. Arendt  
**Institution(s):** 1. *Ifa, University of Hawaii*, 2. *Yale University*

### 439.04 – High Resolution SZE Imaging of Galaxy Clusters with MUSTANG-2

Over the past several years the 3.3mm MUSTANG bolometer camera on the GBT has been making pioneering,  $10''$  resolution images of the Sunyaev-Zel'dovich Effect (SZE) in galaxy clusters. These measurements, focusing mainly on the CLASH sample, provide a view of the ICM state and dynamics which complements that provided by other common probes (x-ray imaging and spectroscopy and lower resolution SZE imaging). We present results from this survey, including ICM pressure profile measurements obtained by combining MUSTANG and BOLOCAM data, and discuss work that is underway. In early 2015, MUSTANG's next-generation successor (MUSTANG-2) achieved first light in an engineering run on the GBT. In early 2016 the fully populated 215-feedhorn MUSTANG-2 camera will be installed for an early science run. We present an overview of key SZ science that this instrument aims to address.

**Author(s):** Brian S. Mason<sup>4</sup>, Charles Romero<sup>3</sup>, Simon Dicker<sup>6</sup>, Tony Mroczkowski<sup>5</sup>, Sara Stanchfield<sup>6</sup>, Jack Sayers<sup>2</sup>, Nicole G. Czakon<sup>1</sup>, Craig L. Sarazin<sup>7</sup>, Sunil R. Golwala<sup>2</sup>, Mark J. Devlin<sup>6</sup>  
**Institution(s):** 1. *ASIAA*, 2. *Caltech*, 3. *IRAM*, 4. *NRAO*, 5. *NRL*, 6. *University of Pennsylvania*, 7. *UVA*

### 439.05 – IDCS J1426.5+3508: The Most Massive Galaxy Cluster at $z > 1.5$

We present a deep (100ks) Chandra observation of IDCS J1426.5+3508, a spectroscopically confirmed, infrared-selected galaxy cluster at  $z = 1.75$ . This cluster is the most massive galaxy cluster currently known at  $z > 1.5$ , based on existing Sunyaev-Zel'dovich (SZ) and gravitational lensing detections. We confirm this high mass via a variety of X-ray scaling relations, including  $T_X-M$ ,  $f_g-M$ ,  $Y_X-M$ , and  $L_X-M$ , finding a tight distribution of masses from these different methods, spanning  $M_{500} = 2.3-3.3 \times 10^{14} M_\odot$ , with the low-scatter  $Y_X$ -based mass  $M_{500,Y_X} = 2.6^{+1.5}_{-0.5} \times 10^{14} M_\odot$ . IDCS J1426.5+3508 is currently the only cluster at  $z > 1.5$  for which X-ray, SZ and gravitational lensing mass estimates exist, and these are in remarkably good agreement. We find a relatively tight distribution of the gas-to-total mass ratio, employing total masses from all of the aforementioned indicators, with values ranging from  $f_{gas,500} = 0.087-0.12$ . We do not detect metals in the intracluster medium (ICM) of this system, placing a  $2\sigma$  upper limit of  $Z(r <$

$R_{500}) < 0.18 Z_\odot$ . This upper limit on the metallicity suggests that this system may still be in the process of enriching its ICM. The cluster has a dense, low-entropy core, offset by  $\sim 30$  kpc from the X-ray centroid, which makes it one of the few "cool core" clusters discovered at  $z > 1$ , and the first known cool core cluster at  $z > 1.2$ . The offset of this core from the large-scale centroid suggests that this cluster has had a relatively recent (500 Myr) merger/interaction with another massive system.

**Author(s):** Mark Brodwin<sup>6</sup>, Michael McDonald<sup>2</sup>, Anthony H. Gonzalez<sup>4</sup>, S. Adam Stanford<sup>5</sup>, Peter R. Eisenhardt<sup>1</sup>, Daniel Stern<sup>1</sup>, Gregory Zeimann<sup>3</sup>  
**Institution(s):** 1. *JPL*, 2. *MIT/Kavli*, 3. *Penn State*, 4. *U Florida*, 5. *UC Davis*, 6. *University of Missouri - Kansas City*

### 439.06 – The Dynamics of the Merging Cluster Abell 562

We have analyzed the cluster dynamics of Abell 562 based on our analysis of the redshifts of 100 galaxy members. We confirm that this is a merger system as has been revealed by previous analysis of X-ray data. The perturbed ICM environment is probably responsible for the peculiar morphology of the wide-angle radio source found in this cluster.

**Author(s):** Percy L. Gomez<sup>1</sup>  
**Institution(s):** 1. *Gemini Obs.*

### 439.07 – A Search for Distant Galaxy Cluster Hosting Extreme Central Galaxies

The recent discovery of the "Phoenix cluster" which, at  $z = 0.6$ , is the most X-ray luminous clusters known and harbors a massive starburst at its center, begs the question: *Why was it not discovered until recently?* In fact, the object has been previously detected by several all-sky surveys at a variety of wavelengths, but it is consistently classified as a quasar (QSO) because of the extremely bright central galaxy and a (relative) lack of extended X-ray emission due to its distance. This lead us to question of how many of these Phoenix-like clusters are currently mislabelled in existing all-sky surveys.

A unique property of the Phoenix cluster which helps us identify other Phoenix-like objects is that it is bright at multiple wavelength, including X-ray (intracluster medium and central AGN), near-IR (giant central elliptical galaxy), mid-IR (warm dust from starburst and AGN) and radio (radio-loud central AGN). Therefore, we can identify potential Phoenix-like clusters by cross-correlating all-sky surveys from *ROSAT* (X-ray), *2MASS* (near-IR), *WISE* (mid-IR) and both *SUMSS* and *NVSS* (radio). By requiring sources to be bright in all four surveys, we can quickly find (among other sources) a sample of Phoenix-like clusters that can be followed up either by using archival images from *SDSS* for Northern-hemisphere objects or taking new images from the *Magellan* telescope for Southern-hemisphere objects. Here, we will present the preliminary result from the project.

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**Institution(s):** 1. *Massachusetts Institute of Technology*

### 439.08 – Investigating Galaxy Superwinds and the Circumgalactic Medium

It has been empirically established that galaxy superwinds sourced from star formation eject vast amounts of material into the interstellar medium (ISM) and outside of the galactic plane, which has been observed through measuring Na-I and Mg-II absorption. Yet, it remains unclear whether such outflows serve as feeding mechanisms for the circumgalactic medium (CGM), which can extend out to 200 kpc. We demonstrate through equivalent width and column density measurements of Na-I and Mg-II in the CGM, that baryons in the CGM are most likely not sourced from galaxy outflows in star-forming regions.

**Author(s):** Daniel Brandt<sup>1</sup>, Jason X. Prochaska<sup>2</sup>, Jessica Werk<sup>2</sup>  
**Institution(s):** 1. *Case Western Reserve University*, 2. *University of California, Santa Cruz*  
**Contributing team(s):** COS-Halos Team

### 439.09 – Probing the Properties of Distant Galaxies and their Circumgalactic Medium with Damped, Sub-damped, and Super-damped Lyman-alpha Quasar Absorbers

Excellent tools to measure the chemical and physical properties of distant galaxies and their circumgalactic medium are provided by the high H I column density absorbers in quasar spectra. The damped Lyman-alpha absorbers [DLAs;  $\log N(\text{H I}) \geq 20.3$ ] and the sub-DLA absorbers [ $19.0 \leq \log N(\text{H I}) < 20.3$ ] dominate the neutral gas reservoir available for star formation. The super-DLAs [DLAs with  $\log N(\text{H I}) \geq 21.7$ ] provide ideal laboratories to study the most gas-rich and potentially vigorously star-forming galaxies. We report a study of the DLAs (including super-DLAs) and sub-DLAs, based on observations from Keck, VLT, Magellan, and HST. We combine our results with the literature to examine trends between  $N(\text{H I})$ , metallicity, dust depletion, and gas velocity dispersion. We find that sub-DLAs have higher metallicities than DLAs at all redshifts studied, even after making ionization corrections. We find the super-DLAs have a relatively narrow range of metallicities. A much larger fraction of the super-DLAs lie close to or above the line  $[X/\text{H}] = 20.59 - \log N(\text{H I})$  in the metallicity versus  $N(\text{H I})$  plot, compared to less gas-rich DLAs, suggesting that super-DLAs are more likely to be rich in molecules. Relative abundances of Si, S, Mn, Fe, Ni, and Zn suggest a mixture of dust depletion and alpha-enhancement. We confirm a strong correlation between metallicity and Fe depletion for DLAs, and also find a correlation between metallicity and Si depletion. For sub-DLAs at  $z < 0.5$ , we find  $[N/\text{S}]$  below the level for secondary N production. For some super-DLAs, we estimate star formation rates from potential detections of Lyman-alpha emission. We discuss constraints on electron densities from C II\*/C II and Si II\*/Si II. The DLAs and sub-DLAs appear to have different metallicity vs. velocity dispersion relations. We also find that the super-DLAs may have somewhat narrower velocity dispersions than the less gas-rich DLAs, and may arise in cooler/ less turbulent gas. We gratefully acknowledge support from the NSF grant AST/1108830, STScI grant HST-GO-12536.01-A, and NASA grant NNX14AG74G.

**Author(s):** Varsha P. Kulkarni<sup>6</sup>, Debopam Som<sup>6</sup>, Sean Morrison<sup>6</sup>, Celine Peroux<sup>3</sup>, Donald G. York<sup>4</sup>, Samuel Quiret<sup>3</sup>, James Thomas Lauroesch<sup>5</sup>, Pushpa Khare<sup>2</sup>, Monique C. Aller<sup>1</sup>  
**Institution(s):** 1. Georgia Southern University, 2. IUCAA, 3. Laboratoire d'Astrophysique de Marseille, 4. Univ. of Chicago, 5. Univ. of Louisville, 6. Univ. Of South Carolina

### 439.10 – Fingerprints of the First Stars: The Discovery of Possible Population III Remnants at Redshift 3.5

The first stars, known as population III, produced the first heavy elements, thereby enriching their surrounding pristine gas. However, previous detections of metals in intergalactic gas clouds find a heavy element enrichment  $1/1000$  to  $\sim 1$  times that of the solar environment, which is higher than expected for population III remnants. Here, we report the discovery of a Lyman limit system at redshift 3.53 with the lowest metallicity seen in gas with discernable metals,  $10^{-(3.44 \pm 0.24)}$  times the solar value. The carbon-to-silicon abundance ratio is  $10^{-(0.21 \pm 0.16)}$  times the solar value, and the metals are offset in velocity by 6 to 10 km/s from the bulk of the hydrogen. These properties are all consistent with enrichment by a population III star formation event. A recent enrichment scenario by population II stars cannot be ruled out, but the large cloud size ( $> 30$  kpc) suggests it is not part of a cold accretion stream, and the 400 km/s velocity width of the system suggests it is not in a low-mass halo. Relative abundance measurements in this near-pristine regime open a new avenue for testing models of early gas enrichment and metal mixing.

**Author(s):** John O'Meara<sup>1</sup>, Neil H. M. Crighton<sup>2</sup>, Michael Murphy<sup>2</sup>  
**Institution(s):** 1. Saint Michael's College, 2. Swinburne University of Technology

## 440 – The Evolution of Galaxies Late Poster Session

### 440.01 – The evolution of individual galaxies in numerical simulations and semi-analytic models

We compare results from high-resolution cosmological hydrodynamic zoom simulations with those from a semi-analytic model (SAM) of galaxy formation. We present a detailed comparison of the histories of baryonic, morphological, and structural properties as well as key observational scaling relations as predicted by both simulation and SAM. Our sample consists of more than a dozen galaxies with halo masses ranging from  $M_{\text{vir}} \sim (10^{10} - 10^{12}) M_{\odot}$  at  $z = 0$ . In order to make direct comparisons, we run the SAM within halo merger trees extracted from the simulation output snapshots, and produced using the ROCKSTAR halo finder/merger tree code. We also present a new tool used to visualize the merger histories of dark matter halos in 3D space using the open-source, data analysis application ParaView.

**Author(s):** Yotam Cohen<sup>1</sup>, Rachel S. Somerville<sup>1</sup>, Alyson Brooks<sup>1</sup>, Charlotte Christensen<sup>2</sup>, Sheehan Ahmed<sup>1</sup>  
**Institution(s):** 1. Rutgers University, 2. University of Arizona

### 440.02 – Constraining the Major Merger History of Massive Galaxies from $z=0$ to $z \sim 3$ using Pairs from CANDELS & SDSS

Major merging may play an important role in the morphological transformation and mass assembly at play in the evolution of massive galaxies. An important way to measure the impact of merging is to study close pairs of nearly equal-mass galaxies. We do this by using data from the Cosmic Assembly Near-Infrared Deep Extragalactic Legacy Survey (CANDELS) and the SDSS to measure the evolution between redshifts  $0 \leq z \leq 3$  of massive (stellar masses  $M_{\text{host}} > 2 E_{10} M_{\odot}$ ) galaxies that are involved in major ( $1 \leq M_{\text{host}}/M_{\text{comp}} \leq 4$ ), close ( $\leq 50$  kpc separation) pairs. Our preliminary results are based on data from two of the legacy fields: UDS and GOODS-S. If we simply define major pairs based on H-Band flux ratios and corrected for line-of-sight contamination, we find that the fraction of massive galaxies in such pairs increases from  $\sim 2\%$  ( $z=0$ ) to  $\sim 20\%$  ( $z \sim 3$ ), in agreement with a broad range of previous studies. In contrast, when we consider stellar mass ratios and attempt to account for close redshift proximity using the best available redshifts (either spectroscopic or photometric), the pair fraction and fraction of galaxies in pairs each follow a broken redshift dependence where there is an increase ( $\sim (1+z)^2$ ) from  $z=0$  to  $z \sim 1$ , followed by a decreasing ( $\sim (1+z)^{-1.1}$ ) redshift dependence to  $z \sim 3$ . Thus, our results point towards diminishing importance of major merging at  $z \geq 1$ , consistent with recent findings by Man et al.

**Author(s):** Kameswara Bharadwaj Mantha<sup>5</sup>, Daniel H. McIntosh<sup>5</sup>, Ryan Brennan<sup>2</sup>, Joshua Cook<sup>5</sup>, Christopher Conselice<sup>4</sup>, Jennifer Lotz<sup>3</sup>, Nimish P. Hathi<sup>1</sup>  
**Institution(s):** 1. Aix Marseille Université, CNRS, LAM (Laboratoire d'Astrophysique de Marseille), 2. Rutgers University, 3. Space Telescope Science Institute, 4. The University of Nottingham, 5. University of Missouri-Kansas City  
**Contributing team(s):** CANDELS collaboration

### 440.03 – Constraints on the Star Formation Efficiency of Galaxies During Cosmic Reionization

Cosmic reionization is thought to have occurred in the redshift range of  $6 < z < 9$ , which is now being probed by both deep galaxy surveys and CMB observations. Using halo abundance matching over the redshift range  $5 < z < 8$  and an analytic prescription of gas accretion, we develop a model for the star formation efficiency  $f_*$  of dark matter halos at  $z > 6$  that matches the measured galaxy luminosity functions at these redshifts. We find that the star formation efficiency peaks near  $\sim 10\%$  at halo masses  $M \sim 10^{11} - 10^{12} M_{\odot}$ , in qualitative agreement with its behavior at lower redshifts. Recent lensing observations of  $z \sim 7$  galaxies suggest that the efficiency declines toward smaller masses, with  $f_*$  proportional to  $M^{1/2}$  down to  $M \sim$

$10^{10} M_{\odot}$  as expected by models of stellar feedback, albeit with large uncertainties. We then investigate the cosmic star formation histories and the corresponding models of cosmic reionization for a range of extrapolations to small halo masses. We compare these to a variety of observations, using them to further constrain the characteristics of the galaxy populations. Our approach provides an empirically-calibrated, physically-motivated model for the properties of star-forming galaxies sourcing the epoch of reionization. By modeling the redshift evolution of  $f^*$ , we find a generally slower evolution of the cosmic star formation rate density compared to that predicted by  $f^*$  fixed in time. In the case where star formation in low-mass halos is maximally efficient, an average escape fraction  $\sim 0.1$  can reproduce the CMB optical depth observed by Planck, whereas less efficient star formation in these halos requires about twice as many UV photons to escape, or an escape fraction that increases towards higher redshifts. Our models also predict how future observations with JWST can improve our understanding of these galaxy populations.

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**Institution(s):** 1. *University of California, Los Angeles*

#### 440.04 – Numerical Simulations of Interacting Galaxies NGC3395/96

Galaxy collisions act as an empirical laboratory that allow us to analyze how star formation is affected by major restructuring of the galaxy's shape due to interactions with another galaxy. Many past observational studies have been conducted with the goal of understanding the link between galaxy interaction and induced star formation. To date, numerical studies of two systems, NGC4676 and NGC7252 (Barnes 2004, Chien & Barnes 2010), have shown that star formation induced by shocks can predict prompt and less-concentrated star formation due to interactions, which gives more accurate observed properties. We present our preliminary result of a merging pair NGC3395/96, using the same shock-induced star formation mechanism. These results will be compared with observations of ages and distributions of star clusters throughout the galaxy.

**Author(s):** Curtis Dankof<sup>1</sup>, Elizabeth Gehret<sup>1</sup>, Li-Hsin Chien<sup>1</sup>  
**Institution(s):** 1. *Northern Arizona University*

#### 440.05 – The stellar mass assembly of galaxies in the Illustris simulation: growth by mergers and the spatial distribution of accreted stars

We use the Illustris simulation to study the relative contributions of in situ star formation and stellar accretion to the build-up of galaxies over an unprecedentedly wide range of masses ( $M^* = 10^9 - 10^{12} M_{\text{sun}}$ ), galaxy types, environments, and assembly histories. We find that the 'two-phase' picture of galaxy formation predicted by some models is a good approximation only for the most massive galaxies in our simulation – namely, the stellar mass growth of galaxies below a few times  $10^{11} M_{\text{sun}}$  is dominated by in situ star formation at all redshifts. The fraction of the total stellar mass of galaxies at  $z = 0$  contributed by accreted stars shows a strong dependence on galaxy stellar mass, ranging from about 10% for Milky Way-sized galaxies to over 80% for  $M^* \approx 10^{12} M_{\text{sun}}$  objects, yet with a large galaxy-to-galaxy variation. At a fixed stellar mass, elliptical galaxies and those formed at the centers of younger halos exhibit larger fractions of ex situ stars than disk-like galaxies and those formed in older halos. On average,  $\sim 50\%$  of the ex situ stellar mass comes from major mergers (stellar mass ratio  $\mu > 1/4$ ),  $\sim 20\%$  from minor mergers ( $1/10 < \mu < 1/4$ ),  $\sim 20\%$  from very minor mergers ( $\mu < 1/10$ ), and  $\sim 10\%$  from stars that were stripped from surviving galaxies (e.g. flybys or ongoing mergers). These components are spatially segregated, with in situ stars dominating the innermost regions of galaxies, and ex situ stars being deposited at larger galactocentric distances in order of decreasing merger mass ratio.

**Author(s):** Vicente Rodriguez-Gomez<sup>1</sup>, Annalisa Pillepich<sup>1</sup>, Lars E. Hernquist<sup>1</sup>  
**Institution(s):** 1. *Harvard University*

#### 440.06 – Metal enrichment of the CGM through

#### outflows

Galactic outflows enrich the circumgalactic medium through the redistribution of metals from the disks of galaxies. We examine the history of this enrichment by analyzing the outflows of twenty high-resolution simulated galaxies spanning two and a half orders of magnitude in halo mass. These simulations match many observed trends, including the mass-metallicity relation. By tracking particles in the simulations, we follow the removal and reaccretion of metals between redshift 3.5 and 0. We also determine the enrichment of the outflowing gas compared to the local interstellar media. Finally we compare the redshift zero metal census to observed values.

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#### 440.07 – The OH and H<sub>2</sub>O Megamaser Connection: H<sub>2</sub>O Emission Toward OH Megamaser Hosts

Questions surround the connection of luminous extragalactic masers to galactic processes. The observation that water and hydroxyl megamasers rarely coexist in the same galaxy has given rise to a hypothesis that the two species appear in different phases of nuclear activity. The detection of simultaneous hydroxyl and water megamaser emission toward IC694 has called this hypothesis into question but, because many megamasers have not been surveyed for emission in the other molecule, it remains unclear whether IC694 occupies a narrow phase of galaxy evolution or whether the relationship between megamaser species and galactic processes is more complicated than previously believed. In this paper, we present results of a systematic search for 22 GHz water maser emission among OH megamaser hosts to identify additional objects hosting both megamaser. Our work roughly doubles the number of galaxies searched for emission in both molecules which host at least one confirmed maser. We confirm a definitive ( $>8\sigma$ ) detection of water emission toward IIZw96, firmly establishing it as the second object to co-host both water and hydroxyl megamasers after IC694. We find high luminosity, narrow features in the water feature in IIZw96. All dual megamaser candidates appear in merging galaxy systems suggestive that megamaser coexistence may signal a brief phase along the merger sequence. A statistical analysis of the results of our observations provide possible evidence for an exclusion of H<sub>2</sub>O kilomasers among OH megamaser hosts.

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**Institution(s):** 1. *Brigham Young University*

#### 440.08 – Searching for the Most UV-Luminous Galaxies in the Distant Universe

How galaxies grow and evolve over cosmic time is one of the largest unanswered questions in astronomy. With 50% of the stellar mass in today's galaxies having formed before  $z \sim 1$  (Dickinson et al. 2003) and the cosmic star formation density peaking between  $1 < z < 3$  (Madau & Dickinson 2014), the epoch at  $z > 3$  is particularly important for understanding the rise of the Hubble sequence at later times. We present multi-wavelength photometry from the the unprecedentedly large 28 deg<sup>2</sup> Hobby Eberly Telescope Dark Energy Experiment (HETDEX) / Spitzer-HETDEX Exploratory Large Area (SHELA) survey in a study of 800,000 galaxies at redshifts of 1.9 to 3.5 including significant numbers of the most massive and most rare galaxies, unseen in pencil-beam deep field surveys. We use ugriz photometry from the Dark Energy Camera (DECam) and fit galaxy spectral energy distributions (SEDs) with stellar population spectral templates to select LBGs at  $z \sim 3-4$  and measure the rest-frame ultraviolet (UV) luminosity function. Our survey's large area and moderate depth provide a unique view of the bright-end ( $M_{\text{AB}} < -22$ ). Contamination by stellar sources or active galactic nuclei (AGNs) can be ruled out by the inclusion of multi-wavelength data. Probing a volume of 0.5 Gpc<sup>3</sup> at  $1.9 < z < 3.5$ , similar to that of the Sloan Digital Sky Survey (SDSS) at  $z < 0.5$ , we provide the most definitive constraints for numerical models of cosmic galaxy evolution, expanding our knowledge of galaxy growth during this critical era in cosmic history.

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**Contributing team(s):** HETDEX Team

#### 440.09 – X-Ray Properties Along the Toomre Sequence of Galaxy Merger

As part of a study on the X-ray evolution of galaxies, we have analyzed the hot gas and X-ray binary population of merging galaxies. The Toomre sequence of merging galaxies is ideally suited to examine the role interactions and mergers play in the development and evolution of X-ray features.

The sample data from the Chandra X-ray Observatory archive includes the Brassington et al. (2007) and Fuse (2009) samples and an additional 7 merging galaxy pairs. By including a larger number of merging systems, a finer set of timesteps across the Toomre sequence can be analyzed and any trends can be better understood. The sample contains galaxy pairs early in their interactions, ~700 Myrs before nuclear coalescence, through systems ~4 Gyrs after merger.

The Brassington et al. (2007) study finds that the X-ray gas luminosity peaks 300 Myr before nuclear coalescence. Fuse (2009) identified the same trend for both the halo gas and the X-ray binary population. We are investigating the correlation between the hot gas and X-ray point sources, as well as the timing of the peak of X-ray emission.

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**Institution(s):** 1. Rollins College

#### 440.10 – Constraints on Feedback in the Local Universe: The Relation Between Star Formation and AGN Activity in Early Type Galaxies

We address the relation between star formation and AGN activity in a sample of 231 nearby ( $0.0002 < z < 0.0358$ ) early type galaxies by carrying out a multi-wavelength study using archival observations in the UV, IR and radio. Our results indicate that early type galaxies in the current epoch are rarely powerful AGNs, with  $P < 10^{22} \text{ WHz}^{-1}$  for a majority of the galaxies. Only massive galaxies are capable of hosting powerful radio sources while less massive galaxies are hosts to lower radio power sources. Evidence of ongoing star formation is seen in approximately 7% of the sample. The SFR of these galaxies is less than  $0.1 M_{\odot} \text{ yr}^{-1}$ . They also tend to be radio faint ( $P < 10^{22} \text{ WHz}^{-1}$ ). There is a nearly equal fraction of star forming galaxies in radio faint ( $P < 10^{22} \text{ WHz}^{-1}$ ) and radio bright galaxies ( $P \geq 10^{22} \text{ WHz}^{-1}$ ) suggesting that both star formation and radio mode feedback are constrained to be very low in our sample. We notice that our galaxy sample and the Brightest Cluster Galaxies (BCGs) follow similar trends in radio power versus SFR. This may be produced if both radio power and SFR are related to stellar mass.

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#### 440.11 – Most Massive Group Galaxies at Intermediate Redshifts

I present a study of the most massive group galaxies in the Group Environment and Evolution Collaboration (GEEC) sample of optically- and X-ray-selected groups at redshift  $z \sim 0.4$ . We include only those groups with sufficient completeness, ensuring that the most massive galaxy (MMG) has been observed spectroscopically. The position and dominance of the MMGs in their host groups is explored, basic properties of the MMGs are compared to those of control samples of satellites and field galaxies at similar stellar mass and redshift, and correlations of MMG properties with host group properties examined. While many MMGs are projected to lie close to the luminosity-weighted center, a broad range in the stellar mass fraction is found with some MMGs containing a large fraction of the total group stellar mass while others are not at all dominant.

Compared to central group galaxies in the local universe, the SSFR of the MMG in similar mass systems is found to be significantly higher. Star formation rates, morphologies, and mass fractions of the MMGs are also compared to control samples of non-MMG galaxies with similar stellar mass and redshift. While MMGs and satellite galaxies have SSFRs that agree at the 40% level, MMGs definitely do not come from the same distribution as field galaxies. As a function of stellar mass, the fraction of passive galaxies for both MMGs and satellites is systematically higher than the field. We cannot however confirm that, at the same stellar mass, MMGs are more quenched than satellites, as has been found in the local universe. 19 GEEC MMGs were imaged with HST-ACS and many show significant disk components, but the sample is too small to conclude whether or not the MMG morphologies are the same as stellar and redshift matched control samples of satellite and field galaxies. Finally, we search for correlation of MMG and global group properties, including group masses and dynamics. Thus far MMG properties appear to be only weakly correlated with the properties of the groups they inhabit in this redshift regime.

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#### 441 – Galaxies of all Types Late Poster Session

##### 441.01 – DECam Observations of the Tidal Shells Around NGC 3923

Stellar shells around elliptical galaxies are thought to be the results of near-radial mergers with low mass companions. Thus, the shell systems contain information about the merger history and gravitational potential of the elliptical galaxy. We present a preliminary census of the shell system of NGC 3923 from extremely deep g and i-band DECam imaging. NGC 3923 has the largest known shell system, with different studies finding between 27 and 42 shells. We present an overview of the DECam data reduction and an initial analysis of the shell system.

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##### 441.02 – Chandra Galaxy Atlas

We present the new results from the Chandra Galaxy Atlas project. We have systematically analyzed the archival Chandra data of 50 early type galaxies to study their hot ISM. Taking full advantage of the Chandra capabilities, we produced spatially resolved data products with additional spectral information. We will make these products publicly available and use them for our focused science goals, e.g., gas morphology, scaling relation, X-ray based mass profile, circum-nuclear gas.

**Author(s):** Dong-Woo Kim<sup>2</sup>, Craig Anderson<sup>2</sup>, Doug Burke<sup>2</sup>, Giuseppina Fabbiano<sup>2</sup>, Antonella Fruscione<sup>2</sup>, Jennifer L. Lauer<sup>2</sup>, Michael L. McCollough<sup>2</sup>, Doug Morgan<sup>2</sup>, Amy Mossman<sup>2</sup>, Ewan O'Sullivan<sup>2</sup>, Alessandro Paggi<sup>2</sup>, Ginevra Trinchieri<sup>1</sup>  
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##### 441.03 – The multi-wavelength Tully-Fisher relation: hunting for the intrinsic scatter

The statistical properties of the Tully-Fisher relation provide important constraints for semi-analytical models and numerical simulations of galaxy formation and evolution. Over the past decades, the scatter in the Tully-Fisher relation has been decreased significantly by accurate photometric measures in the NIR bands. However, the small measurement errors on total luminosity can no longer explain the observed scatter. Therefore, we abandon the classical concept of the Tully-Fisher relation as a correlation using

the width of global HI profile and consider instead the internal kinematics of gas in galaxies. As it is still not clear at which wavelengths the smallest scatter in the relation can be achieved, we assemble the Tully-Fisher relation for a calibrator sample of galaxies with measured TRGB/Cepheid distances over the broad wavelength range from FUV to 22 mm. We implement an improved kinematic measure by deriving high quality rotation curves, taking into account warps and streaming motions in the disk due to spiral arms or a bar.

As a result, our studies show that besides the wavelength dependence, statistical properties of the Tully-Fisher relation are highly sensitive to the internal kinematics of gas.

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#### **441.04 – M31AGES: Studying the intermediate-aged populations in the satellites, smooth halo, and substructure of Andromeda**

Recent large-scale surveys of M31 have enabled the study of its satellites, smooth halo, and substructure in exquisite detail. In particular, the Spectroscopic Landscape of Andromeda's Stellar Halo (SPLASH) survey has obtained moderate resolution optical spectra with the DEIMOS spectrograph on the Keck II/10-m telescope, and optical photometry from various ground-based telescopes. These data have been used to map the kinematics and metallicity distributions in the dSphs and dEs, detect and characterize substructure, and study the large-scale radial surface brightness and metallicity profiles of the "smooth" halo. Notwithstanding this progress [or] In spite of these advances, there are a number of outstanding questions that cannot be answered with these data alone, including the fraction of the halo that was formed *in situ* vs by accretion, and the degeneracy between massive early accretion events and less massive recent accretion events. The M31 Asymptotic Giant Extended Survey (M31AGES) aims to address these questions by using NIR photometry to identify intermediate-age AGB stars in the satellites, streams, and smooth halo of M31. We present the details of the observations (now completed), the plan for public release of data products, and preliminary results.

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**Contributing team(s):** M31AGES Survey Team

#### **441.05 – The Evolution of Dwarf Galaxies**

Dwarf galaxies are the most numerous galaxies in the Universe, yet the driving forces in their evolution remain elusive. The proposed evolutionary link between dwarf irregular and dwarf elliptical/spheroidal galaxies is investigated using broad-band UBVR photometry obtained for a sample of 29 dwarf galaxies. The galaxies span a range of absolute B-band magnitude from -13.67 to -19.86 mag. Broad-band colors and Sérsic surface brightness profile fits are compared for the two morphological types. All optical parameters are statistically different between the two subsamples, as evidenced by the significance level of the Kolmogorov-Smirnov statistic.

Others have noted that dwarf ellipticals might have looked much like the currently observed dwarf irregulars in the past based on optical colors. An overlap between in the range of colors observed is noted for these targets, implying the possibility of an evolutionary link. A difference is noted between the two samples in the value of  $n$  (the power-law exponent determined from the Sérsic profile fitting), suggesting that the two main types of dwarf galaxy are structurally distinct. The differences in the structure of the stellar components would imply that dwarf irregulars do not evolve to become dwarf ellipticals in isolation, meaning that some sort of external interaction is required if the transformation is to occur. However, when the brightest dwarf elliptical targets are eliminated from the comparison, the two dwarf samples are much more similar in their values and range for the power-law exponent, which again suggests a possible evolutionary link. The environments of the galaxies are initially classified as either field or group/cluster, though no definitive environmental comparison is presented here.

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#### **441.06 – A Receding Halo Sub-structure Towards Norma**

We present results from follow-up spectroscopic observations of clustered Cepheid candidates identified from *K*-band light curves towards the Norma constellation (Chakrabarti et al. 2015), as well as others that we have found more recently. The average radial velocity of these stars is  $\sim 200$  km/s, which is large and distinct from that of the Galaxy's stellar disk. These objects at  $l \sim -27$  and  $b \sim -1$  are therefore halo stars; using the period-luminosity relation of Type I Cepheids, they are at  $\sim 90$  kpc. While the spectra do not have sufficient *S/N* to independently determine the metallicity and spectral type of the stars, there is a clear correspondence between the observed Brackett series lines in these observations and in known Type I Cepheids. Distances determined from the *K*-band period-luminosity relation (Matsunaga et al. 2013) and the  $3.6 \mu\text{m}$  period-luminosity relation (Scowcroft et al. 2011) agree closely, and *I*-band observations have confirmed the periods of these sources. The extinction corrected  $J - K_s$  colors of these sources are comparable to known Type I Cepheids (Persson et al. 2004). The observed radial velocity of these stars agrees with predictions from dynamical models (Chakrabarti & Blitz 2009). If these stars are indeed members of the predicted dark-matter dominated dwarf galaxy that perturbed the outer HI disk of the Milky Way, this would represent the first application of Galactoseismology. These observations also challenge models of the Galactic halo. Young Cepheid variables are unexpected in models of the Galactic halo, though star formation due to infall of gas-rich dwarf galaxies may well produce a small population of yet undiscovered Cepheids in the outer halo.

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### **442 – Gravitational Waves, Lenses and GRBs Late Poster Session**

#### **442.01 – A Search for Structure in Gamma Ray Burst X-ray Flares Confirming Whether They Are Similar To The Three Pulse Structure Found In Propt Emission Pulses**

Gamma Ray Bursts (GRBs) are the the most luminous electromagnetic events known to occur throughout the Universe. These violent explosions produce relativistic jets in a short burst of prompt emission and are followed by an afterglow emitted across the electromagnetic spectrum. During the afterglow, there are periods of sporadic increase in the X-ray flux, known as flares. Only  $\sim 1/2$  of all GRBs produce flares. We present a sample selection of the brightest isolated flares observed by the Swift X-Ray Telescope (XRT). Using light curves from the XRT Team repository at the University of Leicester between 2005 and 2014, and our own light curve fits, the sample was filtered using a stringent set of criteria. We selected bursts that: 1) had a high peak flare flux to afterglow ratio, and/or 2) a high fluence (integrated flux). By further analyzing these flares, we will study the structure of flares, searching for the three components that have been seen in isolated prompt emission pulses: an initial small rapidly decaying pulse, followed by the main flare which then decays over time and is followed by another small but slower decaying pulse. Seeing a similar behavior in X-ray flares as we see in prompt pulses will inform models for the physics of relativistic shocks.

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#### **442.02 – A sample gamma-ray bursts with low luminosity afterglow to statistically derive their properties**

It is well known that some peculiar gamma-ray bursts have a low luminosity prompt phase. From this set of 2-3 events, it was derived what should be the general properties of these events, without statistical validations. We have constructed a sample of events with a

low-luminosity afterglow phase in order to perform this statistical validation. We can confirm that this population is in general also faint in the prompt phase, albeit a few exceptions, and do not follow the Amati relation. We have studied their intrinsic properties (spectral index, decay index, distance, luminosity, isotropic radiated energy and peak energy) to assess whether they belong to the same population than the brighter afterglow events. We can statistically validate the hypothesis previously done that these events belong to a population of nearby events, different from that of the general population of long gamma-ray bursts. Last, we notice that about 65% of the confirmed gamma-ray burst-supernova associations belong to this group of faint events. While this is probably due to a selection effect, we discuss its consequence (these supernova templates should not be used blindly on normal long gamma-ray bursts).

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#### 442.03 – Observing Gravitational Waves from Core-Collapse Supernovae in the Advanced Detector Era

The next galactic core-collapse supernova (CCSN) has already exploded, and its electromagnetic (EM) waves, neutrinos, and gravitational waves (GWs) may arrive at any moment. We present an extensive study on the potential sensitivity of prospective detection scenarios for GWs from CCSNe within 5Mpc, using realistic noise at the predicted sensitivity of the Advanced LIGO and Advanced Virgo detectors for 2015, 2017, and 2019. We quantify the detectability of GWs from CCSNe within the Milky Way and Large Magellanic Cloud, for which there will be an observed neutrino burst. We also consider extreme GW emission scenarios for more distant CCSNe with an associated EM signature. We find that a three detector network at design sensitivity will be able to detect neutrino-driven CCSN explosions out to  $\sim 5.5$  kpc, while rapidly rotating core collapse will be detectable out to the Large Magellanic Cloud at 50kpc. Of the phenomenological models for extreme GW emission scenarios considered in this study, such as long-lived bar-mode instabilities and disk fragmentation instabilities, all models considered will be detectable out to M31 at 0.77 Mpc, while the most extreme models will be detectable out to M82 at 3.52 Mpc and beyond.

**Author(s):** Sarah Gossan<sup>1</sup>, Patrick Sutton<sup>2</sup>, Amber L. Stuver<sup>4</sup>, Michele Zanolin<sup>3</sup>, Kiranjyot Gill<sup>3</sup>, Christian D. Ott<sup>1</sup>

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#### 442.04 – X-ray Line Profile Variations During Quasar Microlensing

Observations of gravitationally lensed quasars have revealed X-ray line profile variations occurring during microlensing events. We simulate the effect using a simple model: a microlensing fold caustic crossing a spatially resolved model of Fe K $\alpha$  line emission from a thin accretion disk around a Kerr black hole. We demonstrate the appearance of additional peaks and edges in the line profile. We illustrate the underlying mechanism of their generation and derive analytical expressions for their shape.

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#### 442.05 – Multi-messenger astronomy of gravitational-wave sources with flexible wide-area radio transient surveys

We explore opportunities for multi-messenger astronomy using gravitational waves (GWs) and prompt, transient low-frequency radio emission to study highly energetic astrophysical events. We review the literature on possible sources of correlated emission of GWs and radio transients, highlighting proposed mechanisms that lead to a short-duration, high-flux radio pulse originating from the

merger of two neutron stars or from a superconducting cosmic string cusp. We discuss the detection prospects for each of these mechanisms by low-frequency dipole array instruments such as LWA1, the Low Frequency Array and the Murchison Widefield Array. We find that a broad range of models may be tested by searching for radio pulses that, when de-dispersed, are temporally and spatially coincident with a LIGO/Virgo GW trigger within a  $\sim 30$  s time window and  $\sim 200$ – $500$  deg(2) sky region. We consider various possible observing strategies and discuss their advantages and disadvantages. Uniquely, for low-frequency radio arrays, dispersion can delay the radio pulse until after low-latency GW data analysis has identified and reported an event candidate, enabling a prompt radio signal to be captured by a deliberately targeted beam. If neutron star mergers do have detectable prompt radio emissions, a coincident search with the GW detector network and low-frequency radio arrays could increase the LIGO/Virgo effective search volume by up to a factor of  $\sim 2$ . For some models, we also map the parameter space that may be constrained by non-detections.

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**Contributing team(s):** Cregg C. Yancey, Brandon E. Bear, Bernadine Akukwe, Kevin Chen, Jayce Dowell, Jonathan D. Gough, Jonah Kanner, Kenneth Obenberger, Peter Shawhan, John H. Simonetti, Gregory B. Taylor, Jr-Wei Tsai

### 443 – Cosmology Late Poster Session

#### 443.01 – Quasar clustering at intermediate redshift - Analysis of systematics and of luminosity effects

We measure the clustering of over 55,000 quasars at redshifts  $2.2 < z < 3.4$  drawn from the final sample of the Baryonic Oscillation Spectroscopic Survey (BOSS). This is by far the largest sample ever used to study quasar clustering at "intermediate" redshifts. We ameliorate the effect of observational systematics on our clustering analyses by weighting our control catalogues of random points by maps of how observational systematics correlate with the BOSS quasar target density. We find that there is no significant evolution in the quasar correlation length and bias over our studied redshift range, implying that the masses of the dark matter halos that host quasars decreases slightly from  $z \sim 2.2$  to  $z \sim 3.4$ . Our result also contradicts a monotonic relation between the optical luminosity of quasars near redshift 2.5 and their host halo masses. To begin to study whether this contradiction holds for quasars' bolometric luminosity, we use data from the Wide-field Infra red Survey Explorer (WISE) to study whether the luminosity or detection of BOSS quasars in the mid-IR is correlated with the masses of quasars' host halos. This work was partially supported by NSF award 1211112.

**Author(s):** Sarah Eftekharzadeh<sup>6</sup>, Adam D. Myers<sup>6</sup>, Ehsan Kourkchi<sup>8</sup>, Michael A. DiPompeo<sup>6</sup>, Martin White<sup>11</sup>, David, H. Weinberg<sup>4</sup>, Andreu Font-Ribera<sup>10</sup>, Jian Ge<sup>5</sup>, Isabelle Paris<sup>9</sup>, Nicholas P. Ross<sup>7</sup>, Donald P. Schneider<sup>3</sup>, Yue Shen<sup>2</sup>, Alina Streblyanska<sup>1</sup>

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#### 443.02 – Possible New Horizons Fundamental Contribution to Cosmology

The New Horizons (NH) spacecraft (S. Alan Stern, PI) is now past Pluto, and in our poster we explore the possibility of making observations, using the NH P-Alice ultraviolet spectrometer, of the cosmic diffuse ultraviolet background radiation, particularly at high northern and southern Galactic latitudes. In the paper, "The Mystery of the Cosmic Diffuse Ultraviolet Background Radiation," by Richard Conn Henry, Jayant Murthy, James Overduin, Joshua Tyler, ApJ,

798:14 (25pp), 2015 January 1, we demonstrated the existence of a *second component* of the diffuse far ultraviolet background radiation beyond that provided by dust-scattered starlight. The critical question is, does that second component (of unknown origin) extend shortward of the Lyman limit of 912 Å? If it does, then it seems likely that we have discovered the source of the reionization of the Universe that occurred some time after recombination. As things stand at the moment, there is no known source that has been demonstrated to be capable of performing the reionization: reionization that clearly did occur. Our current understanding of P-Alice suggests that it may well be capable of demonstrating the presence (or absence) of such ionizing cosmic diffuse radiation. At low Galactic latitudes, all such radiation would be totally erased by the presence, in large quantities, of interstellar neutral hydrogen; this will allow us to test the reality of any such flux that we may discover at higher Galactic latitudes.

**Author(s):** Richard Conn Henry<sup>2</sup>, Jayant Murthy<sup>1</sup>  
**Institution(s):** 1. *Indian Institute of Astrophysics*, 2. *Johns Hopkins Univ.*

#### 443.03 – The HST Frontier Fields: High-Level Science Data Products for the First 4 Completed Clusters, and Latest Data on the Remaining Clusters

The Hubble Space Telescope Frontier Fields program is a large Director's Discretionary program of 840 orbits, to obtain ultra-deep observations of six strong lensing clusters of galaxies, together with parallel deep blank fields, making use of the strong lensing amplification by these clusters of distant background galaxies to detect the faintest galaxies currently observable in the high-redshift universe. The first four of these clusters are now complete, namely Abell 2744, MACS J0416.1-2403, MACS J0717.5+3745 and MACS J1149.5+2223, with each of these having been observed over two epochs, to a total depth of 140 orbits on the main cluster and an associated parallel field, using ACS (F435W, F606W, F814W) and WFC3/IR (F105W, F125W, F140W, F160W). The remaining two clusters, Abell 370 and Abell S1063, are currently in progress. Full sets of high-level science products have been generated for all these clusters by the team at STScI, including a total of 24 separate cumulative-depth data releases during each epoch, as well as full-depth version 1.0 releases at the end of each completed epoch. These products include all the full-depth distortion-corrected mosaics and associated products for each cluster, which are science-ready to facilitate the construction of lensing models as well as enabling a wide range of other science projects. Many improvements beyond default calibration for ACS and WFC3/IR are implemented in these data products, including corrections for persistence, time-variable sky, and low-level dark current residuals, as well as improvements in astrometric alignment to achieve milliarcsecond-level accuracy. The resulting high-level science products are delivered via the Mikulski Archive for Space Telescopes (MAST) to the community on a rapid timescale to enable the widest scientific use of these data, as well as ensuring a public legacy dataset of the highest possible quality that is of lasting value to the entire community.

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**Contributing team(s):** HST Frontier Fields Team

#### 443.04 – 21 cm Fluctuations of the Cosmic Dawn with the Owens Valley Long Wavelength Array

The Owens Valley Long Wavelength Array (OVRO LWA) is a 288-antenna interferometer covering 30 to 80 MHz located at the Owens Valley Radio Observatory (OVRO) near Big Pine, California. I am leading the effort to detect spatial fluctuations of the 21 cm transition from the cosmic dawn ( $z \sim 20$ ) with the OVRO LWA. These spatial fluctuations are primarily sourced by inhomogeneous X-ray heating from early star formation. The spectral hardness of early X-ray sources, stellar feedback mechanisms, and baryon streaming therefore all play a role in shaping the power spectrum. I will present the application of m-mode analysis (Shaw et al. 2014, Shaw et al.

2015) to OVRO LWA data to: 1. compress the data set, 2. create maps of the northern sky that can be fed back into the calibration pipeline, and 3. filter foreground emission. Finally I will present the current status and future prospects of the OVRO LWA for detecting the 21 cm power spectrum at  $z \sim 20$ .

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**Institution(s):** 1. *Caltech*  
**Contributing team(s):** The Owens Valley LWA collaboration

#### 443.05 – The halo mass function goes nonlinear

When using cluster number counts to estimate cosmological parameters, cosmological model information at the nonlinear level can be incorporated into the halo mass function. Here the halo mass function is carefully recalibrated to include the effect of dark energy perturbations for an accurate description, employing the spherical collapse formalism. Using our MCMC likelihood analysis of X-ray cluster samples together with standard cosmological data sets, we constrain cosmological parameters when incorporating these nonlinear corrections. We emphasize the impact on the constraints of the cosmological parameters and the relevance of including these corrections in the cluster mass function calculation.

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**Institution(s):** 1. *Argelander-Institute for Astronomy*, 2. *Dark Cosmology Centre, University of Copenhagen*, 3. *Department of Astronomy and Astrophysics, University of Chicago*, 4. *SLAC National Accelerator Laboratory*, 5. *Stony Brook University*

#### 443.06 – The Co-evolution of Cosmic Entropy and Structures in the Universe

According to the second law of thermodynamics, the arrow of time points to an ever increasing entropy of the Universe. However, exactly how the entropy evolves with time and what drives the growth remain largely unknown. Here, for the first time, we quantify the evolving entropy of cosmic structures using a large-scale cosmological hydrodynamical simulation. Our simulation starts from initial conditions predicted by the leading  $\Lambda$ CDM cosmology, self-consistently evolves the dynamics of both dark and baryonic matter, star formation, black hole growth and feedback processes, from the cosmic dawn to the present day. Tracing the entropy contributions of these distinct components in the simulation, we find a strong link between entropy growth and structure formation. The entropy is dominated by that of the black holes in all epochs, and its evolution follows the same path as that of galaxies: it increases rapidly from a low-entropy state at high redshift until  $z \sim 2$ , then transits to a slower growth. Our results suggest that cosmic entropy may co-evolve with cosmic structure, and that its growth may be driven mainly by the formation of black holes in galaxies. We predict that the entropy will continue to increase in the near future, but likely at a constant rate.

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#### 443.07 – The Environmental Dependence of the Galaxy Luminosity Function in the ECO Survey

We study the environmental dependence of the galaxy luminosity function in the ECO survey and compare it with models that associate galaxies with dark matter halos. Specifically, we quantify the environment of each galaxy in the ECO survey using an Nth nearest neighbor distance metric, and we measure how the galaxy luminosity distribution varies from low density to high density environments. As expected, we find that luminous galaxies preferentially populate high density regions, while low luminosity galaxies preferentially populate lower density environments. We investigate whether this trend can be explained simply by the correlation of galaxy luminosity and dark matter halo mass combined with the environmental dependence of the halo mass function. In other words, we test the hypothesis that the luminosity of a galaxy depends solely on the mass of its dark matter halo and

does not exhibit a residual dependence on the halo's larger environment. To test this hypothesis, we first construct mock ECO catalogs by populating dark matter halos in an N-body simulation with galaxies using a model that preserves the overall clustering strength of the galaxy population. We then assign luminosities to the mock galaxies using physically motivated models that connect luminosity to halo mass and are constrained to match the global ECO luminosity function. Finally, we impose the radial and angular selection functions of the ECO survey and repeat our environmental analysis on the mock catalogs. Though our mock catalog luminosity functions display similar qualitative trends as those from the ECO data, the trends are not in agreement quantitatively. Our results thus suggest that the simple models used to build the mocks are incomplete and that galaxy luminosity is possibly correlated with the larger scale density field.

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**Contributing team(s):** Andreas A. Berlind, Victor Calderon, Kathleen D. Eckert, Sheila J. Kannappan, Amanda J. Moffett, David V. Stark

#### **443.08 – Searches for Decaying Sterile Neutrinos with the X-Ray Quantum Calorimeter Sounding Rocket**

Rocket borne X-ray spectrometers can produce high-resolution spectra for wide field-of-view observations. This is useful in searches for dark matter candidates that produce X-ray lines in the Milky Way, such as decaying keV scale sterile neutrinos. In spite of exposure times and effective areas that are significantly smaller than satellite observatories, similar sensitivity to decaying sterile neutrinos can be attained due to the high spectral resolution and large field of view. We present recent results of such a search analyzing the telemetered data from the 2011 flight of the X-Ray Quantum Calorimeter instrument as well as ongoing progress in expanding the data set to include the more complete onboard data over additional flights.

**Author(s):** David Goldfinger<sup>1</sup>

**Institution(s):** 1. Massachusetts Institute of Technology

**Contributing team(s):** The XQC Collaboration

### **444 – Catalog, Surveys, Computation and Related Topics Late Poster Session**

#### **444.01 – The Hubble Spectroscopic Legacy Archive**

With no future space ultraviolet instruments currently planned, the data from the UV spectrographs aboard the Hubble Space Telescope have a legacy value beyond their initial science goals. The Hubble Spectroscopic Legacy Archive will provide to the community new science-grade combined spectra for all publicly available data obtained by the Cosmic Origins Spectrograph (COS) and the Space Telescope Imaging Spectrograph (STIS). These data will be packaged into “smart archives” according to target type and scientific themes to facilitate the construction of archival samples for common science uses. A new “quick look” capability will make the data easy for users to quickly access, assess the quality of, and download for archival science starting in Cycle 24, with the first generation of these products for the FUV modes of COS available online via MAST in early 2016.

**Author(s):** Molly S. Peeples<sup>2</sup>, Jason Tumlinson<sup>2</sup>, Andrew Fox<sup>2</sup>, Alessandra Aloisi<sup>2</sup>, Thomas R. Ayres<sup>3</sup>, Charles Danforth<sup>3</sup>, Scott W. Fleming<sup>2</sup>, Edward B. Jenkins<sup>1</sup>, Robert I. Jedrzejewski<sup>2</sup>, Brian A. Keeney<sup>3</sup>, Cristina M. Oliveira<sup>2</sup>

**Institution(s):** 1. Princeton University, 2. Space Telescope Science Institute, 3. University of Colorado

#### **444.02 – Proposal Auto-Categorizer and Manager for Time Allocation Review at Space Telescope Science Institute**

The Space Telescope Science Institute annually receives more than one thousand formal proposals for Hubble Space Telescope time,

exceeding the available time with the observatory by a factor of over four. With JWST, the proposal pressure will only increase, straining our ability to provide rigorous peer review of each proposal's scientific merit. Significant hurdles in this process include the proper categorization of proposals, to ensure Time Allocation Committees (TACs) have the required and desired expertise to fairly and appropriately judge each proposal, and the selection of reviewers themselves, to establish diverse and well-qualified TACs. The Panel Auto-Categorizer and Manager (PACMan; a naive Bayesian classifier) was developed to automatically sort new proposals into their appropriate science categories and, similarly, to appoint panel reviewers with the best qualifications to serve on the corresponding TACs. We will provide an overview of PACMan and present the results of its testing on five previous cycles of proposals. PACMan will be implemented in upcoming cycles to support and eventually replace the process for constructing the time allocation reviews.

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**Institution(s):** 1. Johns Hopkins University, 2. Space Telescope Science Institute

#### **444.03 – NASA Astrophysics Funds Strategic Technology Development**

The COR and PCOS Program Offices (POs) reside at the NASA Goddard Space Flight Center (GSFC), serving as the NASA Astrophysics Division's implementation arm for matters relating to the two programs. One aspect of the PO's activities is managing the COR and PCOS Strategic Astrophysics Technology (SAT) program, helping mature technologies to enable and enhance future astrophysics missions. For example, the SAT program is expected to fund key technology developments needed to close gaps identified by Science and Technology Definition Teams (STDTs) planned to study several large mission concept studies in preparation for the 2020 Decadal Survey.

The POs are guided by the National Research Council's “New Worlds, New Horizons in Astronomy and Astrophysics” Decadal Survey report, NASA's Astrophysics Implementation Plan, and the visionary Astrophysics Roadmap, “Enduring Quests, Daring Visions.” Strategic goals include dark energy, gravitational waves, and X-ray observatories. Future missions pursuing these goals include, e.g., US participation in ESA's Euclid, Athena, and L3 missions; Inflation probe; and a large UV/Optical/IR (LUVOIR) telescope.

To date, 65 COR and 71 PCOS SAT proposals have been received, of which 15 COR and 22 PCOS projects were funded. Notable successes include maturation of a new far-IR detector, later adopted by the SOFIA HAWC instrument; maturation of the H4RG near-IR detector, adopted by WFIRST; development of an antenna-coupled transition-edge superconducting bolometer, a technology deployed by BICEP2/BICEP3/Keck to measure polarization in the CMB signal; advanced UV reflective coatings implemented on the optics of GOLD and ICON, two heliophysics Explorers; and finally, the REXIS instrument on OSIRIS-REx is incorporating CCDs with directly deposited optical blocking filters developed by another SAT-funded project.

We discuss our technology development process, with community input and strategic prioritization informing calls for SAT proposals and guiding investment decisions. We also present results of this year's technology gap prioritization and showcase our current portfolio of technology development projects.

**Author(s):** Bernard D. Seery<sup>1</sup>, Opher Ganel<sup>1</sup>, Bruce Pham<sup>1</sup>

**Institution(s):** 1. NASA's GSFC

#### **444.04 – Derivation of Johnson-Cousins Magnitudes from DSLR Camera Observations**

The RGB Bayer filter system consists of a mosaic of R, G, and B filters on the grid of the photo sensors which typical commercial DSLR (Digital Single Lens Reflex) cameras and CCD cameras are equipped with. Lot of unique astronomical data obtained using an RGB Bayer filter system are available, including transient objects, e.g. supernovae, variable stars, and solar system bodies. The utilization of such data in scientific research requires that reliable photometric transformation methods are available between the

systems. In this work, we develop a series of equations to convert the observed magnitudes in the RGB Bayer filter system ( $R_B$ ,  $G_B$ , and  $B_B$ ) into the Johnson-Cousins BVR filter system ( $B_J$ ,  $V_J$ , and  $R_C$ ). The new transformation equations derive the calculated magnitudes in the Johnson-Cousins filters ( $B_{Jcal}$ ,  $V_{Jcal}$ , and  $R_{Ccal}$ ) as functions of RGB magnitudes and colors. The mean differences between the transformed magnitudes and original magnitudes, i.e. the residuals, are  $(B_J - B_{Jcal}) = 0.064$  mag,  $(V_J - V_{Jcal}) = 0.041$  mag, and  $(R_C - R_{Ccal}) = 0.039$  mag. The calculated Johnson-Cousins magnitudes from the transformation equations show a good linear correlation with the observed Johnson-Cousins magnitudes.

**Author(s):** Woojin Park<sup>3</sup>, Soojong Pak<sup>3</sup>, Hyunjin Shim<sup>4</sup>, Huynh Anh N. Le<sup>3</sup>, Myungshin Im<sup>5</sup>, Seunghyuk Chang<sup>2</sup>, Joonkyu Yu<sup>1</sup>  
**Institution(s):** 1. Hwasangdae Observatory, 2. Korea Advanced Institute of Science and Technology (KAIST), 3. Kyunghee University, 4. Kyungpook National University, 5. Seoul National University

#### 444.05 – First parallax results from URAT data

The first USNO Robotic Astrometric Telescope catalog (URAT1) was released in April 2015. The catalog contains 228 million objects covering most of the sky north of declination -15 degrees for observations made between 2012 April 24 until 2014 June 21. The URAT northern observations were completed in June 2015 and all individual epoch positions with typical 10 to 70 mas errors are available for this study. The average number of observation per star is about 25.

We have created a URAT parallax pipeline utilizing code from the Research Consortium On Nearby Stars (RECONS) parallax pipeline. The URAT pipeline reads in all 'good' epoch data of a given object then calculates a mean position, proper motion and relative parallax using the JPL DE405 ephemerides.

We compare results of 696 objects found in both the Hipparcos and Yale Parallax Catalog (YPC) north of -10 degrees declination which also have a URAT relative parallax. URAT results are consistent with Hipparcos and YPC data, getting meaningful results, particularly for stars with a parallax of 40 mas or larger. Typical URAT parallax errors are between 5 and 15 mas, depending on observing history. The main goal of this project is to find new nearby stars using the URAT epoch data. First results are presented for stars which previously did not have a published parallax.

**Author(s):** Norbert Zacharias<sup>2</sup>, Charlie T. Finch<sup>2</sup>, Wei-Chun Jao<sup>1</sup>  
**Institution(s):** 1. RECONS, 2. U.S. Naval Observatory

#### 444.06 – WorldWide Telescope: A Newly Open Source Astronomy Visualization System

After eight years of development by Microsoft Research, WorldWide Telescope (WWT) was made an open source project at the end of June 2015. WWT was motivated by the desire to put new surveys of objects, such as the Sloan Digital Sky Survey in the context of the night sky. The development of WWT under Microsoft started with the creation of a Windows desktop client that is widely used in various education, outreach and research projects. Using this, users can explore the data built into WWT as well as data that is loaded in. Beyond exploration, WWT can be used to create tours that present various datasets a narrative format.

In the past two years, the team developed a collection of web controls, including an HTML5 web client, which contains much of the functionality of the Windows desktop client. The project under Microsoft has deep connections with several user communities such as education through the WWT Ambassadors program, <http://wwtambassadors.org/> and with planetariums and museums such as the Adler Planetarium. WWT can also support research, including using WWT to visualize the Bones of the Milky Way and rich connections between WWT and the Astrophysical Data Systems (ADS, <http://labs.adsabs.harvard.edu/adsabs/>). One important new research connection is the use of WWT to create dynamic and potentially interactive supplements to journal articles, which have

been created in 2015.

Now WWT is an open source community lead project. The source code is available in GitHub (<https://github.com/WorldWideTelescope>). There is significant developer documentation on the website (<http://worldwidetelescope.org/Developers/>) and an extensive developer workshops ([http://wwtworkshops.org/?tribe\\_events=wwt-developer-workshop](http://wwtworkshops.org/?tribe_events=wwt-developer-workshop)) has taken place in the fall of 2015. Now that WWT is open source anyone who has the interest in the project can be a contributor. As important as helping out with coding, the project needs people interested in documentation, testing, training and other roles.

**Author(s):** Jonathan Fay<sup>1</sup>, Douglas A. Roberts<sup>2</sup>  
**Institution(s):** 1. Microsoft, 2. Northwestern University

#### 444.07 – The effect of plasma shear flow on drift Alfvén instabilities of a finite beta plasma and on anomalous heating of ions by ion cyclotron turbulence

It was derived that the drift-Alfvén instabilities with the shear flow parallel to the magnetic field have significant difference from the drift-Alfvén instabilities of a shearless plasma when the ion temperature is comparable with electron temperature for a finite plasma beta. The velocity shear not only modifies the frequency and the growth rate of the known drift-Alfvén instability, which develops due to the inverse electron Landau damping, but also triggers a combined effect of the velocity shear and the inverse ion Landau damping, which manifests the development of the ion kinetic shear-flow-driven drift-Alfvén instability. The excited unstable waves have the phase velocities along the magnetic field comparable with the ion thermal velocity, and the growth rate is comparable with the frequency. The development of this instability may be the efficient mechanism of the ion energization in shear flows. The levels of the drift-Alfvén turbulence, resulted from the development of both instabilities, are determined from the renormalized nonlinear dispersion equation, which accounts for the nonlinear effect of the scattering of ions by the electromagnetic turbulence. The renormalized quasilinear equation for the ion distribution function, which accounts for the same effect of the scattering of ions by electromagnetic turbulence, is derived and employed for the analysis of the ion viscosity and ions heating, resulted from the interactions of ions with drift-Alfvén turbulence. In the same way, the phenomena of the ion cyclotron turbulence and anomalous anisotropic heating of ions by ion cyclotron plasma turbulence has numerous practical applications in physics of the near-Earth space plasmas. Using the methodology of the shearing modes, the kinetic theory of the ion cyclotron turbulence of the plasma with transverse current with strong velocity shear has been developed.

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**Institution(s):** 1. Pusan National University

#### 444.08 – The Dark Energy Survey Pipeline

The Dark Energy Survey (DES) is a large optical survey that is intended to study cosmology using Type Ia supernovae, baryon acoustic oscillations, galaxy cluster counting and gravitational lensing. DES comprises two five year surveys (roughly 100 nights per year) on the Blanco 4-m telescope at the Cerro Tololo Interamerican Observatory (CTIO) in Chile. The first is a 5,000 square degree survey of the high Galactic latitude Southern sky to roughly 24th magnitude in the  $g$ ,  $r$ ,  $i$ ,  $z$  and  $Y$  filters. The second is a set of ten 3 square degree fields that are observed roughly once every five nights as a supernova survey. DES will be significantly deeper than and have superior image quality to previous wide field surveys like SDSS and Pan-STARRS1. Reduced DES images are made public at NOAO roughly one year after the images are taken. DES plans to release its first two years of data (images and catalogs) in 2017 and its entire dataset after it finishes taking data in 2018. The National Center for Supercomputing Applications (NCSA) at the University of Illinois is leading the DES data processing. I describe this data processing, the DES pipeline and the DES data in this poster.

**Author(s):** Eric Morganson<sup>1</sup>

**Institution(s):** 1. National Center for Supercomputing Applications

**Contributing team(s):** Dark Energy Survey Data Management Team

## 445 – Instrumentation on Earth and in Space Late Poster Session

### 445.01 – Gemini South Multi-Object Spectrograph (GMOS-S) detector Video boards upgrade: improved performance for the Hamamatsu CCDs.

GMOS-S was upgraded with new Hamamatsu CCDs on June 2014, featuring an improved red sensitivity with respect to the previous detectors and significantly less fringing. Early after the commissioning, an issue was identified when observing in any of the binned readout modes, namely that saturated pixels produced a decrease of counts with respect to the bias level in neighboring pixels. This effect, also known as 'banding', spanned the entire width of the amplifier, and while it did not destroy information, it rendered data reduction very cumbersome. Making matters worse, due to the saturation of a bad column on amplifier number 5 (on CCD2, near the middle of the focal plane), it ended up affecting the entire amplifier for almost all exposures longer than a minute. A team of Gemini instrument scientists and engineers investigated the issue and identified the root cause of the problem as originated in the ARC controller video boards. After significant lab testing, it was verified that a newly available revision of the video boards would solve the problem, though modification of the software was required in order to be compatible with them. This work was performed during the last semester of 2014 and the first semester of 2015. The new video boards were installed and commissioned during August 2015. As of September 1st, the new boards are fully installed and integrated, and the 'banding' effect has been completely eliminated. A short period of time was devoted to the recharacterization of the detector system and the new values for the gains, read noise and full well capacity have been derived. As an added benefit, the full well was increased by ~ 10 percent with respect to the previous value. The GMOS-S new detectors are now operating normally in the Gemini observing queue, and performing at full capacity.

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**Institution(s):** 1. Gemini Observatory, 2. Gemini Observatory

### 445.02 – The Alignment System for a Medium-Sized Schwarzschild-Couder Telescope Prototype for the Cherenkov Telescope Array

The Cherenkov Telescope Array (CTA) is an international project for a next-generation ground-based gamma-ray observatory. CTA, conceived as an array of tens of imaging atmospheric Cherenkov telescopes, comprising small, medium and large-size telescopes, is aiming to improve on the sensitivity of current-generation experiments by an order of magnitude and provide energy coverage from 20 GeV to more than 300 TeV. The Schwarzschild-Couder design is a candidate 9-m diameter medium-sized telescope featuring a novel aplanatic two-mirror optical design capable of a wide field of view with significantly improved imaging resolution as compared to the traditional Davies-Cotton optical design. Achieving this imaging resolution imposes strict mirror alignment requirements that necessitate a sophisticated alignment system. This system uses a collection of position sensors between panels to determine the relative position of adjacent panels; each panel is mounted on a Stewart platform to allow motion control with six degrees of freedom, facilitating the alignment of the optical surface for the segmented primary and secondary mirrors. Alignments of the primary and secondary mirrors and the camera focal plane with respect to each other are performed utilizing a set of CCD cameras which image LEDs placed on the mirror panels to measure relative translation, and custom-built auto-collimators to measure relative tilt between the primary and secondary mirrors along the optical axis

of the telescope. In this contribution we present the status of the development of the SC optical alignment system, soon to be materialized in a full-scale prototype SC medium-size telescope (pSCT) at the Fred Lawrence Whipple Observatory in southern Arizona.

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**Institution(s):** 1. Columbia University

**Contributing team(s):** V Vassiliev group in UCLA division of Astronomy and Astrophysics, P Kaaret group at Iowa University Department of Physics and Astronomy, for the CTA Consortium

### 445.03 – The Gemini Science User Support

#### Department: A community-centered approach to user support

The Gemini Science User Support Department (SUSD) was formed a little more than a year ago to create a collaborative community of users and staff and to consolidate existing post-observing support throughout the observatory for more efficient use of resources as well as better visibility amongst our user community. This poster is an opportunity to exchange ideas about how Gemini can improve your experience while working with the Observatory and present details about new avenues of post-observing support coming soon. We encourage your feedback at any time.

Shortly after its creation, the SUSD conducted a complete revision of the communication cycle between Gemini and its community of researchers. The cycle was then revisited from the perspective of an astronomer interested in using Gemini for their research. This exercise led to a series of proposed changes that are currently under development, and the implementation of a sub-selection is expected in 2016, including the following. (1) Email notifications: Gemini users will receive new forms of email communications that are more instructive and tailored to their program. The objective is to direct the users more efficiently toward the useful links and documentation all along the lifecycle of the program, from phase II to after the data are completely reduced. (2) HelpDesk system: The HelpDesk will become more user-friendly and transparent. (3) Webpages: The organization of the Gemini webpages will be redesigned to optimize navigation; especially for anything regarding more critical periods like phase IIs and phase IIs. (4) Data Reduction User Forum: Following recommendations from Gemini users, new capabilities were added to the forum, like email notifications, and a voting system, in order to make it more practical. This forum's objective is to bring the Gemini community together to exchange their ideas, thoughts, questions and solutions about data reduction, a sort of Reddit, StackOverflow or Slashdot for Gemini data.

**Author(s):** André-Nicolas Chené<sup>1</sup>, Joanna Thomas-Osip<sup>1</sup>

**Institution(s):** 1. Gemini Observatory

### 445.04 – Non-interferometer Phase-differential Imaging Method with a Single Telescope Installation

Non-interferometer phase-differential imaging method for direct imaging of the astronomical objects will be presented. The feasibility of non-interferometry method to retrieve the phase differential images of the astronomical objects is demonstrated in the laboratory experiments exploiting the two-dimensional Foucault knife-edge filtering method which is installed on a single telescope. The experiment setup is essentially analogous to the Schlieren imaging apparatus that can be taken images using an incoherent light source. The fractional derivation filtering by the two-dimensional knife-edge filter is developed in order to acquire the phase information of the object. The intensities of filtering images by the 2D knife-edge at several points along the optical axis of the telescope are substituted in the transport-intensity equation to obtain phase-differential images of the astronomical objects. Then the phase-differential images are obtained by two image intensities taken along the optical axis. In our experiment, a mono-directional scanning scheme of the 2DFK was exploited to reduce number of scan as well as increase the spatial resolution of images. An illuminated light out of a bundle of optical fibers as an artificial astronomical object is used our laboratory based experiment. The light from the each optical fibers in the fiber bundle that intensities have exiguously different or barely visible are represented the brightness of the astronomical objects. The experiment result, the phase contrast images, shows that barely

identified object from an intensity based image has rendered almost equivalent contrast as the bright object. It represents that our proposed method can be recovered from phase difference of the object light that could not be identified from the intensity of objects brightness. The proposed method has a feature of render phase-differential images as well as compensates atmospheric turbulence with the setup mounting on a single-telescope. The presentation will be described the scheme of the non-interferometer phase-differential imaging and the image recovery process for the astronomical applications.

**Author(s): Jaeho Choi<sup>1</sup>**

**Institution(s):** 1. Dankook University

#### **445.05 – Status And Performance Of The Virgin Islands Robotic Telescope at Etelman Observatory**

The Virgin Islands Robotic Telescope is an 0.5m robotic telescope located at the easternmost and southernmost optical observatory in the United States at a latitude of 18.5N and longitude of 65W. The observatory is located on the island of St Thomas in the USVI. Astronomers from the College of Charleston, the US Air Force Academy, and the University of the Virgin Islands collaborate to maintain and operate the facility. The primary scientific focus of the facility is the optical follow-up of high-energy transients though a variety of other science interests are also being pursued including follow-up of candidate extra-solar planets, rotation studies of cool stars, and near-Earth asteroid and space situational awareness studies. The facility also supports a wide-reaching education and outreach program dedicated to raising the level of STEAM engagement and enrichment in the USVI. We detail the characteristics, capabilities, and early results from the observatory. The observatory is growing its staff and science activities and potential topics for collaboration will be discussed.

**Author(s): David C. Morris<sup>3</sup>, Bruce Gendre<sup>3</sup>, James E. Neff<sup>1</sup>, Timothy W. Giblin<sup>2</sup>**

**Institution(s):** 1. College of Charleston, 2. United States Air Force Academy, 3. University of the Virgin Islands

#### **445.06 – Development of an Inexpensive Telescope System for Very High Energy Astronomy: EL CHEAPO**

Over the past ten years, the field of very high energy (VHE) astrophysics has developed dramatically, with the number of known sources jumping from 30 in 2005 to over 160 today, as reported by TeVcat. The Cherenkov Telescope Array (CTA) is the next major international project in the field, scheduled for first observations in 2018. However, as with any telescope, CTA will have a finite field of view and limited number of observing hours per year. The ultimate goal of this project is to demonstrate that it is possible to build a relatively low cost (~\$50,000) telescope, complimentary to the capabilities of CTA, capable of studying VHE (>1TeV) gamma rays. Over the course of the summer the mounting and pointing systems for a prototype imaging atmospheric Cherenkov telescope will be completed. This will involve both hardware additions to the system and the development of a software program to control pointing and tracking. Ultimately, the prototype telescope will be installed at the Goddard Geophysical and Astronomical Observatory, and will be integrated with the components developed by external collaborators.

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**Institution(s):** 1. Columbia University, 2. NASA/GSFC

#### **445.07 – Compton-Pair Production Space Telescope: Extending Fermi-LAT Discoveries into MeV Gamma-ray Astronomy**

The gamma-ray energy range from several hundred keV to a hundred MeV has remained largely unexplored, since the observations by instruments on the Compton Gamma-Ray Observatory (1991- 2000) and on INTEGRAL (since 2002). Accurate measurements in this energy range are critical for answering a broad range of astrophysical questions, but they are particularly challenging because this range encompasses the Compton scattering/pairproduction transition zone (~10 MeV) where the interaction cross section is minimized. These interaction processes require different optimizations in both

detection and event reconstruction. We are developing a MIDE-scale wide-aperture discovery mission, Compton-Pair Production Space Telescope (ComPair), to investigate the energy range from 200 keV to >500 MeV with high energy and angular resolution and with sensitivity approaching a factor of 20-50 better than COMPTEL. This instrument will be capable of measuring both Compton-scattering events at lower energy and pair-production events at higher energy. ComPair will build on the heritage of successful space missions including Fermi-LAT, CGRO, INTEGRAL, AGILE, AMS and PAMELA, and will utilize well-developed space-qualified detector technologies including Si-strip and CdZnTe-strip detectors, heavy inorganic scintillators, and plastic scintillators.

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**Contributing team(s):** ComPair Team

#### **445.08 – Chandra X-ray Observatory Optical Axis and Aimpoint**

Chandra X-ray Observatory revolutionized the X-ray astronomy as being the first, and so far the only, X-ray telescope achieving sub-arcsecond resolution. Chandra comprises of three principal elements: the High Resolution Mirror Assembly (HRMA), Pointing Control and Aspect Determination (PCAD) system, and the Science Instrument Module (SIM). To achieve and retain the unprecedented imaging quality, it is critical that these three principal elements stay rigid and stable for the entire life time of the Chandra operation. Tracking the Chandra optical axis and aimpoint with respect to detector positions is the most relevant measurement for understanding telescope stability. The study shows that both the optical axis and the aimpoint has been drifting since Chandra launch. I will discuss the telescope focal-point, optical axis, aimpoint, their position

drifts during the mission, the impact to Chandra operations, and the permanent default aimpoint, to be implemented in Chandra cycle 18.

**Author(s): Ping Zhao<sup>1</sup>**

**Institution(s):** 1. Harvard-Smithsonian, CfA

#### **445.09 – Developing A New Test Stand For Lifetime Measurements Using A Narrow Gap Detector**

The University of the Virgin Islands (UVI) recently won a proposal “The First Four-Year Physics and Astronomy Degree at the University of the Virgin Islands; A new Era in Caribbean Participation in NASA Science” in collaboration with NASA Goddard Space Flight Center (GSFC). The proposal included building a detector life-test chamber at UVI to support the degree program as well as assist NASA by running tests on detector components and reporting the results.

The team at GSFC is developing X-ray polarimeters that can be used in detecting and imaging astrophysical sources such as black holes and neutron stars. The purpose of our research is to understand the effects that the degradation of gas has on the performance of the detectors. The current generation of time projection polarimeter incorporates a narrow gap detector assembled with epoxy. The addition of the epoxy allows a smaller gap with the minimal amount of changes from the original design, enhancing the performance of the detectors.

With the use of epoxy, lifetime measurements have to be made to see how the epoxy detectors compared to previous iterations. We have been studying the effects on the narrow gap detector in the Mahaffey chamber in order to determine whether the epoxy affects the cleanliness of the gas. Tests have been conducted with a residual gas analyzer (RGA) in order to monitor the cleanliness of the gas inside of the Mahaffey chamber while being baked out. Results show that the detector is in fact getting cleaner as time progresses. The plan is to recreate a detector that meets the performance criteria for 2 years and has minimal degradation.

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**Institution(s):** 1. NASA/GSFC, 2. University of the Virgin Islands

#### **445.10 – Fabrication of Metallic Freeform Mirrors for**

## Wide-Field Space Infrared Telescope

We experimentally demonstrate an error compensation method for high form accuracy of metallic freeform mirrors. The technique is based on single point diamond turning on the rotational asymmetric surfaces. We compensate tool path by subtracting form error patterns which are converted into the polynomial expression. The experimental results illustrate that RMS form error value is reduced from 1.168 $\mu$ m to 0.211 $\mu$ m which is applicable in Near Infrared regions. We analyze that error compensation is also applicable to the rotational asymmetric tool path. We highlight that our approach is applied only diamond turning technique without additional manufacturing process like polishing and figuring. The proposed scheme is useful to enhance productivity of freeform mirrors.

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## 445.11 – Need for a network of observatories for space debris dynamical and physical characterization

Space debris represents a major concern for space missions since the risk of impact with uncontrolled objects has increased dramatically in recent years. Passive and active mitigation countermeasures are currently under consideration but, at the base of any of such corrective actions is the space debris continuous monitoring through ground based surveillance systems.

At the present, many space agencies have the capability to get optical measurements of space orbiting objects mainly relying on single observatories. The recent research in the field of space debris, demonstrated how it is possible to increase the effectiveness of optical measurements exploitation by using joint observations of the same target from different sites.

The University of Rome "La Sapienza", in collaboration with Italian Space Agency (ASI), is developing a scientific network of observatories dedicated to Space Debris deployed in Italy (*S5Scope* at Rome and *SPADE* at Matera) and in Kenya at the Broglio Space Center in Malindi (*EQUO*). ASI founded a program dedicated to space debris, in order to spread the Italian capability to deal with different aspects of this issue. In this framework, the University of Rome is in charge of coordinating the observatories network both in the operation scheduling and in the data analysis. This work describes the features of the observatories dedicated to space debris observation, highlighting their capabilities and detailing their instrumentation. Moreover, the main features of the scheduler under development, devoted to harmonizing the operations of the network, will be shown. This is a new system, which will autonomously coordinate the observations, aiming to optimize results in terms of number of followed targets, amount of time dedicated to survey, accuracy of orbit determination and feasibility of attitude determination through photometric data.

Thus, the authors will describe the techniques developed and applied (i) to implement the multi-site orbit determination and (ii) to solve the attitude motion of uncontrolled orbiting objects by exploiting photometric quasi-simultaneous measurements.

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## 446 – Education Topics Late Poster Session

### 446.01 – Improving Science Communication and Engaging the Public in Astronomy and Nature

A partnership between Carthage College and the Appalachian Mountain Club has delivered a successful public education and outreach program that merges natural environment topics and astronomy. Over the four years of activity, over 25,000 people have received programming. The effort has trained nature educators,

permanent and seasonal AMC staff, and undergraduate physics and astronomy students to integrate diverse topical material and deliver high quality programming to the lay public. Unique to the program is the holistic nature of the material delivered - an 'atypical' astronomy program. Linking observable characteristics of the natural world with astronomical history and phenomena, and emphasizing the unique sequence of events that have led to human life on Earth, the program has changed attitudes and behaviors among the public participants. Successful interventions have included hands-on observing programs (day and night) that link nature content to the observed objects; table-talk presentations on nature/astronomy topics; dark skies preservation workshops; and hands-on activities developed for younger audiences, including schools, camps, and family groups. An extensive evaluation and assessment effort managed by a leading sociologist has demonstrated the effectiveness of the approach, and contributed to continuous improvement in the program content and methods. This work was supported in part by NSF Grant 1432662.

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### 446.02 – Solar Eclipse Computer API: Planning Ahead for August 2017

With the total solar eclipse of 2017 August 21 over the continental United States approaching, the U.S. Naval Observatory (USNO) on-line Solar Eclipse Computer can now be accessed via an application programming interface (API). This flexible interface returns local circumstances for any solar eclipse in JavaScript Object Notation (JSON) that can be incorporated into third-party Web sites or applications. For a given year, it can also return a list of solar eclipses that can be used to build a more specific request for local circumstances.

Over the course of a particular eclipse as viewed from a specific site, several events may be visible: the beginning and ending of the eclipse (first and fourth contacts), the beginning and ending of totality (second and third contacts), the moment of maximum eclipse, sunrise, or sunset. For each of these events, the USNO Solar Eclipse Computer reports the time, Sun's altitude and azimuth, and the event's position and vertex angles. The computer also reports the duration of the total phase, the duration of the eclipse, the magnitude of the eclipse, and the percent of the Sun obscured for a particular eclipse site.

On-line documentation for using the API-enabled Solar Eclipse Computer, including sample calls, is available (<http://aa.usno.navy.mil/data/docs/api.php>). The same Web page also describes how to reach the Complete Sun and Moon Data for One Day, Phases of the Moon, Day and Night Across the Earth, and Apparent Disk of a Solar System Object services using API calls.

For those who prefer using a traditional data input form, local circumstances can still be requested that way at <http://aa.usno.navy.mil/data/docs/SolarEclipses.php>.

In addition, the 2017 August 21 Solar Eclipse Resource page (<http://aa.usno.navy.mil/data/docs/Eclipse2017.php>) consolidates all of the USNO resources for this event, including a Google Map view of the eclipse track designed by Her Majesty's Nautical Almanac Office (HMNAO). Looking further ahead, a 2024 April 8 Solar Eclipse Resource page (<http://aa.usno.navy.mil/data/docs/Eclipse2024.php>) is also available.

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**Institution(s):** 1. Her Majesty's Nautical Almanac Office, 2. US Naval Observatory

### 446.03 – The Role of the Modern Planetarium as an Effective Tool in Astronomy Education and Public Outreach

As the planetarium approaches its 100<sup>th</sup> anniversary, today's planetarium educator must reflect on the role of such technology in contemporary astronomy education and outreach. The projection planetarium saw "first light" in 1923 at the Carl Zeiss factory in Jena,

Germany. During the 20<sup>th</sup> century, the concept of a star projector beneath a dome flourished as an extraordinary device for the teaching of astronomy. The evolution of digital technology over the past twenty years has dramatically changed the perception / utilization of the planetarium. The vast majority of modern star theaters have shifted entirely to full-dome digital projection systems, abandoning the once ubiquitous electromechanical star projector altogether. These systems have evolved into ultra-high resolution theaters, capable of projecting imagery, videos, and any web-based media onto the dome. Such capability has rendered the planetarium as a multi-disciplinary tool, broadening its educational appeal to a wide variety of fields -- including life sciences, the humanities, and even entertainment venues. However, we suggest that what is at the heart of the planetarium appeal is having a theater adept at projecting a beautiful / accurate star-field. To this end, our facility chose to keep / maintain its aging Zeiss V star projector while adding full-dome digital capability. Such a hybrid approach provides an excellent compromise between presenting state of the art multimedia while at the same time maintaining the ability to render a stunning night sky. In addition, our facility maintains two portable StarLab planetariums for outreach purposes, one unit with a classic electromechanical star projector and the other having a relatively inexpensive full-dome projection system. With a combination of these technologies, it is possible for the planetarium to be an effective tool for astronomical education / outreach well into the 21<sup>st</sup> century.

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**Institution(s):** 1. Fernbank Science Center

#### **446.04 – AstroPAL: A Mentoring Program for Grad Students**

The Astronomy Peer Advising Leaders program (AstroPAL) provides guidance for incoming grad students from a team of student volunteers who have passed their 2nd year Qualifier Exam. The purpose is to pair first years with a mentor who can help them through some of the stresses or difficulties that come with being a new grad student. AstroPALs and mentees meet privately about once a month in a casual setting to talk about how they're adjusting to the new surroundings, how they're handling the workload, etc.

New students can join AstroPAL at any time during their first two years, and can stop receiving guidance once they feel comfortable in the program. Mentees will be assigned an AstroPAL based on preference and availability, and an AstroPAL Liaison will always be in place to facilitate mentor reassignments or other issues if necessary. After passing the 2nd year Qualifier Exam, mentees are eligible to serve as mentors to incoming students.

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**Institution(s):** 1. Georgia State University

#### **446.05 – Evaluation of Data Visualization Software for Large Astronomical Data Sets**

This study investigates the efficacy of a 3D visualization application used to classify various types of stars using data derived from large synoptic sky surveys. Evaluation methodology included a cognitive walkthrough that prompted participants to identify a specific star type (Supernovae, RR Lyrae or Eclipsing Binary) and retrieve variable information (MAD, magratio, amplitude, frequency) from the star. This study also implemented a heuristic evaluation that applied usability standards such as the Shneiderman Visual Information Seeking Mantra to the initial iteration of the application. Findings from the evaluation indicated that improvements could be made to the application by developing effective spatial organization and implementing data reduction techniques such as linking, brushing, and small multiples.

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#### **446.06 – Exploring Lifelong Learners Engaged in an Astronomy-Related Massively Open Online Course**

Massively open online courses (MOOCs) are becoming increasingly popular ways to reach diverse lifelong learners all over the world. Although MOOCs resemble more formal classes (e.g. videos of content, quizzes, activities), they are often used by informal audiences from home. Recently, MOOCs have become more utilized by universities to conduct outreach as they explore how to use MOOCs to reach new potential learners. Despite the rapid adaption of MOOCs, little is known about individuals who choose to take a MOOC, how they interact with the course materials, and what motivates them to finish the course.

We present results of a study of lifelong learners engaged in an astronomy "101" MOOC. Through analysis of registered learners' behaviors as well as self-reported responses to a survey about science, we were able to characterize a subset of the learners engaged in the MOOC during its first offering. Overall, 25363 learners from over 100 countries registered for the MOOC. Of those, 14900 accessed at least one part of the course. Learners were recruited to complete a survey of their knowledge and attitudes towards science. Of the learner group who opened the course, 2889 individuals completed the survey, 2465 of those were able to be linked to their usage of the MOOC through a unique identifier.

Learners represented a wide-range of ages, professions, and previous science experience. The best predictors for MOOC completion were engagement in the first activity and first writing assignment and engagement in the online forum. Learners were very interested in science prior to their registration, had higher basic science knowledge than most undergraduate students enrolled in a parallel astronomy course, and used online searches and science sites to get their information about science. As we reach out to a worldwide audience to learners in these massively open online courses, understanding their motivations and behaviors will be essential. This work is helping us understand and characterize lifelong learners who are interested in engaging in these types of free-choice learning environments and better serve their needs.

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#### **446.07 – Modeling Asteroid Geometries using Photometry at the Glendale Community College North Observatory**

The students of the Glendale Community College's Astronomy Students for Telescope Research and Outreach (A.S.T.R.O.) Club have expanded their exoplanet transit observing program into observing asteroids. The students, most of whom are non-science majoring undergraduates, observed the asteroid 15 Eunomia using the 8-inch telescopes at the GCC North Observatory in Glendale, Arizona.

Using concepts and skills learned in introductory astronomy courses for non-science majors, the co-authors measured the variability of the asteroid due to its rotation and constructed its lightcurve. Using the lightcurve inversion software from the Database of Asteroid Models from Inversion Techniques (DAMIT), a 3-dimensional model of the shape of 15 Eunomia was calculated. These results demonstrate that, given equipment that is readily available and affordable, asteroid observations have long-term educational potential for authentic, practical experience in both observational astronomy and numerical modeling, even with a small student body majoring in the physical sciences.

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**Institution(s):** 1. Glendale Community College

#### **446.08 – GRAD-MAP: A Joint Physics and Astronomy Diversity Initiative at the University of Maryland**

Graduate Resources for Advancing Diversity with Maryland's Astronomy and Physics (GRAD-MAP), builds connections between UMD and mid-Atlantic HBCUs, Minority-Serving Institutions, and community colleges, and uses seminars, forums, and workshops to foster a diverse community of undergraduates prepared to succeed in graduate school, and is now in its third year. GRAD-MAP launched with a three-pronged approach: 1) Collaborative Seminars, 2) A Winter Workshop, and 3) A Spring Symposium. This program allows GRAD-MAP to do more than just increase the numbers of minority students participating in astronomy and physics research (or, worse, simply shuffle around students who already are or would be); it is committed to identifying students who are otherwise underserved or overlooked by the traditional academic pipeline, not only to get them on the path to be successful undergraduate researchers and eventual

graduate applicants, but also to make the climate of academic physics and astronomy more inclusive to them and all other underrepresented minority students. Our poster describes the key elements of our program, and highlights successes and lessons learned; GRAD-MAP can serve as a model for other universities committed to diversity and inclusion.

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