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100 – Education

100.01 – Scientists: Get Involved in Planetary Science Education and Public Outreach! Here's How!

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The Planetary Science Education and Public Outreach (E/PO) Forum is a team of educators, scientists, and outreach professionals funded by NASA's Science Mission Directorate (SMD) that supports SMD scientists currently involved in E/PO - or interested in becoming involved in E/PO efforts – to find ways to do so through a variety of avenues. There are many current and future opportunities and resources for scientists to become engaged in E/PO. The Forum provides tools for responding to NASA SMD E/PO funding opportunities (webinars and online proposal guides), a one-page Tips and Tricks guide for scientists to engage in education and public outreach, and a sampler of activities organized by thematic topic and NASA's Big Questions in planetary science. Scientists can also locate resources for interacting with diverse audiences through a number of online clearinghouses, including: NASA Wavelength, a digital collection of peer-reviewed Earth and space science resources for educators of all levels (http://nasawavelength.org); the Year of the Solar System website (http://solarsystem.nasa.gov/yss), a presentation of thematic resources that includes background information, missions, the latest in planetary science news, and educational products, for use in the classroom and out, for teaching about the solar system organized by topic – volcanism, ice, astrobiology, etc.; and EarthSpace (http://www.lpi.usra.edu/earthspace), a community website where faculty can find and share resources and information about teaching Earth and space sciences in the undergraduate classroom, including class materials, news, funding opportunities, and the latest education research. Also recently developed, the NASA SMD Scientist Speaker's Bureau (http://www.lpi.usra.edu/education/speaker) offers an online portal to connect scientists interested in getting involved in E/PO projects – giving public talks, classroom visits, and virtual connections – with audiences. Learn more about the opportunities to become involved in E/PO and to share your science with students, educators, and the general public at http://smdepo.org.

100.02 – CIOC_ISON: Pro-Am Collaboration for Support of NASA Comet ISON Observing Campaign (CIOC) via Social Media

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Contributing teams: CIOC_ISON, NASA_CIOC

From the initial discovery of C/2012 S1 (ISON) by Russian amateur astronomers in September 2012 to present day, amateur astronomers provide valuable resources of global coverage, data and legacy knowledge to the professional community. C/ISON promises to be the rare and brightest of comets if predictions of its evolution are correct. NASA has requested a small group of cometary scientists to facilitate, support and coordinate the observations of this potential bright comet. The Comet ISON Observing Campaign (CIOC) goals (www.isoncampaign.org) are: (i) a detailed characterization of a subset of comets (sun grazers) that are usually difficult to identify and study in the few hours before their demise; and (ii) facilitate collaborations between various investigators for the best science possible. One of the tangible products is the creation of CIOC_ISON, a professional – amateur astronomer collaboration network established on Facebook, with members from the scientific, amateur, science outreach/education, public from around the globe (www.facebook.com/groups/482774205113931/). Members, by invitation or request, provide the details of their equipment, location and observations and post their observations to both share and provide a forum for interactive discussions. Guidelines for observations and their logs are provided and updated as deemed necessary by the scientists for useful data. The long lead time between initial discovery of C/ISON in September 2012 and its perihelion in November 2013 provides a rare opportunity for the scientific and amateur astronomer communities to study a sungrazer comet on its initial (and possibly) only passage through the inner solar system. These collaborations, once an occasional connection, are now becoming essential and necessary, changing the paradigm of research. Unlike Citizen Science, these interactive and collaborative activities are the equivalent of Inverse Citizen Science, with the scientific community relying on the amateur astronomer community and its data to develop research strategy for observations and an outreach bridge to the public.

100.03 – Engaging Undergraduate Students in Transiting Exoplanet Research with Small Telescopes

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Brigham Young University has a relatively large undergraduate physics program with 300 to 360 physics majors. Each of these students is required to be engaged in a research group and to produce a senior thesis before graduating. For the astronomy professors, this means that each of us is mentoring at least 4-6 undergraduate students at any given time. For the past few years I have been searching for meaningful research projects that make use of our telescope resources and are exciting for both myself and my students. We first started following up Kepler Objects of Interest with our 0.9 meter telescope, but quickly realized that most of the transits we could observe were better analyzed with Kepler data and were false positive objects. So now we have joined a team that is searching for transiting planets, and my students are using our 16' telescope to do ground based follow-up on the hundreds of possible transiting planet candidates produced by this survey. In this presentation I will describe our current telescopes, the observational setup, and how we use our telescopes to search for transiting planets. I'll describe some of the software the students have written. I'll also explain how to use the NASA Exoplanet Archive to gather data on known transiting planets and Kepler Objects of Interests. These databases are useful for determining the observational limits of your small telescopes and teaching your students how to reduce and report data on transiting planets. Once that is in place, you are potentially ready to join existing transiting planet missions by doing ground-based follow-up. I will explain how easy it can be to implement this type of research at any high school, college, or university with a small telescope and CCD camera.

101 – Asteroids 1: NEOs- Visitors and Targets

101.01 – Results From Ground-based Observations of Asteroid 2012 DA_{14} During Its Close-Approach to the Earth on February 15th, 2013

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Near-Earth asteroid 2012 DA_{14} (hereafter DA14) made its closest approach to the Earth on February 15th, 2013, when it passed at a distance of 27,700 km from the Earth's surface. It was the first time an asteroid of moderate size (~ 45 m estimated before the approach) was predicted to come that close to the Earth becoming bright enough to permit a detailed study from ground-based telescopes. With the aim of collecting the most varied and useful information within our grasp, we designed and carried out an observational campaign that involved five ground-based telescopes with very different characteristics. Visible colors and spectra were obtained from the 10.4m Gran Telescopio Canarias and the 2.2m CAHA telescope; near-infrared colors were obtained from the 3.6m Telescopio Nazionale Galileo; time-series photometry were obtained using the f/3 0.77m telescope in La Hita Observatory and the f/8 1.5m telescope in Sierra Nevada Observatory (all telescopes placed in Spain). The analysis of the data showed that this NEA can be classified as an L-type, with an estimated geometric albedo in the visible $p_v = 0.44 \pm 0.20$. L-type asteroids are uncommon, and most of them display unusual characteristics, which indicate that their surfaces could be covered by a mixture of high- and low-albedo particles similar to what is observed for some carbonaceous chondrites (CV3 and CO3). The object is very elongated, and its equivalent diameter is 18 m. This is less than a half of the a priori estimation, which suggests that close approaches with objects such as DA14 are several times more frequent than initially estimated before this work (once every 40 years). Using photometric time series pre- and post-encounter, we show that the object probably experienced a spin-up due to the gravitational forces of the Earth decreasing the rotational period from 9.8 ± 0.1 hr. to 8.95 ± 0.08 hr.

101.02 – Goldstone Radar Images of Near-Earth Asteroid 2012 DA14

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2012 DA14 made an extremely close approach within 0.00023 AU (0.09 lunar distances) on February 15, 2013. This was the closest encounter known in advance by a near-Earth asteroid with an absolute magnitude brighter than 25. We took advantage of this opportunity to image 2012 DA14 at Goldstone on February 16, 18, and 19 as the asteroid was receding from Earth. The imaging started at 00:46 UTC, slightly more than five hours after the closest approach, when the asteroid was at a distance of 0.00088 AU (0.34 lunar distances). The echoes were extraordinarily strong and we obtained some of the highest signal-to-noise ratios for any near-Earth asteroid ever observed at Goldstone. The images achieved resolutions as fine as 3.75 m x 0.00625 Hz that spatially resolve 2012 DA14 into a few dozen pixels; however, due to the diminutive dimensions of the asteroid, even this extremely high resolution is insufficient to show detailed surface features. The images indicate that 2012 DA14 is an asymmetric, angular, and elongated object with major axes of roughly 40 x 20 meters. The sequence of images obtained on February 16 spans 7.8 hours, during which the orientation of the asteroid appeared to complete close to one full rotation, suggesting that the rotation period is somewhat longer than ~8 hours. Radar speckle tracking with the Very Large Array and elements of the Very Long Baseline array show that 2012 DA14 has a relatively low obliquity and constrain the amplitude of any non-principal axis wobble after the flyby to be < 30 degrees. 2012 DA14 is among the smallest near-Earth asteroids ever spatially resolved by radar and it highlights the substantial scientific potential of the new chirp imaging system at Goldstone.

101.03 – The Near-Earth Flyby of Asteroid 2012 DA14

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On UT 2013 February 15, the approximately 30 meter near-Earth asteroid 2012 DA14 made a close flyby of the Earth at a distance of approximately 27,000 km or 4 Earth-radii. This passage was inside the orbital distance of geosynchronous satellites and close to the Earth's Roche limit. This close encounter was unprecedented in our advance knowledge of the incoming trajectory, thereby allowing us to forge a detailed coordinated plan for observation and testing of physical models predicting tidal effects near our planet's Roche limit. Predicted outcomes of such close encounters include tidal disruption, changes in rotation state, and mass loss or mass redistribution due to seismic shaking. Each of these effects sensitively depend on how tidal energy is dissipated in the interior of the asteroid: a rubble pile will dissipate tidal energy differently than a solid or partially fractured monolith. The internal properties of asteroids in general and particularly those in the size range of 2012 DA14 are largely unknown. This encounter represents one of the first ever opportunities to observationally test models of the interior structure of small planetary bodies. We will present the results of a large multi-observatory campaign that obtained visible-wavelength photometric and spectroscopic observations of 2012 DA14 during its discovery epoch in 2012, and surrounding its close approach in 2013. These results include clear evidence that 2012 DA14 is now in a non-principal axis rotation state, requiring a multi-periodic tumbling model to fit its post-flyby rotational light curve. The ultimate goal of this campaign will be to investigate changes to 2012 DA14's physical properties induced by its gravitational interactions with the Earth.

101.04 – Binary Near-Earth Asteroid (285263) 1998 QE2: Goldstone and Arecibo Radar Imaging and Lightcurve Observations

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We observed near-Earth Amor asteroid 1998 QE2 with the Goldstone and Arecibo Observatory planetary radar systems, as well as with infrared and optical telescopes in the United States, Slovakia, Australia, and Colombia. Using radar, we observed the asteroid and its moon for 12 days in May and June of 2013 with a close approach of 0.039 AU to Earth on May 31, providing high signal-to-noise delay-Doppler radar images of the binary system. On June 4 we covered one full rotation of the primary (4.75 ± 0.01 hours) with 19 meter resolution delay-Doppler images. The imaging resolution varied with observing circumstances from 7.5-75 meters/pixel, with most of the observations made at 15-30 meters/pixel resolution. Radar images show a cratered primary 3 kilometers across with an elongated secondary about 600 meters in size. For the primary to have a discovery H magnitude of 16.4, it must be optically quite dark, with a geometric albedo of about 0.06 to be consistent with the diameter of the primary. Infrared spectra taken at the IRTF show QE2 as dark and reddened, perhaps primitive. The rotation period of 4.75 hours, photometrically derived, is one of the slowest known for a primary in any NEA binary system with a similar size ratio to that of QE2. The secondary appears to be in a synchronous, approximately circular orbit of approximately 32 hours with a semimajor axis of at least four primary radii. Features in the Goldstone images show evidence for an equatorial ridge, subtle in single radar frames but evident in animations. An optical lightcurve amplitude observed between 0.17 and 0.22 magnitudes confirms modest elongation of the primary as seen in radar images. Photometric observations detected seven mutual events; more data remains to be reduced and may cover more events. We will present more detailed information on the shape of the QE2 primary as well as the orbit of the secondary, and also additional surface properties from both the infrared and optical data.

101.05 – Goldstone/VLA Radar Observations of Near-Earth Asteroid 4179 Toutatis in 2012

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Near-Earth asteroid 4179 Toutatis is close to a 4:1 orbital resonance with Earth. It has been observed extensively with radar during close Earth flybys in 1992, 1996, w0, 2004, 2008, and 2012. Previous radar observations have shown that Toutatis is bifurcated, ~4.5 km long, with an unusual non-principal-axis spin state. In December of 2012, Toutatis approached within 0.0463 AU (6.93 million km) of Earth, the last flyby within 0.2 AU until 2069. We conducted an extensive campaign of radar imaging and radar speckle tracking with Goldstone and with elements of the Very Large Array. The radar images were obtained on 16 days between December 4 and December 22 and include time on December 13 when the Chang'e 2 spacecraft flew by the asteroid. The radar images on December 12 and 13 had range resolution of 3.75 m/pixel and show a wealth of surface features, many previously unseen, including radar-bright spots that we interpret as decameter-scale boulders similar to those visible in the Chang'e 2 images. Both the 2012 radar images and the spacecraft images confirm the radar-based Toutatis shape model published by Hudson et al. 2003 (Icarus 161, 346-355) but also show where that model can be improved – particularly the big end of Toutatis, which was not imaged extensively by radar prior to 2012. During each orbit, Toutatis' spin state changes by up to 0.1% of the asteroid's total angular momentum due to gravitational tides from the Sun and Earth. We have constructed a model of Toutatis' spin state in which

we numerically integrate the tidal torques on the asteroid to match the orientation of Toutatis at each apparition. The tidal spin state changes and the non-principal-axis rotation allow us to estimate Toutatis' moments of inertia independently of its shape. We will present the 2012 radar images and describe our current knowledge of the asteroid's shape and spin state. The unprecedented resolution and orientation coverage of the 2012 radar data and Chang'e 2 images will allow us to improve our model of Toutatis' shape, surface properties, spin state, and internal structure.

101.06 – Physical Characterization of Deep Impact Flyby Target (163249) 2002 GT

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Contributing teams: 2002 GT Observing Team

We report on the ongoing physical characterization campaign for near-Earth asteroid (163249) 2002 GT, the target of a Deep Impact spacecraft flyby set for Jan. 2020. With a collaboration of over 45 colleagues we have gathered a wide range of observational data that inform us of the nature of this sub-km PHA. We have gathered spectra at UV, VIS and NIR wavelengths, which point to a Q or Sq taxonomic type with visible albedo 25% or higher. Visible photometry yields an absolute magnitude H = 18.71 ± 0.17, which taken together with the albedo constraint implies an effective diameter 350-500 m. Arecibo radar observations are consistent with this size range, and radar delay measurements have significantly improved the orbit. Photometric light curves have constrained the rotation period to P=3.7663±0.0007 h and indicate an elongation ratio >1.16. Of particular importance is a series of unambiguous attenuations seen in some of the light curves, presumably due to eclipse or occultation events from a secondary component. The magnitude of the attenuations indicates a secondary/primary size ratio ~0.3, and the lack of a secondary detection with Arecibo implies a size ratio <0.5. We will report on attempts to resolve a possible companion to 2002 GT with both Keck Adaptive Optics and Hubble Space Telescope imaging. The June 2013 apparition was the last time 2002 GT will be brighter than magnitude 18 until after the 2020 spacecraft flyby and thus represents a unique opportunity to characterize this potential space mission target. The information gained from this effort will aid planning and development of the flyby imaging sequence and interpretation of associated imagery.

101.07 – Temporally-Resolved UV/VIS Reflectance Spectra of Near-Earth Asteroid 163249 2002 GT

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The Deep Impact spacecraft has been targeted by NASA to image near-Earth asteroid 163249 2002 GT when it passes nearby in 2020. To place the images it will acquire in context, a campaign to observe 2002 GT was conducted during its last, brightest apparition before fly-by in spring 2013. As part of this campaign, the asteroid was observed using the MMT 6.5-m telescope with the facility Blue Channel spectrograph on UT June 19 (V ~ 16.2). Fifteen spectra covering a wavelength range of 320 – 640 nm were obtained across a 4.57-hr time interval, exceeding the 3.766-hr rotational period of the asteroid. Each exposure was 5 min. Additional UV/blue spectra were also obtained of other S-complex main-belt and near-Earth asteroids. We have previously shown that, in the inner Solar System, space weathering affects spectra of S-complex asteroids at UV/VIS wavelengths with a 'bluing' of the spectral reflectance. This effect of space weathering is consistent with the addition of iron or iron-bearing opaque minerals. In the 150-450 nm range, we expect space-weathered surfaces consisting of iron-bearing opaques to be less spectrally red (bluing) and potentially brighter than non-weathered surfaces with lower amounts of iron-bearing minerals. Further, we expect to see the onset and effects of space weathering more rapidly in the UV/blue than at VNIR wavelengths, as short wavelengths are more sensitive to thin coatings on grains that could be the result of weathering processes. The preliminary examination of the temporally-resolved spectra of 2002 GT suggests some variation, indicating a slight difference in level of weathering across the asteroid's surface. We discuss all data collectively within this context.

101.08 – 2009 BD as a Candidate for an Asteroid Retrieval Mission

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The small near-Earth asteroid 2009 BD has emerged as one of the candidates for a proposed asteroid retrieval mission. An ideal target would be small, in a well known and accessible orbit, as well as rotating slowly. New data on 2009 BD show that it may have the best combination of these various properties among the objects known at the present time. During 2010, the WISE spacecraft scanned the field containing 2009 BD several times. After stacking all the available exposures in Band 3, the 12 micron band most sensitive to the thermal emission from the asteroid, the object was not detected, putting a preliminary thermal model upper limit on the size of the object at around 10 meters. Few of the known asteroids are smaller than this size. Most of the asteroids as small as or smaller than 2009 BD are seen only during a brief close Earth encounter. However, for 2009 BD we have over 200 astrometric observations of the asteroid spanning 2009 Jan 16 to 2011 Jul 2, making the orbit known well enough to find with a spacecraft. This asteroid's orbit is very similar to the Earth's orbit and is very accessible, as indicated in a recent NASA study, in which a journey to the asteroid would take less than 2 years, and the retrieval less than an additional 3 years. Of considerable concern, however, is the spin state of the target asteroid. The very fastest rotating asteroids are among the objects smaller than about 100 meters in diameter, and despinning an asteroid may prove to be the single most difficult aspect of a retrieval mission. However, our extensive 2011 dataset suggests a rotation period longer than 3 hours, rather than tens of seconds like other NEOs in this size range. At that speed, the possibility that the asteroid is not in a state of principal axis rotation must be considered. Our earlier detection of the signature of solar radiation pressure acting on 2009 BD indicated a low density, thus providing the added benefit of a small mass to move. Our latest astrometry has refined the area to mass ratio, with the albedo being the largest source of uncertainty in the mass.

101.09 – Goldstone radar imaging and shape modeling of near-Earth Asteroid (214869) 2007 PA8

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We report Goldstone radar (8560 MHz, 3.5 cm) observations of potentially hazardous asteroid (214869) 2007 PA8. 2007 PA8 approached within 0.043 AU (17 lunar distances) on November 5, 2012 when it was the target of an extensive radar observing campaign. Images obtained with Goldstone's new chirp system at 3.75 m range resolution placed thousands of pixels on its surface and revealed that 2007 PA8 is an elongated, asymmetric object that shows a wealth of surface topography including angular features, multiple facets, and a possible concavity approximately several hundred meters across. The visible range extents varied between ~525 m and ~1150 m and the Doppler bandwidths varied between 0.88 Hz and 1.5 Hz. A preliminary shape model suggests that the asteroid has rough dimensions of 1.9x1.4x1.3 km, that it is in retrograde spin state with a pole within 10 deg of ecliptic latitude Beta = -90 deg, and that it has a very slow rotation period of 101.6 p/m 2.0 h.

102 – Mercury

102.01 – On Mercury's entrapment into the 3:2 spin-orbit resonance

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The rotational dynamics of Mercury is a peculiar case in the Solar System, since it is a supersynchronous, 3:2 resonant state, with the spin period being 2/3 of the orbital one. While it is widely accepted that the significant eccentricity (0.206) favours this configuration, the history of Mercury's despinning remains nonetheless a matter of discussion. At least three scenarios can be found in the scientific literature. The first one considers a homogeneous Mercury that was trapped after several crossings of the resonance, these crossings made possible by the chaotic evolution of the eccentricity (Correia & Laskar 2004). The second scenario includes friction at the core-mantle boundary, which increases the probabilities of capture during one crossing (Peale & Boss 1977, Correia & Laskar 2009). The third scenario assumes that Mercury had had a retrograde rotation, then a synchronous one, and only

later came into the current 3:2 resonance. We here use a realistic model of tides, based on the Darwin-Kaula expansions combined with both the elastic rebound and anelastic creep of solids. Within this model, we find that the 3:2 spin-orbit resonance is the most probable for a homogeneous Mercury. Moreover, we find that leaving a resonance after being trapped is impossible or virtually impossible, thus excluding the possibility of a past 2:1 resonance. This also indicates that entrapment is likely to happen before the differentiation of Mercury takes place.

102.02 – How core-mantle pressure coupling ensures determination of Mercury's interior structure

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Contributing teams: MESSENGER Science Team, MESSENGER Engineering Team, MESSENGER management team

That the measured orientation of Mercury's spin axis be coincident with the Cassini state orientation (whereby the spin precesses with the orbit while coplanar with the orbit normal and the normal to the Laplace plane) is crucial to the determination of C/MR^2 and C_m/C. (C is the moment of inertia about spin axis, C_m is the moment of inertia of the mantle plus crust, M and R are mass and radius of Mercury, respectively.) These two ratios along with M constrain the density distribution and the location of the core-mantle boundary (CMB). However, dissipative viscous coupling between the liquid core and solid mantle, if acting alone, causes a displacement of the spin that far exceeds the one-standard-deviation uncertainty in the radar determination of the spin axis location unless the core viscosity at the CMB exceeds $8.75\times 10^5\, {\rm cm^2/s}$, which may not prevail. Fortunately, gravitationally induced distortion of the CMB to an ellipsoidal shape causes a pressure coupling at the CMB along with viscous dissipation that drives the spin of the mantle plus crust firmly to the Cassini state independent of the magnitude of the dissipative coupling. The spin axis of the liquid core is displaced from that of the mantle by 3.5 arcmin, and it lags the precession of the plane containing the Cassini state by an angle that increases with core viscosity. The measured obliquity being that of the Cassini state allows us to constrain Mercury's interior structure with some confidence.

102.03 – Global resurfacing of Mercury 4.0–4.1 billion years ago by heavy bombardment and volcanism

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Early work, based on Mariner 10 data, estimated that the most heavily cratered terrains on Mercury were about 4 billion years (Gyr) old. This conclusion was based on images of only about 45 per cent of the surface; even older regions could have existed in the unobserved portion. The most heavily cratered terrains have a lower density of craters less than 100 km in diameter than does the Moon, an observation attributed to preferential resurfacing on Mercury. In this work, we present global crater statistics of Mercury's most heavily cratered terrains on the entire surface. Craters larger than 25 km diameter were measured on a global mosaic with a resolution of 500 meters per pixel based on MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) images obtained during its first year orbiting Mercury. Applying a recent model for early lunar crater chronology and an updated dynamical extrapolation to Mercury, we find that the oldest surfaces were emplaced just after the start of the Late Heavy Bombardment (LHB) about 4.0–4.1 Gyr ago. Mercury's global record of large impact basins, which has hitherto not been dated, yields a similar surface age. This agreement implies that resurfacing was global and was due to volcanism, as previously suggested. This activity ended during the tail of the LHB, within about 300–400 million years after the emplacement of the oldest terrains on Mercury. These findings suggest that persistent volcanism could have been aided by the surge of basin-scale impacts during this bombardment.

102.04 – A Modeling Investigation of the Observed Differences Between Secondary Crater Fields on the Moon and Mercury

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Large, complex craters of the same size on the Earth's moon and the planet Mercury display marked differences in the nature of their respective secondary crater fields, an observation that dates back to the 1974 Mariner 10 flyby of Mercury and the Apollo era of lunar exploration. Mercurian secondary craters are generally larger, more circular, and more numerous as compared to lunar secondary craters at the same distance from the primary crater rim, for large craters of the same size on each body. The recent MESSENGER mission to Mercury has tremendously expanded our view of the mercurian surface, in both resolution and overall coverage. In similar fashion, the recently revived interest in lunar exploration has significantly improved our coverage of that body, as well. Crater measurement and counting studies conducted on both bodies utilizing this modern data set confirm the earlier finding of characteristic differences in the size, shape, and numbers of secondary craters produced at a given distance from a large, primary crater when comparing the two bodies. In this work, we explore and explain these observed differences utilizing a modern set of impact cratering scaling relationships for transient and final crater size, crater excavation flow-field properties, and secondary crater production. This analytical modeling approach demonstrates that the observed differences between lunar and mercurian secondary craters is well explained through a combination of (1) the difference in surface gravity between the two bodies, and (2) the difference in heliocentric impact speeds for objects striking each body. That is, mean surface gravity and mean impact speed differences alone are generally sufficient to account for the observed secondary crater field differences, assuming identical target surface material properties. While general target material properties differences (from the impact cratering standpoint) most likely do exist between the two bodies, these differences seem to play only a minor role in producing the observed secondary crater characteristic differences between the Moon and Mercury.

102.05 – The Distribution of Magnesium on Mercury's Surface as Measured by the MESSENGER X-Ray Spectrometer

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We have used >6000 individual measurements acquired over two years by MESSENGER's X-Ray Spectrometer (XRS) to construct a global map of the Mg/Si ratio across Mercury's surface. In the northern hemisphere, both spatial coverage and resolution are sufficient to compare our map with geologic features. The global Mg/Si ratio varies from 0.15 to 0.90, which we attribute mainly to variations in Mg given that MESSENGER gamma-ray measurements indicate little variation in Si. Our work supports earlier results showing that large expanses of volcanic smooth plains at northern latitudes and in the interior of the Caloris basin have relatively uniform and low Mg/Si. In contrast, older intercrater plains and heavily cratered terrain (IcP-HCT) show striking variability in Mg/Si. The highest Mg/Si ratios (> 0.7) are seen in low-reflectance ejecta deposits that surround the Rachmaninoff impact basin, and in a large (>5×10^6 km^2), relatively homogeneous region that is centered at ~30°N, 290°E. This region also has the lowest Al and highest Ca and S abundances derived from XRS data. Comparison with a map of crustal thickness (derived from MESSENGER geophysical data) shows that the large Mg-rich region coincides with an area of relatively thin crust. The shared boundaries (between high and low Mg, and between thick and thin crust) are particularly sharp along the northern and eastern edges; the latter is also near a major north-south-oriented fold-and-thrust belt and a region with a high density of observed hollows. There may also be a correlation between the Mg content and age of Mercury's surface. The large Mg-rich region overlaps partly with some of Mercury's oldest terrain as inferred from crater densities. Younger parts of the IcP-HCT (e.g., around Amaral crater) have significantly lower Mg/Si than the planetary average. Mercury's surface is likely to have been extensively resurfaced by volcanism early in the planet's history, so Mg/Si variations within regions of IcP-HCT may be indicative of temporal variation in the depth or degree of partial melting and/or chemical heterogeneity in Mercury's mantle.

102.06 – Observations of Mercury's Exosphere from MESSENGER: An Overview

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The Ultraviolet and Visible Spectrometer (UVVS) channel of the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) aboard the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission began routine orbital observations of both the dayside and nightside exosphere on March 29, 2011. We have accumulated more than 9 Mercury years of exosphere data covering all local times; those observations allow statistical analyses of both seasonal and local-time variability of key components of Mercury's near-surface exosphere: sodium, calcium, and magnesium. An overview of the UVVS exospheric observations highlights the balance between observing scenarios from orbit and challenges we have encountered retrieving exosphere composition and structure. MESSENGER's UVVS offers an exciting potential for observing the near-surface exosphere above Mercury's hollows, as well as the comas and tails of comets C/2012 S1 (ISON) and 2P/Encke as they fly by the innermost planet.

102.07 – Sodium Escape in Mercury's Atmosphere: Ground-Based Observations in Support of MESSENGER

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Recent observations characterizing the escape of neutral sodium from Mercury's exosphere are presented. To supplement the MESSENGER mission, 27 nights of observations spanning true anomaly angles 45-152° have been conducted since orbital insertion. Two co-aligned telescopes at the McDonald Observatory in Ft. Davis, Texas are used in this study, and their simultaneous data gives the added benefit of cross-calibration. In the first instrument, a wide-field coronagraph equipped with a narrowband (~14 Å) filter images the escaping Na tail out to distances of nearly ~1500 planetary radii. The second is an integral field unit, in which a 2.5 arc-minute field is imaged over a bundle of 400 fiber optic wave-guides that feed into an Echelle spectrograph. With a spectral resolution R ~60000, Mercury's exospheric Na emissions are well separated from those of the terrestrial mesosphere due to their Doppler shift. Dithering and combining several images reveals spatial features in the Na tail, which often display asymmetry between north and south lobes. Such features may reflect the magnetosphere's influence over sources of the neutral exosphere. A large variability in escape rates is determined from these observations associated with the orbital modulation of solar radiation pressure. In this way, the Na exosphere exhibits seasonal characteristics.

102.08 – Planetary ephemeris construction and general relativity tests of PPN-formalism with MESSENGER radioscience data

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Current knowledge of Mercury orbit is mainly brought by the direct radar ranging obtained from the 60s to 1998 and five Mercury flybys made by Mariner 10 in the 70s, and MESSENGER made in 2008 and 2009. On March 18, 2011, MESSENGER became the first spacecraft orbiting Mercury. The radioscience observations acquired during the orbital phase of MESSENGER drastically improved our knowledge of the Mercury orbit. An accurate MESSENGER orbit is obtained by fitting one-and-half years of tracking data using GINS orbit determination software. The systematic error in the Earth-Mercury geometric positions, also called range bias, obtained from GINS are then used to fit the INPOP dynamical modeling of the planet motions. An improved ephemeris of the planets is then obtained, INPOP13a, and used to perform general relativity test of PPN-formalism. Our estimations of PPN parameters (β and γ) are most stringent than previous results.

103 – Exoplanets 1: Climate and Habitability

103.01 – High Stellar FUV/NUV Ratio and Oxygen Contents in the Atmospheres of Potentially Habitable Planets

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Contributing teams: MUSCLE

Searching for life around M dwarfs is considered the fast track to find a second Earth. However, recent observations of several planet-hosting M dwarfs show that they all have FUV/NUV flux ratios 1000 times greater than that of the Sun (France et al. 2013). It has been shown that the atmospheric oxygen contents (O2 and O3) of potentially habitable planets in the habitable zone of M dwarf GJ876 be 2~3 orders of magnitude greater than those of their counterparts around Sun-like stars as a result of decreased photolysis of O3, H2O2, and HO2. Thus detectable levels of atmospheric oxygen, in combination with the existence of H2O and CO2, are not reliable biosignatures on habitable planets or moons around GJ876 (Tian et al. 2013). In this work we will report results of photochemical simulations using the UV spectra of the other observed M dwarfs, including the GJ667C system containing 3 potentially habitable planets. Different hydrological and outgassing activity levels will also be considered.

103.02 – Comparison of model spectra of the first detected exoplanets in the HZ

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Water planets and planets with continents in the habitable zone are expected to have distinct geophysics and geochemistry of their surfaces and atmospheres. We explore these properties motivated by two key questions: whether such planets could provide habitable conditions and whether they exhibit discernable spectral features that distinguish a water planet from a rocky Earth-like planet. The recently discovered planets Kepler-62e and -62f are the first viable candidates for habitable zone water planet. We use these planets as test cases for discussing those differences in detail. We generate atmospheric spectral models and find that potentially habitable water planets show a distinctive spectral fingerprint depending on their position in the habitable zone.

103.03 – Effects of Exoplanet Planetesimal Carbon Chemistry on Habitability

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We explore the effects of reported differences in C/O values for exoplanet host stars on the composition of planetesimals formed beyond the snow line in these systems. Since the value of C/O in a planet forming nebula has a strong effect on amount of oxygen available for water ice in an oxidizing nebula, exoplanet systems for host stars with C/O greater than the solar value may have planetesimals with very little or no water ice. We have estimated the composition of volatile and refractory material in extrasolar planetesimals using a set of stars with a wide range of measured C/O abundances (Johnson et al. ApJ. 757(2), 192, 2012). The volatile ice content of planetesimals in these systems varies significantly with C/O, controlled primarily by the availability of O for H_2O ice condensation. Systems with C/O less than the solar value (C/O = 0.55) should have very water ice rich planetesimals, while water ice mass fraction decreases rapidly with increasing C/O until only ices of CO and CO_2 are left in significant proportions. If a significant fraction of C is in the form of refractory CHON particles, C and O are removed from the gas phase and the condensates for super-solar C/O values will be water-poor mixtures of silicates and metal, carbon, and carbon-bearing volatile ices, depending on temperature. For very carbon-rich systems, oxidizing conditions cannot be sustained beyond about C/O=1, due to the oxygen sequestered in solid silicates, oxides and CHON, for refractory C fractions within the Pollack et al. range of 0.4 – 0.7 (ApJ. 421, 615, 1994). These results have implications for assessing the habitability of exoplanets since they constrain the amount of water available beyond the snow line for dynamical delivery to inner planets, depending on the host star's C/O in the circumstellar nebula. Thus one the key chemical ingredients for habitability may be in short supply in carbon-rich, oxygen-poor systems even if planets exist in the 'habitable zone'. TVJ acknowledges government support at JPL/Caltech, under a contract with NASA. NM acknowledges support from Yale University. JIL was supported by the JWST Project through NASA. O.M. acknowledges support from CNES.

103.04 – Climate Hysteresis for Planets Orbiting Stars of Different Spectral Type

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Contributing teams: Virtual Planetary Laboratory

Planetary climate can be affected by the interaction of the host star spectral energy distribution with the wavelength-dependent reflectivity of ice and snow. We have explored this effect with a hierarchy of models. Results from both one-dimensional (1-D) radiative transfer and energy balance models and a three-dimensional (3-D) general circulation model indicate that terrestrial planets orbiting stars with higher near-UV radiation exhibit a stronger ice-albedo feedback. We found that ice extent is much greater on a planet orbiting an F-dwarf star than on a planet orbiting a G- or M-dwarf star at an equivalent flux distance, assuming fixed CO_2 (present atmospheric level on Earth). The surface ice-albedo feedback effect becomes less important at the outer edge of the habitable zone for main-sequence stars, where the maintenance of surface liquid water requires high atmospheric CO_2 concentrations. We show that □3–10 bar of CO_2 will entirely mask the climatic effect of ice and snow, leaving the outer limits of the habitable zone unaffected by the spectral dependence of water ice and snow albedo. However, less CO_2 is needed to maintain open water for a planet orbiting an M-dwarf star than would be the case for hotter main-sequence stars. Both entrance into and exit out of a snowball state are sensitive to host star spectral energy distribution. Our simulations indicate a smaller climate hysteresis on M-dwarf planets, as measured by the range of instellation that permits multiple stable ice line latitudes. While M-dwarf planets appear less susceptible to snowball episodes than G- or F-dwarf planets over the course of their evolution, any snowball planets that are found orbiting M-dwarf stars may more easily melt out of these states as stellar luminosity increases over time. This effect is due to the lower-albedo ice on M-dwarf planets which, compounded with near-IR absorption by atmospheric gases, reduces the amount of increased stellar insolation, or "instellation", necessary to melt these planets out of a snowball state.

103.05 – Water Cycling Between Ocean and Mantle: Super-Earths Need Not be Waterworlds

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Simple scaling relations dictate that ocean depth should increase with planetary mass, with the generic prediction that large terrestrial planets should be entirely covered in water, so-called waterworlds. Water is partitioned, however, between a surface reservoir, the ocean, and an interior reservoir, the mantle. If a planet undergoes plate tectonics, then water can move between these reservoirs on geological timescales: ocean crust formation at mid-ocean ridges releases water into the ocean, while subduction of serpentinized crust carries water into the mantle. Motivated by Earth's approximately steady-state deep water cycle, we develop a two-box model of the hydrosphere including potential feedbacks from sea-floor pressure, as well as the effects of isostatic adjustment. Using this model, we derive analytic and numerical steady-state solutions to the water-partitioning on terrestrial planets. We show that isostatic adjustment allows for a wide range of ocean volumes without submerging continents. Since surface gravity does not affect the steady state isostatic balance, this leeway applies just as well to super-Earths, despite their reduced topography. Moreover, the deep water cycle is mediated by sea-floor pressure, which is proportional to gravity. Super-Earths with a deep water cycle should therefore store the majority of their water in the mantle. We conclude that tectonically active planets with water mass fractions below about 0.004 will have exposed continents like Earth.

103.06 – Habitability and Habitable Zone in Multiple Star Systems

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During the course of its successful operation, in addition to detecting more than 3000 planets and planetary candidates, the Kepler space telescope has identified over 2000 binary stars as well as numerous multiple stars systems, especially some with mutual stellar separations of 20 AU and smaller. The discovery of such multi-star systems prompted us to study the possibility of the formation of terrestrial planets in these systems, and explore their habitability. To determine the habitable zone (HZ) in multiple star systems, we have extended our recent methodology for calculating HZ in and around binary stars, to systems with arbitrary numbers of stellar components, and have developed a generalized formalism for calculating the boundaries of the HZ in any planetary system with two or more stars. Our methodology takes into account the stellar energy distribution of each star, which determines the interaction between the radiation received at the location of the planet and the planet's atmosphere, and accounts for the motion and dynamics of the stellar system and its consequences on the spatial variations of the boundaries of the HZ. In this talk, we present our methodology and discuss its application to several multiple star systems detected by the Kepler. We show how the boundaries of the HZ are determined, and demonstrate their variations as the stars move in their orbits. Combined with the results of the studies of the orbital stability of an Earth-like planet in our multiple star systems, we discuss the habitability of these systems and the prospect of the detection of Earth-like planets in their habitable zones.

104 – Historical Astronomy Division: Invited Talks

104.01 – Clyde W. Tombaugh, Discoverer of Pluto: A Personal Retrospective

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This talk offers a retrospective of the life, times, and ideas of Clyde W. Tombaugh. One of the premier observers of the twentieth century, Tombaugh began observing as a teenager and was hired by the Lowell Observatory in Flagstaff, Arizona, in 1928, to resume and conduct the searh for "Planet X", the world postulated by Percival Lowell, founder of the observatory. Tombaugh discovered this object on February 18, 1930, and it was subsequently named Pluto a few months later. Tombaugh's life following the discovery was busy, full, and sometimes difficult. He continued his search for about fifteen years, discovering five open clusters, one globular cluster, a new cataclysmic variable star, and likely the first known supercluster of galaxies. He also discovered a comet, but that find was not confirmed for 81 years until it was rediscovered by the Tenagra Observatories just a few months ago and named Comet Tombaugh-Tenagra. Tombaugh was as well known for his delightful sense of humor and fun as he was for his abilities as an observer. However it would be difficult to present such a talk without some mention of the concern and depression he endured at the end of his life about the changing status of his signature discovery. Ultimately, this presentation will try to offer a personal perspective of the man and the scientist I knew for the decades since I first heard him speak in 1963 until his death in 1997.

104.02 – Gerard Kuiper and the Infrared Detector

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The life and contributions of Gerard Kuiper have been documented by Dale Cruikshank in his National Academy of Sciences biography. I will argue that particularly important in this eventful life was Kuiper's war time experiences. Kuiper's wartime role evolved as the war unfolded, but towards the end he was charged by the US military with reporting German progress with war-related technologies and the activities of scientists under Nazi control. He interviewed a great many scientists, including his own PhD mentor (Ejnar Hertzsprung), and when Kuiper was the only person available, he interviewed concentration-camp victims. He carried briefing sheets that identified the technologies being sought by the allies and the major fraction of these involved infrared equipment. He sent back to the USA boxes of documents, and large amounts of equipment, and he stressed to the military his interest in these for his own research. It seems very likely that in this way an effective PbS infrared detector, so critical to Kuiper's career and the future of planetary science, came to the USA and to Robert Cashman's laboratory at Northwestern University. As the war was winding down, Cashman and Kuiper worked together to develop a practical infrared spectrometer for astronomical use. Within months, Kuiper discovered the CO2 atmospheres on Mars and Venus.

104.03 – Rocks From Space: A Historical Perspective

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The notion that rocks could fall to Earth from space was not seriously considered until the early nineteenth century. The impact origin of the lunar craters reached a scientific consensus only in the mid twentieth century and a wide understanding that the Earth's neighborhood is crowded with millions of near-Earth asteroids that could cause impact damage to Earth is less than a few decades old. In the late seventeenth century, even such notable scientists as Robert Hooke and Isaac Newton ruled out the existence of small bodies in space. In 1794, the German physicist and father of acoustics Ernst F.F. Chladni published a short list of fireball events and effectively argued that these events and the meteorites they dropped could not have been atmospheric and were likely due to cosmic rocks entering the Earth's atmosphere. In 1802 the British chemist Edward Charles Howard showed that several meteoritic stones had similar chemical compositions and that nickel, which is seldom present in terrestrial rocks except in trace amounts, was common to all of them. These two pivotal works, along with a number of early nineteenth century falls, slowly strengthened the notion that fireball events and the stones they dropped were of celestial, rather than atmospheric, origin. Even so, it was well into the mid twentieth century before Meteor Crater in particular and the obvious lunar craters in general were widely considered as impact phenomena rather than being due to volcanic eruptions or steam generated explosions. It seems that despite Mother Nature's best attempts to point out the importance of impact events in the solar system and the existence of a vast population of near-Earth asteroids, much of the scientific community reached these viewpoints rather late. Likely reasons for this slow acceptance of rocks from space will be discussed.

105 – Exoplanets 2: Atmospheres

105.01 – Exoplanet transits in X-rays: a new observational window to the exoplanetary atmosphere

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Exoplanets in short-period orbits are subject to strong irradiation from their host star and can lose mass through evaporation. The main driver for this evaporation is high-energy emission from the host star. However, it is observationally unclear where in the exoplanetary atmosphere the bulk of the high-energy radiation is absorbed, and the energy budget for the evaporation is not well constrained. We have observed seven transits of the Hot Jupiter HD 189733 b in front of its host star, using X-ray observations with Chandra and XMM-Newton. We detect the exoplanetary transit in X-rays for the first time. We find a surprisingly large X-ray transit depth of 6-8%, in stark contrast to an optical transit depth of only 2.4%. We can trace this back to extended outer atmosphere layers of the planet which reach out to 1.75 optical planetary radii in altitude. We are able to derive density and temperature estimates for the outer planetary atmosphere, as well as a revised energy budget for planetary evaporation due to the large X-ray absorbing radius. These observations, together with accepted further programs in the X-ray regime, will allow us to build a comprehensive picture of the atmospheres of strongly irradiated exoplanets.

105.02 – Exploring the atmosphere of HD 189733b at high spectral resolution

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In addition to measuring the transit and secondary eclipse depths, the atmosphere of the hot Jupiter HD 189733b can also be studied using high-resolution spectroscopy. With this method, we are sensitive to Doppler-shifted absorption lines in the planet's atmosphere, allowing the firm detection of molecules, as well as determining the orbital velocity of the planet, and with this the mass of the star and planet. Also, constraints on the temperature profile and gas abundances can be placed. We present our detections of CO and H2O in the atmosphere of HD 189733b using CRIRES on the VLT, as well as ongoing work on CRIRES measurements during the planet's transit. Also, we will discuss constraints placed on the atmosphere by these measurements and discuss what additional measurements can be made with CRIRES that will improve our knowledge of this planetary atmosphere.

105.03 – Clouds in Low-mass, Low-density Planets

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The Kepler Space Telescope has revealed huge populations of low-mass, low-density planets, but their compositions remain elusive. For example, the density of GJ 1214b is consistent with either a water-world with a water atmosphere or a rock-iron core with a H/He envelope. Other super-Earths must contain hydrogen and helium to match their observed masses and radii. To understand this population of objects, we must be able to characterize their compositions through spectroscopy. The formation of clouds in exoplanet atmospheres significantly changes their observable spectra. For exoplanets, the opacity of hazes or clouds has been invoked as a possible explanation for the observed flat transmission spectrum of transiting super-Earth GJ 1214b as well as for the strong Rayleigh scattering feature in HD 189733b, the best-studied hot Jupiter. Here, we examine the effect of clouds on low-mass, low-density exoplanet spectra. We include the condensates that are present in chemical equilibrium for objects at these temperatures (500-900 K) which include minerals like sulfides and alkali salts. The most important of these clouds are sodium sulfide, potassium chloride, and zinc sulfide. These clouds should be most prominent at low surface gravity, strongly super-solar atmospheric abundances, and at the slant viewing geometry appropriate for transits. Hence they could be quite important for affecting the transmission spectra of cool low density super-Earth and Neptune-class planets. Another class of clouds may also dramatically alter the spectra of irradiated planets: photochemical hazes. We additionally include a hydrocarbon haze layer similar to the tholin haze in Titan's atmosphere. We calculate the location and density of the haze layer using photochemical models from Kempton et al. 2012. We present new results that show that for enhanced metallicity atmospheres, either the clouds that form in equilibrium or a hydrocarbon haze layer could become sufficiently optically thick to reproduce the observations of GJ 1214b. We also present predictions for other low-mass, low-density exoplanets which will be targets of future observational campaigns: HD 97658b and GJ 3470b.

105.04 – A Featureless Transmission Spectrum for the Neptune-Mass Exoplanet GJ 436b

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Observations of eclipsing extrasolar planets offer an invaluable window into the properties of planetary atmospheres. The Neptune-mass exoplanet GJ 436b has a size intermediate between hydrogen-dominated gas giants and the compositionally diverse "super-Earths," and observations of its atmosphere therefore provide important clues as to the nature of planets in this transitional mass regime. Moses et al. (2013) recently proposed that this planet's puzzling dayside chemistry could be explained if its atmosphere is enhanced in elements heavier than H and He by a factor of ten or more relative to Neptune. We present complementary observations of GJ 436b's transmission spectrum obtained with the Hubble Space Telescope. By measuring the wavelength-dependence of the planet's near-infrared transit depth when it passes in front of its host star we should have been able to determine the amount of water vapor in its atmosphere. Our observations instead indicate that the planet's transmission spectrum is effectively featureless, ruling out cloud-free, hydrogen-dominated atmosphere models with high statistical significance. The measured spectrum is consistent with either a high cloud deck located at a pressure of approximately 1 mbar or with a hydrogen-poor atmospheric composition. A hydrogen-poor atmosphere would place stringent constraints on the bulk composition and corresponding formation scenarios for this planet unless it can be shown that proximity to a younger and more luminous primary could have stripped off a primordial hydrogen atmosphere.

105.05 – Atmospheric Composition of the ExoNeptune HAT-P-11b

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We present new observations of the transiting exo-Neptune HAT-P-11b from a joint HST and warm Spitzer program to measure the transmission spectrum of its massive atmosphere. Our data cover a wide span of wavelength space, including warm Spitzer IRAC 3.6 & 4.5 micron photometry and Hubble WFC3 1.1 - 1.7 micron spectroscopy from our observations, as well as Kepler's optical photometry centered at 632nm. Our WFC3 spectroscopic observations are among the first using HST's new spatial scanning mode for optimised signal-to-noise spectroscopy. In addition, HAT-P-11 is one of the most active planet-hosting stars; observations of HAT-P-11b's atmosphere therefore allow us to shed light on the role that stellar activity may play in shaping the atmospheric chemistry of Neptune-sized planets. We use the Kepler photometry to model and remove the effects of the stellar activity during and surrounding our warm Spitzer transit observations. Our observations allow us to search for evidence of atmospheric hazes and to place constraints on the relative abundances of methane, water, and CO for the case of a cloud-free atmosphere.

105.06 – Ground-Based Transmission Spectroscopy of Moderately-Irradiated Exoplanets

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The atmospheres of moderately-irradiated exoplanets (MIEs) are expected to undergo different types of chemistry from their hot-Jupiter counterparts. Below an equilibrium temperature of ~1100 K, CH_4 (not CO) is favored as the dominant carbon-bearing molecule, hydrocarbon production becomes viable, and different hazes or clouds may begin to form. There exists, however, very little spectroscopic data for this class of exoplanet. We will present the first high-quality transmission spectra for several MIEs, including the non-flat spectrum of WASP-42b, which we obtained using the LDSS3 instrument at Magellan. We will also present our best-fit atmospheric models, discuss constraints on the atmospheric composition and metallicity, and give our interpretation of the non-flat transmission spectrum.

105.07 – Exoplanet Transit Spectroscopy of Hot Jupiters Using HST/WFC3

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The Wide Field Camera 3 (WFC3) on the Hubble Space Telescope (HST) provides the potential for spectroscopic characterization of molecular features in exoplanet atmospheres, a capability that has not existed in space since the demise of NICMOS on HST and the IRS on Spitzer. We present analysis of transit spectroscopy for three extrasolar planets observed during the HST Cycle 18: WASP-12 b, WASP-17 b, and WASP-19 b. WASP-12 b and WASP-19 b are two of the hottest exoplanets discovered to date, while WASP-17 b has a much lower equilibrium temperature but has one of the largest atmospheric radii of known transiting planets; measurement of molecular absorption in the atmospheres of these planets offers the chance to explore several outstanding questions regarding the atmospheric structure and composition of these highly irradiated, Jupiter-mass objects. The observations cover a single primary transit for each planet, and we analyze the data using a strategy that allows us to correct for channel- or wavelength-dependent instrumental effects by utilizing the band-integrated time series and measurements of the drift of the spectrum on the detector over time. The inclusion of these additional systematic trends in our light curve model allows us to remove the effects of spectral shifts and photometric variability in individual spectral bins, and we achieve almost photon-limited results. However, the uncertainties in the transit depth for each bin and especially for the band-integrated data are greatly hampered by the uneven sampling of the light curve imposed by the orbital phasing of HST's observations. Our final transit spectra are consistent with the presence of a broad absorption feature at 1.4 microns most likely due to water, but the amplitude of the absorption is less than expected based on previous observations with Spitzer, possibly due to hazes absorbing in the NIR. However, carbon-rich compositions cannot be ruled out at this precision due to the low amplitude of the observed spectral features, precluding unambiguous constraints on the atmospheric composition without a comprehensive multi-wavelength analysis.

105.08 – Statistical Significance of Trends in Exoplanetary Atmospheres

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Contributing teams: the UCF Exoplanets Group

Cowan and Agol (2011) and we (Harrington et al. 2007, 2010, 2011, 2012, 2013) have noted that at higher equilibrium temperatures, observed exoplanet fluxes are substantially higher than even the elevated equilibrium temperature predicts. With a substantial increase in the number of atmospheric flux measurements, we can now test the statistical significance of this trend. We can also cast the data on a variety of axes to search further for the physics behind both the jump in flux above about 2000 K and the wide scatter in fluxes at all temperatures. This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G.

105.09 – A ~0.1 bar Rule for Tropopause Temperature Minima in Thick Atmospheres of Planets and Large Moons

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Tropopause temperature minima are fundamental for understanding planetary atmospheric structure. Inversions in the stratospheres of Earth, Jupiter, Saturn, Titan, Uranus, and Neptune lead to temperature minima that, remarkably, all occur near 0.1 bar, despite very different insolation, atmospheric composition, gravity, and internal heat flux. We examined the atmospheric thermal structure of these worlds with an analytic 1-D radiative-convective model, which assumes gray thermal radiative transfer. Shortwave radiation is divided into two channels, for heating aloft and at depth. We assume that a convective profile sits below the radiative portion of the atmosphere. Finally, the model uses a power-law scaling between the gray infrared optical depth and pressure, which is physically justified for tropospheres and lower stratospheres where opacity is dominated by collision-induced absorption and/or strong pressure broadening. We find that tropopause temperature minima always lie in the radiative regime, above the radiative-convective boundary. Thus, the shared 0.1 bar tropopause arises from the common physics of infrared radiative transfer. Model fits to solar system worlds show that the gray infrared optical depth where the tropopause minimum occurs is ~0.1. Furthermore, the gray infrared optical depths at a pressure of 1 bar are typically of order a few. These, along with the aforementioned scaling between pressure and optical depth, set the tropopause pressure at ~0.1 bar. Moving beyond the solar system, we show that the typical gray infrared optical depth of the tropopause minimum is ~0.1 for a wide range of plausible atmospheric compositions. This optical depth marks the transition into an upper region of an atmosphere that is very transparent to thermal radiation. Here, shortwave absorption can dominate the temperature profile and, thus, create an inversion and corresponding temperature minimum. These findings imply that the common 0.1 bar tropopause levels seen in the solar system atmospheres are more universal. Thus, we hypothesize that many exoplanets will possess a 0.1 bar tropopause temperature minimum.

106 – Asteroids 2: Dynamics and Collisions

106.01 – The non-uniform distribution of the perihelia of near-Earth objects

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We show that each sub-group of NEOs (Amors, Apollos and Atens) has different observational selection effects that cause distinctive features in the apparent distribution of their angular elements. We also reveal that the NEOs' perihelia (argument of perihelion and longitude of perihelion ϖ) have intrinsically non-uniform distributions caused by secular planetary perturbations: ω is non-uniform for the Apollo asteroids because of secular dynamics associated with eccentricity–ω coupling, and the Amors' ϖ distribution is peaked along the secularly forced eccentricity vector. These secular effects are dominated by Jupiter's perturbations, and it is remarkable that this strongly chaotic population of minor planets reveals the presence of Jupiter in its angular distributions.

106.02 – A New Population Model of the Orbits and Absolute Magnitudes of Near-Earth Objects

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We construct a new near-Earth object (NEO) population model which incorporates debiased information of both orbits (semimajor axis a, eccentricity e, and inclination i) and absolute magnitudes H. The new model is an upgrade to the decade-old model by Bottke et al. (2002, Icarus 156). We use the same approach as Bottke et al.; we fit biased residence-time distributions in (a,e,i) space computed for various source populations and escape routes to the observed NEO population and solve for the relative weights of the different source populations as well as their absolute-magnitude distributions. The observational data for calibrating the model is provided by the Catalina and Mt Lemmon stations of the Catalina Sky Survey. The two stations have discovered or serendipitously detected some 2500 NEOs each from 2005 to 2012. We have computed the observational biases in (a,e,i,H) space for the two telescopes using their pointing history and their nightly detection efficiencies in apparent magnitude. Initial conditions for the orbital integrations used to build the residence-time probability distributions are produced by integrating the orbits of bright main-belt objects. We assume (i) that small km- and sub-km diameter asteroids have the same orbits and (ii) that they drift in semimajor axis via the Yarkovsky effect until they enter the NEO region or reach 100 Myr evolution time. The resulting residence-time distributions have a higher resolution and a more realistic inclination distribution than those used for the Bottke model. We have identified about 30 different source regions (or main-belt escape routes) and combine these into about 12 groups which we use for our model as compared to 5 in the Bottke model. The new model, valid for objects with $13 < H < 25$, describes a wavy H distribution, which is consistent with predictions from recent observational work as well as the size distribution of young lunar craters. The debiased NEO orbital distribution (and source region predictions) are broadly consistent with Bottke et al., but some intriguing differences exist (e.g., a possible deficit of low perihelion NEOs).

106.03 – High precision predictions for near-Earth asteroids: the strange case of (3908) Nyx

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In November 2004 near-Earth asteroid (3908) Nyx was successfully observed from the Arecibo radio telescope. However, the radar measurements turned out to be 7.5 sigma away from the orbital prediction. We prove that this anomaly was caused by a poor astrometric treatment and an inaccurate dynamical model. To improve the astrometric treatment, we applied the Chesley et al. (2010) debiasing and weighting scheme, and used an aggressive outlier rejection scheme. The main issue related to the dynamical model is due to the unaccounted Yarkovsky effect. Though the dataset available in 2004 allowed at best a marginal detection of the Yarkovsky signal, including the Yarkovsky effect in the model closes the gap between the orbital prediction and the radar measurements by both improving the nominal prediction and increasing the prediction uncertainty to a more realistic level. This analysis is an important lesson that shows the sensitivity of high precision predictions to the astrometric treatment and the Yarkovsky effect. By using the full observational dataset we obtain a 5 sigma detection of the Yarkovsky effect acting on Nyx from which we derive constraints on thermal inertia and bulk density. In particular, we obtain that the bulk density of Nyx is close to 1 g/cm^3. To make sure that our results are not corrupted by an asteroid impact or a close approach with a perturbing asteroid not included in our dynamical model, we rule out the possibility that Nyx experienced an instantaneous velocity variation while crossing the Main Belt region.

106.04 – A Genetic Cluster of Martian Trojan Asteroids

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Trojan asteroids lead 60 degrees ahead (L4) or trail 60 degrees behind (L5) a planet's position along its orbit. The Trojans of Jupiter and Neptune are thought to be primordial remnants from the solar system's early evolution (Shoemaker et al., 1989; Sheppard et al., 2006). Mars is the only terrestrial planet known to host stable Trojans (Scholl et al., 2005) with ~50 km-sized objects expected to exist (Tabachnik and Evans, 1999). I identified 6 additional candidate Martian Trojans within the Minor Planet Center database, including three with multi-opposition orbits. 100 dynamical clones for each of the three asteroids were integrated for 100 Myr under a force model that included the Yarkovsky effect. All clones persisted as L5 Trojans of Mars, implying that their residence time is longer still. This is further supported by recent Gyr numerical integrations (de la Fuente Marcos and de la Fuente Marcos, 2013). The number of stable Martian Trojans is thus raised to 7, 6 of which are at L5. To investigate this asymmetry, I apply a clustering test to their orbits and compare them with the Trojan population of Jupiter. I find that, while Jupiter Trojans are spread throughout the domain where long-term stability is expected, L5 martian Trojans are far more concentrated. The implication is that these objects may be genetically related to each other and to the largest member of the group, 5261 Eureka. If so, it represents the closest such group to the Earth's orbit, still recognizable due to the absence of planetary close encounters which quickly scatter NEO families (Schunova et al., 2012). I explore the origin and nature of this ` Eureka cluster', including the thesis that its members are products of the collisional fragmentation and/or rotational fission of Trojan progenitors. I constrain the cluster's age under these scenarios and argue that collisions may be responsible for the observed paucity of km-sized objects. Finally, I discuss how the hypothesis of a genetic association may be further scrutinized by new models and observations. Astronomical Research at Armagh Observatory is funded by the Northern Ireland Department of Culture, Arts and Leisure (DCAL).

106.05 – A new 6-part collisional model of the Main Asteroid Belt.

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In this work, we constructed a new model for the collisional evolution of the Main Asteroid Belt. Our goals are to test the scaling law from the work of Benz & Asphaug (1999) and ascertain if it can be used for the whole belt. We want to find initial size-frequency distributions (SFDs) for the considered six parts of the belt, and to verify if the number of asteroid families created during the simulation matches the number of observed families as well. We used new observational data from the WISE satellite (Masiero et al., 2011) to construct the observed SFDs. We simulated mutual collisions of asteroids with a modified Boulder code (Morbidelli et al., 2009), in which the results of hydrodynamic (SPH) simulations from the work of Durda et al. (2007) are included. Because material characteristics can affect breakups, we created two models - for monolithic asteroids and for rubble-piles (Benavidez et al., 2012). To explain the observed SFDs in the size range D = 1 to 10 km we have to also account for dynamical depletion due to the Yarkovsky effect. Our work may also serve as a motivation for further SPH simulations of disruptions of smaller targets (parent body size of the order of 1 km). The work of MB was supported by grant GACR 13-013085 of the Czech Science Foundation and the Research Programme MSM0021620860 of the Czech Ministry of Education.

106.06 – The Unusual Evolution of Billion-Year Old Asteroid Families by the Yarkovsky and YORP Effects

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An interesting application of the coupled Yarkovsky and YORP effects (YY) is how they can be used to determine asteroid family ages. After an asteroid disruption event, smaller fragments drift faster than the larger ones on average, producing a characteristic "V"-shape in semimajor axis, absolute magnitude (or asteroid diameter) space. If properly modeled, the "V" can be used as a clock to date the time of the break-up and constrain the migration of the family's fragments into the NEA population (Vokrouhlicky et al. 2006). Curiously, while our existing YY models work well for younger families (< 300 My), they fail for older ones. The reason is that small asteroids spinning up or down by YORP eventually reach an endstate: they spin so fast that they shed mass, or they spin so slowly that they enter into a tumbling rotation state. These "YORP cycles" can change an asteroid's Yarkovsky drift direction by flipping the orientation of its spin pole. Thus, YORP cycles cause asteroids to random walk in Yarkovsky drift direction. Over time, YORP cycles should turn families from V's into blobs in semimajor axis, diameter space. This is observed for ancient families (e.g., Maria, Koronis). The question is why we do not see it for middle-aged families (e.g., Eulalia, Flora), where most of their observed members should have experienced multiple YORP cycles. A possible solution is a mechanism we call "variable YORP". Statler (2009) found that tiny shape changes to small asteroids (e.g., boulder movement, small crater formation) can alter the strength and direction of an asteroid's YORP torques. This allows asteroid spin rates but not obliquities to random walk over time. We find

the inclusion of variable YORP slows down the onset of YORP cycles, allowing middle-aged families to maintain their V-shapes. Using an asteroid evolution model that includes a formulation of variable YORP, we will show how we can, for the first time, compute accurate formation ages for roughly billion-year old families such as Eulalia, Flora, and New Polana.

106.07 – Larger classification allows a new interpretation of the Vesta Family

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A new classification of asteroids into dynamical families, with a total of 86743 members, has been obtained from 336219 synthetic proper elements sets (http://hamilton.dm.unipi.it/astdys2/index.php?pc=5). From the very fine details of the family structures it is possible to investigate individual collisional events contributing to the formation of the families we now detect as statistical entities. One of the largest is the family of (4) Vesta, with 7865 members. Only fragments with diameter <8 km are in the family. Projected on the proper a-e plane, the dynamical family shows a complex structure, not be the outcome of a single cratering event. The low proper a boundary of the family is defined by the 7/2 mean motion resonance with Jupiter, the high a boundary by the 3/1 resonance. The 1/2 resonance with Mars (at a ~2.417) cuts across the family, the boundary of the low proper e portion of the family has a very regular shape, suggesting a single cratering event. If we define a subgroup of the family with a<2.417 and e<0.102 we have 5324 members. By assuming all have thesame albedo as Vesta, we can estimate the total volume of the asteroids in the subgroup at 20900 km^3, while the total volume of the family is 32600 km^3. The Rheasilvia crater has a total volume of at least 2 million km^3, indicating that the family formed with the crater was much larger than the current family. Although the age of the cratering generating the subgroup has a significant uncertainty, there is no way it could be more than 500 Myr. The family generated with Rheasilvia must be much older, to have had time to dissipate, with most small asteroids reaching the 3/1 and the g g6 resonances by Yarkovsky effect, others escaping through mean motion resonances. The diffusion processes over time scales of Gyr can be assessed by the asteroids which are likely to be vestoids. For a<2.5 there are 1199 numbered asteroids rated vestoids and not in the (4) family, 504 in the family. Even accounting for false positive in the vestoid criterion, the vestoids outside of the family are more than twice the ones in the family. These should be fragments from previous craterizations.

106.08 – Yarkovsky-driven Impact Predictions: Apophis and 1950 DA

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Orbit determination for Near-Earth Asteroids presents unique technical challenges due to the imperative of early detection and careful assessment of the risk posed by specific Earth close approaches. The occurrence of an Earth impact can be decisively driven by the Yarkovsky effect, which is the most important nongravitational perturbation as it causes asteroids to undergo a secular variation in semimajor axis resulting in a quadratic effect in anomaly. We discuss the cases of (99942) Apophis and (29075) 1950 DA. The relevance of the Yarkovsky effect for Apophis is due to a scattering close approach in 2029 with minimum geocentric distance ~38000 km. For 1950 DA the influence of the Yarkovsky effect in 2880 is due to the long time interval preceding the impact. We use the available information from the astrometry and the asteroids' physical models and dynamical evolution as a starting point for a Monte Carlo method that allows us to measure how the Yarkovsky effect affects orbital predictions. We also find that 1950 DA has a 98% likelihood of being a retrograde rotator. For Apophis we map onto the 2029 close approach b-plane and analyze the keyholes corresponding to resonant close approaches. For 1950 DA we use the b-plane corresponding to the possible impact in 2880. We finally compute the impact probability from the mapped probability density function on the considered b-plane. For Apophis we have 4 in a million chances of an impact in 2068, while the probability of Earth impact in 2880 for 1950 DA is 0.04%.

106.09 – Killing the YORP Cycle: A Stochastic and Self-Limiting YORP Effect.

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We present the results of the first simulations that self-consistently model the YORP effect on the spin states of dynamically evolving aggregates. Extensive analyses of the basic behavior of the YORP effect have been previously conducted leading to the idea of a "YORP cycle". These studies are based on the assumption that the objects are rigid bodies but evidence from light curve observations strongly suggests that most asteroids are aggregates. The time scales over which mass reconfiguration occur are much shorter than the time scales over which YORP changes the spin states and Statler [2009] has shown that the YORP effect has an extreme sensitivity to the topography of the asteroids (Icarus 202, 501-513). As the YORP effect changes the spin, the change in spin results in a change of the shape, which subsequently changes the YORP torques. The continuous changes in the shape of an aggregate result in a different evolution of the YORP torques and therefore aggregates do not evolve through the YORP cycle as a rigid body would. Instead of having a spin evolution ruled by long periods of rotational acceleration and deceleration as predicted by the YORP cycle, the YORP effect is self-limiting and stochastic on aggregate asteroids. We provide a description of the stochastic and self-limiting behaviors of the YORP effect along with the results of shape evolution including the types, magnitudes and frequencies of movement and shedding of material. Although rotational acceleration for long periods of time is not achieved, a fraction of objects do present mass-shedding episodes at lower spin rates than the critical spin limit for aggregate asteroids. We also provide the bulk properties of the obtained distribution of changes in the spin rates, which are necessary in order to model correctly the coupled Yarkovsky/YORP evolution.

107 – Moon

107.01 – Measurements of the Near-Surface Column Structure of Lunar Pyroclastic Deposits

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Pyroclastic deposits on the Moon are associated with many types of volcanic constructs, including rilles, pits and linear fractures, and small domes. Prior radar data have revealed buried flows and rocks within some pyroclastics deposits (e.g. Aristarchus), while other deposits have radar polarimetry values that suggest very thick mounds of fine (centimeter-or-less sized) material (Campbell et. al., Geology, 36, 135, 2008; Carter et al., JGR, 114, E11004, doi:10.1029/2009JE003406, 2009). Radar can detect buried blocks or buried structures and provide a measure of roughness, while thermal infrared data provides complimentary information on the surface and near-surface rock abundance. The two wavelength ranges are also sensitive to different sized rocks, and the combined data sets provide the best way to make quantitative measurements of the upper structure of pyroclastic deposits. We use imaging radar data from Arecibo Observatory and the Green Bank Telescope, Lunar Reconnaissance Orbiter (LRO) Mini-RF data, and LRO Diviner rock abundance and regolith temperature maps, to investigate a range of pyroclastic deposits associated with different types of volcanic structures, including Aristarchus, Rima Hyginus, and domes in Mare Tranquillitatis. Thick pyroclastic deposits have low rock abundance in both radar and infrared data, but in many cases (e.g. lunar domes, Aristarchus buried flows), the radar reveals rocks and structures that are not visible in the Diviner data sets. The derived column structure maps will provide an improved estimate of the thickness and degree of regolith mixing of pyroclastic deposits.

107.02 – Tsiolkovskiy Crater Thermophysical Anomaly: Massive Impact Melt or Surface Modification?

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Analyses of data from the Diviner Lunar Radiometer have been used to identify an area of elevated rock abundance and nighttime soil temperature in and around Tsiolkovskiy Crater. Previous studies (e.g. Bandfield et al., 2011) have established a clear relationship between Diviner-derived rock abundances and crater age (most rocks are weathered into regolith within ~1 Ga) that would indicate a relatively young age for Tsiolkovskiy. However, the previously published ages for Tsiolkovskiy's mare-fill (a lower

limit on the crater age) are generally within the range 3.5 ± 0.3 Ga. To study the discrepancy between crater age and apparent "fresh" appearance we have used new datasets from Diviner, Mini-RF, and LROC to probe the near-surface regolith at variable depth and scales. We evaluated several hypotheses for the origin of this anomaly including: (1) inaccuracies in the published age estimates, (2) unusually high abundances of locally-derived, highly competent impact melt, (3) inclusion of significant blocky material from Aristarchus antipodal ejecta, and (4) recent surface modification or disruption. The results of our study favor (2) locally-derived, highly competent impact melt, and (5) recent surface modification or disruption over other mechanisms. This presentation will focus on describing the implications of the favored mechanisms.

107.03 – Small Scale Cold Traps on Airless Planetary Bodies

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Contributing teams: Diviner Lunar Radiometer Science Team

Lacking an atmosphere to transport heat, temperatures on airless bodies are primarily controlled by latitude and local time. However, local topography strongly affects temperatures at the surface and in the subsurface by changing the intensity and timing of insolation. In the case of low-obliquity bodies such as Mercury and the Earth's moon, topography near the poles casts perennial shadows where volatiles such as water ice may be cold-trapped for billions of years. Prior studies have focused primarily on large contiguous cold traps > 1 km resolvable by instruments in lunar orbit. In this investigation, we used infrared measurements of the Moon, thermal models, and a statistical rough surface model to show that such cold traps may exist on a vast range of scales, from the largest impact craters, down to the skin depth of the diurnal temperature oscillation. The extremely insulating nature of planetary regolith leads to extreme temperature gradients and shallow diurnal skin depths. For example, the lunar 29-day diurnal temperature oscillation is damped to ~1% at a depth of 0.5 m. Therefore, at latitudes > 60° where perennial shadow exists, cold traps as small as a few tens of centimeters could exist. As two test cases, we calculated the fractional surface areas on the Moon (obliquity = 1.6°) and Ceres (3-5°) where temperatures remain < 110 K all year round, such that water ice is thermally stable at the surface for billions of years. We also calculated fractional areas where subsurface temperatures are < 145 K, such that subsurface ice deposits are stable on similar timescales. Finally, we will discuss the implications of these proposed small-scale cold traps for other airless bodies, including asteroids and giant planet satellites.

107.04 – Measuring the Moon's Morning Dew

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Water is an important planetary constituent for geological processes and for life. Water or hydroxyl mineral hydration has been discovered on the Moon at all latitudes and with apparent meridional and diurnal variability using reflected-light techniques. These measurements potentially could be limited to detecting merely a monolayer on the observable surface, requiring other techniques that probe deeper into the surface to estimate the actual abundance of hydrogen-bearing species. Neutron remote-sensing is capable of making these measurements, probing about 100 cm into the surface to evaluate the concentration of hydrogen in the regolith. We observe suppression of epithermal neutron emission from the lunar surface using the Lunar Exploration Neutron Detector (LEND) on the Lunar Reconnaissance Orbiter (LRO) near the dawn and dusk terminators at near-equatorial latitude, in the range 30°S to 30°N. The greatest neutron count rate, corresponding to the least flux suppression by the least concentration of hydrogen, is found at a post-meridian local time of about 14:30. The suppression of epithermal neutrons near the terminators and on the night side of the Moon is consistent with the presence of hydrogen in or on the upper regolith with the greatest suppression (greatest hydrogen content) at the dawn terminator. Since the terminator moves across the surface as the Moon rotates, this implies a mobile population of hydrogenated volatiles that dwells near the dawn terminator but resides only transiently in the regolith, with replenishment delivered to the dusk terminator. The difference in the depth of suppression between two epithermal-neutron detection systems in LEND is nominally consistent with isolation of hydrogen in the upper part of the ~100 cm depth probed by neutron remote-sensing. The existence of an active hydrological cycle on even an airless body is a significant increase in the complexity of planetary systems and surface-space interactions.

107.05 – LRO LAMP: Regional Variations in FUV Lunar Signatures

Amanda Hendrix[1], Kurt Retherford[2], Randy Gladstone[2], Dana Hurley[3], Paul Feldman[4], Anthony Egan[5], David Kaufmann[5], Paul Miles[2], Joel Parker[5], Thomas Greathouse[2], Michael Davis[2], Wayne Pryor[6], Mark Bullock[5], Kathy Mandt[2], Alan Stern[5]

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We present results from analysis of dayside data from the Lunar Reconnaissance Orbiter (LRO) Lyman Alpha Mapping Project (LAMP) instrument at far-ultraviolet (FUV) wavelengths. We focus on regional compositional variations, particularly those due to hydration and space weathering effects. The strong 165 nm H20 absorption edge is utilized to detect diurnal variations in hydration as indicated by changes in spectral slope. The diurnal variations in spectral slope are superimposed on latitudinal and spatial variations related to composition and weathering. We use two different spectral regions (164-173 nm and 175-190 nm) to separate out these effects. The diurnal variation in hydration is consistent with a solar wind origin and with a loss of H20 at temperatures above ~320 K (Hurley et al., 2012). We also look for hydration variations related to different terrains; mare regions, as well as the South Pole Aitken Basin, appear to have stronger diurnal variations in the water absorption edge than highlands regions. We find that Compton-Belkovich is a spectrally anomalous region in the FUV and investigate this further.

107.06 – Constraints on water and oxygen-bearing compounds in the lunar exosphere from ion and neutral observations

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Contributing teams: DREAM

The reported overabundance of measured O+ relative to other species in the lunar wake by WIND and AMPTE cannot be explained with neutral oxygen as constrained by LRO observations. If a lunar origin of the O+ observed is posited, volatile molecular ions such as OH+, H2O+, CO+ or CO2+ may be contributing to the O+ and C+ measured by Kaguya and WIND, a possibility suggested by Tanaka et al. [2009]. There have been suggestions that OH and water can efficiently be produced by the impact of the solar wind. Alternatively, new models have shown that almost all of the interplanetary dust particles impacting the moon are composed of carbonaceous chondrites, which contain up to 10 wt% water. We calculate the rate of production of ions from both photoionization of the exosphere and from sputtering at the surface, and use an ion tracer to propagate the resulting ions to the lunar wake. Pickup ions formed from the ionized neutral exosphere were tracked in the interplanetary electric and magnetic fields. The resulting ion density is plotted vs. mass/charge and compared with data from WIND and AMPTE. Our model exosphere is constrained by LRO observations, and the impact vaporization rate is constrained by recent models. We place limits on the water on the moon. Further work is required to constrain carbon compounds.

107.07 – Lunar Atmospheric H_2 Detections by the LAMP UV Spectrograph on the Lunar Reconnaissance Orbiter

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Contributing teams: LAMP Sciecne Team

H_2 in the lunar atmosphere was predicted by Hodges (1973), who theorized that the low H upper limit derived from Apollo 17 Ultraviolet Spectrometer (UVS) (Fastie et al., 1973; Feldman and Morrison, 1991) suggested that the bulk of solar wind protons must become neutralized and form H_2 on the lunar surface. By balancing the H thermal escape rate with the impact rate, Hodges (1973) predicted a night time surface density of $N(H_2) = 1.2 \times 10^4$ cm^{-3}. However, measurements from UVS observations yielded only an upper limit of < 9000 H_2 molecules cm^{-3} (Feldman and Morrison 1991). After reflected energetic neutral hydrogen was

detected by IBEX (McComas et al., 2009) and Chandrayaan-1 (Wieser et al., 2009), Hodges (2011) revisited the H_2 issue. Based on Hodges (2011) model, the solar wind protons exit the lunar surface as neutral H (98.5%) and protons (1%) at escape speeds. The remaining 0.5% are bound to the lunar atmosphere as neutral H with a H surface density that is compatible with Apollo 17 observations (< 17 cm^{-3}; Feldman and Morrison, 1991). Here we report the detection of H_2 seen in twilight observations of the lunar atmosphere observed by the LAMP (Lyman Alpha Mapping Project) instrument aboard NASA's Lunar Reconnaissance Orbiter. Using millions of seconds of lunar atmospheric integration time collected between September 2009 and March 2013, we have identified the presence of H_2 for the first time using ultraviolet spectroscopy. We derive an H_2 surface density of $(1.2 \pm 0.4) \times 10^3$ cm^{-3} at 120 K. This is 10 times smaller than originally predicted, and several times below previous upper limits. We point out that our result is consistent with the prediction made by Wurz et al. (2012), who estimated a surface density between 1050 and 2100 cm^{-3}, depending on how readily atmospheric H_2 escapes.

107.08 – LRO-Lyman Alpha Mapping Project (LAMP) Observations of the GRAIL Impact Plumes

Kurt D. Retherford[1], Thomas K. Greathouse[1], Dana M. Hurley[2], G. R. Gladstone[1], Paul O. Hayne[3], David A. Paige[4], Benjamin T. Greenhagen[3], Elliot Sefton-Nash[4], Maria T. Zuber[5], David E. Smith[5, 11], Anthony Colaprete[6], David E. Kaufmann[7], Paul F. Miles[1], Cesare Grava[1], Henry Throop[7, 8], Paul D. Feldman[9], Amanda R. Hendrix[8], Wayne R. Pryor[10], Timothy J. Stubbs[11], David A. Glenar[12], Joel W. Parker[7], S. A. Stern[7]

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The Lyman Alpha Mapping Project (LAMP) UV spectrograph on the Lunar Reconnaissance Orbiter (LRO) was positioned to directly view the expanding gas plumes from the two GRAIL spacecraft impacts on 17 December 2012. LAMP detected resonantly scattered emissions from Hg and H atoms in the sunlit regions of these plumes. The spectral, spatial, and light-curve analyses used in these gas detections are consistent with previous LAMP observations of the LCROSS impact into the permanently shadowed region of Cabeus crater. LAMP's detection of atomic H by Lyman-α emission at the Moon (a first) was facilitated by pointing at the nightside surface to eliminate sky background noise. Volatile transport of Hg and H species is known to concentrate them near the poles, and in the context of LRO-Diviner temperature measurements of these high-latitude (75.6° N) impact sites the LAMP detections address this process.

107.09 – Plasma environment near lunar magnetic anomalies and its effects on surface processes

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In-situ observations and modeling work have indicated the interactions between the solar wind and lunar crustal magnetic anomalies. These interactions will alter the near-surface plasma environment in the magnetic anomaly regions and may have effects on the formation of unusual albedo features - the 'lunar swirls', and possibly also on the production (or loss) of volatiles (e.g. hydroxyl) as well as electrostatic dust transport. These interactions are complicated by the complex geometries of the lunar crustal magnetic fields. Here we present a series of laboratory investigations of the plasma interactions with magnetic dipole fields above an insulating surface for understanding fundamental physical processes and surface electric fields. We investigated moderate strength dipole fields in which the electrons were magnetized while the ions were unmagnetized. The dipole field was oriented parallel, oblique and normal to the surface. Several physical processes have been identified, including magnetic shielding and focusing, magnetic mirror reflection as well as non-monotonic sheaths. Potential distributions on the surface were complex with enhanced surface charging and electric fields. Our experimental results indicate that plasma environment near the lunar surface can be greatly modified in the magnetic anomaly regions and may thus alter the surface processes. The latest results with a flowing plasma will also be presented.

108 – Historical Astronomy Division: Contributed Talks

108.01 – Budgeting for Exploration: the History and Political Economy of Planetary Science

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The availability of financial resources continues to be one of the greatest limiting factors to NASA's planetary science agenda. Historians and members of the space science community have offered many explanations for the scientific, political, and economic actions that combine to form NASA's planetary science efforts, and this essay will use budgetary and historical analysis to examine how each of these factors have impacted the funding of U.S. exploration of the solar system. This approach will present new insights into how the shifting fortunes of the nation's economy or the changing priorities of political leadership have affected government investment in science broadly, and space science specifically. This paper required the construction of a historical NASA budget data set displaying layered fiscal information that could be compared equivalently over time. This data set was constructed with information collected from documents located in NASA's archives, the Library of Congress, and at the Office of Management and Budget at the White House. The essay will examine the effects of the national gross domestic product, Federal debt levels, the budgets of other Federal agencies engaged in science and engineering research, and party affiliation of leadership in Congress and the White House on the NASA budget. It will also compare historic funding levels of NASA's astrophysics, heliophysics, and Earth science efforts to planetary science funding. By examining the history of NASA's planetary science efforts through the lens of the budget, this essay will provide a clearer view of how effectively the planetary science community has been able to align its goals with national science priorities.

108.02 – 211-YEAR-OLD MYSTERY SOLVED: CREATOR OF THE WORD "ASTEROID" REVEALED

Clifford J. Cunningham[1]

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In 1802, William Herschel famously declared that the newly discovered celestial objects Ceres and Pallas were asteroids, not planets. The term asteroid was rejected by nearly every astronomer in the early nineteenth century, but is now the most widely-used word to describe the small planetary bodies of the solar system. Even so, its origin has remained a mystery. By default, its creation has always been attributed to Herschel himself, but he lacked the knowledge of Greek and Latin to coin a new word to describe Ceres and Pallas. Herschel instead turned to a network of colleagues for advice. A study of contemporary manuscript evidence has now identified the name of the scholar who created the word asteroid.

108.03 – The Planetary and Eclipse Oil Paintings of Howard Russell Butler

Jay M. Pasachoff[1], Roberta J. M. Olson[2]

1. Williams College, Williamstown, MA, United States. 2. New-York Historical Society, New York, NY, United States.

The physics-trained artist Howard Russell Butler (1856-1934) has inspired many astronomy students through his planetary and eclipse paintings that were long displayed at the Hayden Planetarium in New York, the Fels Planetarium at the Franklin Institute in Philadelphia, and the Buffalo Museum of Science. We discuss not only the eclipse triptychs (1918, 1923, and 1925) at each of those institutions but also his paintings of Mars as seen from Phobos and from Deimos (with landscapes of those moons in the foreground depicted in additional oils hung at Princeton University) and the Earth from our Moon. We also describe his involvement with astronomy and his unique methodology that allowed him to surpass the effects then obtainable with photography, as well as his inclusion in a U.S. Naval Observatory eclipse expedition in 1918, as well as his auroral, solar-prominence, and 1932-eclipse paintings.

108.04 – dps45

Donald B. Campbell[1]

1. Cornell University, Ithaca, NY, United States.

November 1 of this year marks the 50th anniversary of the inauguration of the 305-m Arecibo telescope in Puerto Rico. The concept for the telescope originated with then professor of engineering at Cornell University, William E. (Bill) Gordon, in the spring of 1958.

Bill Gordon's interest was in building an antenna/transmitter combination with sufficient sensitivity to detect Thompson scatter from the individual electrons in the Earth's ionosphere and use this capability to investigate ionospheric parameters as a function of height, a technique that was dubbed incoherent scatter. A 1,000 ft (305 m) diameter antenna coupled with a 2.5 MW peak power transmitter operating at a frequency of about 400 MHz was settled on as the best fit to the requirements. Bill Gordon and his colleagues at Cornell realized that the capabilities of such an antenna would also be applicable to radar studies of the planets and to radio astronomy. A combination of Bill Gordon's leadership, engineering talent at Cornell University, interest and support by the newly formed Advanced Research Projects Agency of the Department of Defense and the need for a better understanding of the ionosphere at the beginning of the space age let to the funding and initiation of the project in less than two years.

108.05 – MICROWAVE REMOTE SENSING OF PLANETARY ATMOSPHERES: THE 50 YEARS FROM MARINER 2 TO NASA-JUNO

Paul G. Steffes[1]
1. Georgia Inst. of Tech., Atlanta, GA, United States.

In November 2012, the world celebrated the 50th anniversary of spacecraft-based exploration of planets and satellites other our own. The first successful interplanetary mission (Mariner 2) included the first spaceborne microwave radiometer for studying planetary atmospheres which measured the 1.3 and 2.0 cm emission spectrum of Venus (also known as the Cytherean spectrum), These measurements, plus accompanying earth-based observations of the centimeter-wavelength spectrum were used to establish early models of the composition and structure of Venus. Shortly thereafter, measurements of the microwave emission spectrum of Jupiter (also known as the Jovian spectrum) from 1.18 to 1.58 cm were conducted. In both sets of observations, wavelengths near the 1.35 cm water-vapor resonance were selected in hope of detecting the spectral signature of water vapor, but none was found. Thus the question remained, "where's the water?" The NASA-Juno mission is the first mission since Mariner 2 to carry a microwave radiometer instrument designed specifically for atmospheric sensing. It is expected to finally detect water in the Jovian atmosphere.

109 – Welcome; Kuiper Prize Lecture: Small is NOT Dull: Unravelling the Complexity of Surface Processes on Asteroids, Comets and Small Satellites,J. Veverka

109.01 – Small is NOT Dull: Unravelling the Complexity of Surface Processes on Asteroids, Comets and Small Satellites

Joseph Veverka[1]
1. Cornell Univ., Ithaca, NY, United States.

Four decades of spacecraft exploration have revealed a diversity of surface processes on small bodies in our solar system. While some of these processes are reasonably well understood, many puzzles and enigmas remain to be explained. We will review our growing understanding of these processes from the first Mariner 9 studies of the moons of Mars to the most recent observations of Saturn's small satellites by Cassini. We will also discuss some unresolved issues concerning asteroids and comets, including the formation of grooves, the sorting of asteroid regoliths, downslope movement in low g environments and the formation of surface flows and crater-like pits on comet surfaces.

110 – The Chelyabinsk Airburst Event, Mark Boslough (Sandia National Labs)

110.01 – The Chelyabinsk Airburst Event

Mark Boslough[1]
1. Sandia National Laboratories, Albuquerque, NM, United States.

On Feb. 15, 2013, an asteroid exploded about 40 km from the Russian city of Chelyabinsk. Its proximity led to many injuries and widespread blast damage, but also yielded a plethora of data, providing means to determine the projectile size and entry parameters, and develop a self-consistent model. We will present results of the first physics simulations to be initialized with accurate energy deposition derived from observations. The best estimate of the explosive yield is 400-500 kilotons, making Chelyabinsk the most powerful such event observed since Tunguska (3-5 megatons). Analysis of video combined with subsequent on-site stellar calibrations enable precise estimates of entry velocity (19 km/s), angle (17° elevation) and altitude of peak brightness (29 km). This implies a pre-entry diameter of ~20 m and mass of ~1200 tonnes. Satellite sensors recorded the emission peak at 03:20:33 UT, with a total radiated energy of 3.75×10^{14} J (~90 kilotons). A typical bolide luminous efficiency of 20% implies a total energy of ~450 kilotons, consistent with infrasound and other observations. The maximum radiant intensity was 2.7×10^{13} W/ster, corresponding to a magnitude of -28. The shallow entry angle led to a long bolide duration (16.5 s) and energy was deposited over 100s of km leading to an extended, near-horizontal, linear explosion. The blast was distributed over a large area, and was much weaker than for a steep entry and a more concentrated explosion closer to the surface. The orientation also led to different phenomena than expected for a more vertical entry. There was no ballistic plume as observed from SL9 impacts (45°) or calculated for Tunguska (~35°). Instead, buoyant instabilities grew into mushroom clouds and bifurcated the trail into two contra-rotating vortices. Chelyabinsk and Tunguska are "once-per-century" and "once-per-millennium" events, respectively. These outliers imply that the frequency of large airbursts is underestimated. Models also suggest that they are more damaging than nuclear explosions of the same yield (traditionally used to estimate impact risk). The risk from airbursts is therefore greater than previously thought.

111 – End-of-the-World: Using Science to Dispel Public Fear, D. Morrison (NASA Astrobiology Inst)

111.01 – End-of-the-World: Using Science to Dispel Public Fear

David Morrison[1]
1. NASA Astrobiology Inst., Mountain View, CA, United States.

Polls taken in mid-2012 indicated that 10% of Americans did not expect to survive the "end of the world" on 12/21/12. Children were especially vulnerable, and some contemplated suicide. Comets Elenin and ISON also attracted apocalyptic fears. Elenin was blamed for the several earthquakes, including the Fukushima mega-quake of 03/11/11. Such fears, which seem to harp back to earlier centuries, are now widely promulgated by the Internet and cable TV, where dozens of "documentaries" are shown every week dealing with UFOs, aliens, astrology, and a variety of cosmic threats. In this talk I recount some of my experiences and those of other scientists leading up to the 12/21/12 doomsday. We made a big effort to defuse these fears, and to warn teachers and parents that a substantial fraction of their children were in danger of being taken in by the 2012 hoax. This experience is just one example of an anti-science trend that seems to be growing in the U.S. and around the world. Prime examples are the creationist efforts to deny evolution, the similar tactics of the global warming denialists, and health hoaxes such as homeopathy and the anti-vaccination movement. As scientists, we should consider how best to communicate real science to the public, and when to "go negative" to fight against pseudoscience. We must recognize the presence of powerful anti-science forces that are well funded and skillful at exploiting new communication tools enabled by the Internet. This is a challenge for all of us.

112 – Asteroids Posters 1: First Served

112.01 – Modal mineralogy of VESTA: 1."Ground truth" measurements

Francois Poulet[1], Yves Langevin[1]
1. Institut d'Astrophysique Spatiale, Orsay cedex, France.

The surface of Vesta is constrained using spectral data gathered by DAWN spacecraft in orbit. One of the most successful techniques for determining the surface composition is the near infrared imaging spectroscopy. Virtually the entire surface of Vesta has been mapped using the VIR instrument. Such complex spectral data can be deconvolved into mineral abundances using radiative transfer model (e.g., Shkuratov et al. 1999; Poulet and Erard 2004). This deconvolution technique has been already applied to various similar data providing for instance the modal mineralogy of basaltic terrains of planetary objects. A critical assessment of the application of this method to the surface of VESTA is however required. HED provide important compositional information about surface composition and thus enable "ground-truth" of orbital data. Here we apply the Shkuratov scattering model to the NIR spectra of several HED meteorites and mixtures obtained by Cloutis et al. (2013) in order to retrieve their modal composition. The spectral data between 0.9 and 2.5 μm are successfully reproduced by the model by using several types of pyroxenes. In particular, the 1.25 μm band in spectra of HED is best reproduced by pyroxenes that contain Fe^{2+} in the M1 crystallographic site. The modeled compositions are compared to their actual petrographic characteristics. Abundance estimates of end-members (plagioclase, pigeonite, augite, olivine, orthopyroxene, murchison) are accurate to within 10–20% deepending on the minerals. This example illustrates how such a technique can be used as a tool for characterizing the modal mineralogy of pyroxene-dominated rocks of

Vesta. The next step will be thus to model the public-released VIR data to retrieve the surface composition of specific terrains, with possibly first results presented at the time of the meeting.

112.02 – Resolved Photometry of Vesta Reveals Physical Properties of Crater Regolith

Stefan Schroeder[1], Stefano Mottola[1], Uwe Keller[2], Carol Raymond[3], Chris Russell[4]
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During its year-long orbital mission, the Dawn spacecraft mapped the surface of main-belt asteroid Vesta multiple times at different spatial resolutions and illumination and viewing angles. The on-board Framing Camera acquired thousands of clear filter and narrow band images, which, with the availability of high-resolution global shape models, allows for a photometric characterization of the surface in unprecedented detail. We analyze clear filter images to retrieve the photometric properties of the regolith. We evaluate different photometric models for the global average, and use these results to study variations in albedo and steepness of the phase curve over the surface. Maps of these two photometric parameters show large scale albedo variations that appear to be associated with compositional differences. They also reveal the location of photometrically extreme terrains, where the phase curve is unusually shallow or steep. We find that shallow phase curves are associated with steep slopes on crater walls and faults. On the other hand, the phase curve of ejecta associated with young impact craters is steep. We interpret these variations in phase curve slope in terms of physical roughness of the regolith. The lack of rough ejecta around older craters suggests that initially rough ejecta associated with impact craters on Vesta are smoothed over a relatively short time of several tens of Myr. This process appears to be the result of impact gardening, and as such represents a previously unrecognized aspect of Vesta space weathering. We may expect to encounter this photometric phenomenon on other main belt asteroids.

112.03 – Space Weathering Evolution on Airless Bodies - Laboratory Simulations with Olivine

Tomas Kohout[1, 2], Jan Cuda[3], Todd Bradley[4], Daniel Britt[4], Jan Filip[3], Jiri Tucek[3], Ondrej Malina[3], Josef Kaslik[3], Karolina Siskova[3], Gunther Kletetschka[2], Radek Zboril[3]
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Lunar-type space weathering of airless bodies is associated with nanophase iron (npFe0) production in Fe bearing silicate minerals that is often responsible for observable changes of its reflectance spectra. A new method of controlled npFe0 production on olivine grains was developed in order to quantitatively evaluate spectral changes related to space weathering and presence of npFe0. Through a two-step thermal treatment a series of olivine samples with increasing concentration of iron nanoparticles on the grain surfaces was prepared. The grain size of the npFe0 particles was kept in the same range (~5-20 nm). Magnetic methods were used to estimate npFe0 concentration. Compared to fresh olivine, treated samples exhibit the spectral characteristics of lunar type space weathering (darkening, shallowing of 1 μm olivine absorption band, and reddening) related to increasing presence of npFe0. From quantitative point of view, a logarithmic trend was found between spectral changes and npFe0 concentration. One sample with additional population of larger ~50 nm npFe0 particles follows the darkening and the 1 μm band shallowing trend, but does not fully follow the reddening trend. This is due to fact that the larger (~40 50 nm sized) npFe0 particles do not contribute to the spectral slope change. The observed logarithmic trend between the spectral changes and the npFe0 concentration give constrains on time evolution of space weathering. In the case of constant micro impact, solar wind and cosmic radiation on a regolith, the npFe0 concentration increases linearly with time while spectral changes related to space weathering evolve logarithmically with time.

112.04 – A Spectroscopic and Mineralogical Study of Multiple Asteroid Systems

Sean S. Lindsay[1], Joshua P. Emery[1], Franck Marchis[2], J. Emilio Enriquez[3, 2], Marcelo Assafin[4]
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There are currently ~200 identified multiple asteroid systems (MASs). These systems display a large diversity in heliocentric distance, size/mass ratio, system angular momentum, mutual orbital parameters, and taxonomic class. These characteristics are simplified under the nomenclature of Descamps and Marchis (2008), which divides MASs into four types: Type-1 - large asteroids with small satellites; Type-2 - similar size double asteroids; Type-3 - small asynchronous systems; and Type-4 - contact-binary asteroids. The large MAS diversity suggests multiple formation mechanisms are required to understand their origins. There are currently three broad formation scenarios: 1) ejecta from impacts; 2) catastrophic disruption followed by rotational fission; and 3) tidal disruption. The taxonomic class and mineralogy of the MASs coupled with the average density and system angular momentum provide a potential means to discriminate between proposed formation mechanisms. We present visible and near-infrared (NIR) spectra spanning 0.45 – 2.45 μm for 23 Main Belt MASs. The data were primarily obtained using the Southern Astrophysical Research Telescope (SOAR) Goodman High Throughput Spectrograph (August 2011 - July 2012) for the visible data and the InfraRed Telescope Facility (IRTF) SpeX Spectrograph (August 2008 - May 2013) for the IR data. Our data were supplemented using previously published data when necessary. The asteroids' Bus-DeMeo taxonomic classes are determined using the MIT SMASS online classification routines. Our sample includes 3 C-types, 1 X-type, 1 K-type, 1 L-type, 4 V-types, 10 S-types, 2 Sq- or Q-types, and 1 ambiguous classification. We calculate the 1- and 2-μm band centers, depths, and areas to determine the pyroxene mineralogy (molar Fs and Wo) of the surfaces using empirically derived equations. The NIR band analysis allows us to determine the S-type subclasses, S(I) – S(VII), which roughly tracks olivine-pyroxene chemistry. A comparison of the orbital parameters, physical parameters (size, density, and angular momentum), collisional family membership, and taxonomy is presented in an effort to find correlations, which may give insights to how these MASs formation mechanisms.

112.05 – Detailed Laboratory Study of Asteroid Organics

Kelsey Hargrove[1], Scott Sandford[2], Humberto Campins[1]
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Until April 2010, organic molecules had not been detected on asteroids. They have now been identified on two objects: 24 Themis (Campins et al. 2010), (Rivkin and Emery 2010) and 65 Cybele (Licandro et al. 2011), and the organic absorptions on these objects appear different from each other. To better understand the nature of these organics and their differences we simulated four astronomical ice mixtures containing various ratios of aliphatic and aromatic hydrocarbons. Under ultra-high vacuum we took spectra of these ices in the near- and mid-infrared as we exposed the ices to UV radiation. After approximately 24 hours of UV exposure at a temperature of 15 K, we warmed the ices to 300 K with no UV irradiation. The gradual warming allowed the photoproducts produced by the UV irradiation to combine and react, creating various organics. Our initial results are promising. This study contributes to our understanding of the differences and similarities of the organic molecules that exist amongst the population of primitive asteroids, and may even help us to determine a parent body link to organic-rich meteorites.

112.06 – New Results on the Surface Gravity of Asteroids and Satellites

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It has long been known that the gravitational potential on the surface of a non rotating, homogeneous triaxial ellipsoid is lowest at the ends of its short axis, and highest at the ends of its long axis. Now I prove as well that its surface gravity is strongest at the ends of its short axis, and weakest at the ends of its long axis. The above result has sometimes been assumed implicitly, but has never been proven before, or even stated explicitly. This result still holds for rotating ellipsoids, and for those which are tidally locked satellites; it also holds for a wide range of non-homogeneous internal structures. However, the extrema of the gravitational potential and surface slope shift with tides and/or rotation in complicated ways, as illustrated by sample maps of effective potential, gravity, and slope. This forms the basis of two new classification systems for triaxial ellipsoids, including generalizations of the classic Jacobi and Roche sequences. These are used to classify the known shapes of many asteroids and small moons, with implications for their geophysics.

112.07 – New insights on the main-belt triple asteroid (87) Sylvia

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(87) Sylvia is the first minor planet known to possess two moons (Marchis et al. Nature 2005). Combining Adaptive Optics data from 8-10m class telescopes, with lightcurve observations and the result of an exceptional stellar occultation on Jan. 6 2013, we report new insights on the dynamical and physical properties of (87) Sylvia. Based on Keck, Gemini and VLT AO observations collected from 2001 to 2011 we derived the mutual orbits of the system which can be fitted by a simple Kepler model (J2=0). From this model, we predicted the relative positions of the moons at the time of this event with an accuracy better than 10 km on the Earth. 50 observers were mobilized along the path of the event and 16 of them reported an occultation, 4 of them by Romulus, the outer moon of Sylvia. A new non-convex shape model of Sylvia's primary was built (Deq = 270 +/- 3 km, leading to a density of ϱ =1.3+/-0.1 g/cm3) from this entire set of data (40 lightcurves, 2 well-resolved Keck AO images, and the occultation timings). The analysis of the chords of Romulus give us the opportunity to show that it has an elongated shape (a/b ~ 2.7), and refine its size (Deq~24 km). We will discuss the origin of this triple system and the surprising elongated shape of its satellite. This has been supported by the NASA grant NNX11AD62G and grants GACR P209/10/0537 and P209/12/0229 of the Czech Science Foundation, and by the Research Program MSM0021620860.

112.08 – Observations of NEA 1998 QE2 with the SMA and VLA

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Long wavelength (submm to cm) observations of NEAs are an important tool in their physical characterization. Such observations offer a unique probe into the subsurfaces of these bodies, to depths of 10's of cm, and reveal the surface and near-surface temperatures. These temperatures are critical in constraining the magnitude of the Yarkovsky effect, which is important for these small bodies in the inner solar system as it forces orbital drift [1]. Such observations also probe the physical state of the material in the upper layer of the NEAs; notably the thermal inertia. This is a strong indicator of bulk surface properties and can be utilized to distinguish rocky from porous surfaces. Very low thermal inertia may also indicate 'rubble pile' type internal structure in NEAs [2]. Asteroid 1998 QE2 approached to within 0.04 AU on June 1, 2013; its closest approach in two centuries. With a diameter of ~2.5 km [3], it was a relatively bright target for radio wavelength observations, even given the weakness of the emission at those wavelengths (10's of microJy in the cm to 100's of milliJy in the submm). We used the SubMillimeter Array (SMA) and Very Large Array (VLA) to observe the asteroid from wavelengths of 1 mm to 7 cm. We will present the observed brightness temperatures as a function of wavelength, and implications for temperature and physical state of the surface and near-surface. [1] Delbo et al. 2007, Icarus, 190, 236. [2] Muller et al. 2007, IAUS 236, 261. [3] Trilling et al. 2010, AJ, 140, 770.

112.09 – Coupled Spin and Orbital Dynamics of Binary Near-Earth Asteroids 2000 DP107 and 1991 VH

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Binaries form a significant fraction (~15%) of the near-Earth asteroid (NEA) population. Various models suggest that they are evolving and that some of them might be in an intermediate stage towards the formation of binary pairs, contact binary NEAs, or triple NEAs. Binary NEAs are thought to evolve under the influence of gravitational and radiative forces such as YORP and binary YORP (e.g., Cuk and Burns, 2005). A wide variety of end-states may arise depending on the relative magnitudes of the forces, which are dictated by the component shapes, spins, and mutual orbit of the binary (e.g., Jacobson & Scheeres 2011, Fang & Margot 2012). Because the spins and mutual orbits of binary NEAs are tightly coupled to each other, understanding the spin-orbit interaction is key to modeling binary NEA evolution. This interaction can be studied using asteroid shape models (e.g., Scheeres et al. 2006, Fahnestock and Scheeres, 2006). We will present numerical simulations describing the spin-orbit states of two binary NEAs, 2000 DP107 and 1991 VH, as well as the consequences for the evolution of binary NEAs. Naidu et al. (2011) presented the radar-derived component shape models, masses, densities, spin states, and the mutual orbit of binary near-Earth asteroid 2000 DP107. The smaller component spins synchronously and may exhibit small amplitude (< 5 degree) librations. The mutual orbit pole and primary spin pole fits to the radar data suggest that they are inclined with respect to each other. Such an inclined orbit would precess due to the oblateness of the primary component. For 1991 VH, Naidu et al. (2012) were unable to fit a unique spin period to the elongated secondary using radar images and suggested that it might be in a chaotic spin state on the basis of theoretical considerations and numerical simulations. We will present improved simulations that include spin-orbit coupling.

112.10 – The Origin of Asteroid 162173 (1999 JU3)

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Near-Earth asteroid (162173) 1999 JU3 (henceforth JU3) is a potentially hazardous asteroid and the target of the Japanese Aerospace Exploration Agency's Hayabusa-2 sample return mission. JU3 is also a backup target for two other sample return missions: NASA's OSIRIS-REx and the European Space Agency's Marco Polo-R. We use dynamical information to identify an inner-belt, low-inclination origin through the ν6 resonance, more specifically the region with 2.15 AU < a < 2.5 AU and i < 8 degrees. The geometric albedo of JU3 is 0.07 ± 0.01, and this inner-belt region contains four well- defined low-albedo asteroid families (Clarissa, Erigone, Polana and Sulamitis), plus a recently identified background population of low-albedo asteroids outside these families. Only two of these five groups, the background and the Polana family, deliver JU3-sized asteroids to the ν6 resonance, and the background delivers significantly more JU3-sized asteroids. The available spectral evidence is also diagnostic; the visible and near-infrared spectra of JU3 indicate it is a C-type asteroid, which is compatible with members of the background, but not with the Polana family because it contains primarily of B-type asteroids. Hence, this background population of low-albedo asteroids is the most likely source of JU3.

112.11 – Dynamics and History of Mars Trojans

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Mars is the only terrestrial planet known to have long-term stable Trojan coorbitals. Recently, Christou (2013) and De la Fuente Marcos & De la Fuente Marcos (2013) have shown that several smaller Mars Trojans belong to a dynamical cluster centered on (5261) Eureka. While some of non-cluster Mars Trojans have colors distinct from Eureka (Rivkin et al. 2007), it is not clear if the cluster itself is compositionally homogeneous. Given that cluster member orbits should diverge over the age of the Solar System (Scholl et al. 2005), a recent origin of the cluster is likely. Our preliminary work indicates that the cluster could not have been formed through the slow dissipation of the Yarkovsky effect, in agreement with past results of Fleming & Hamilton (2000). Hence, our current expectation is that the cluster is collisional, and we expect to present an estimate of the age of the cluster at the meeting, based on long-term integrations of the cluster's dynamical diffusion. We will also discuss possible origin scenarios for Mars Trojans. It is now known that the Mars-crosser population was significantly larger in the past (Cuk 2012), and some Mars-crossers can spend time as temporary Trojans. Mechanisms of temporary Trojan stabilization include dynamical chaos and collisions (with some fragments of temporary Trojans becoming long-term stable). These and other routes will be tested using analytical arguments and numerical simulations. This work is supported by NASA PGG award NNX12AO41G.

112.12 – Jovian Trojans: Orbital structures versus the WISE data

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In this work, we study the relation between orbital characteristics of Jovian Trojans and their albedos and diameters as measured by the WISE/NEOWISE mission (Grav et al. 2011, 2012). In our previous work (Broz & Rozehnal 2011), we concluded that there is only one collisional family with parent body size larger than 100 km among Trojans, namely the Eurybates. This finding was based on the analysis of the observed size distributions, colour data from the Sloan Digital Sky Survey, and simulations of orbital evolution. The WISE albedos serve as an independent source of information which allows us to verify our previous results. We also update our database of suitable resonant elements (i.e. the libration amplidude D, eccentricity e, inclination I) of Trojans and we look for new (to-be-discovered) clusters by the Hierarchical Clustering Method. Using the WISE diameters, we can construct more precise size-frequency distributions of Trojans in both the leading/trailing clouds which we compare to SFD of the cluster(s) mentioned above. We then prepare a collisional model (based on the Boulder code, Morbidelli et al. 2009). Initial conditions of our model are based on an assumption that the Trojans were captured from a destabilised transplanetary disc while Jupiter jumped during its close encounter with a Neptune-mass planet – the so-called 'jump capture' (Nesvorny et al. 2013). Within the framework of this model we try to constrain the age of the Eurybates family. The work of MB was supported by grant GACR 13-013085 of the Czech Science Foundation and the Research Programme MSM0021620860 of the Czech Ministry of Education.

112.13 – A Troop of Trojans: Photometry of 24 Jovian Trojan Asteroids

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Because of their greater distance from the Sun, the Jovian Trojans have been less studied than main belt asteroids. Although they are numerous (nearly 6000 have well determined orbits as of July 2013), the Trojans remain mysterious in many ways. Their spectra are unlike those of any meteorites in terrestrial collections. The spectra and the low albedos of Trojans, however, bear a strong resemblance to those of cometary nuclei (Abell et al. 2005; Fornasier et al. 2007; Emery et al. 2011). The Nice Model (Morbidelli et al. 2005; 2009) predicts that the Trojans may well be objects that originated with today's Kuiper Belt Objects. The rotation of asteroids larger than ~50 km in diameter seems to be determined largely by collisions, while that of smaller bodies is shaped primarily by YORP forces and torques (Pravec et al. 2008). We are surveying the rotation properties of Trojans to see whether similar trends are present. We find an abundance of slow rotators, including the first documented tumbler among the Trojans. We present 24 new Trojan lightcurves, mostly from objects ranging from 30-50 km in diameter. We also discuss observations of five sub-20 km Trojans, whose rotation properties are consistent with cometary densities. This research was supported by National Science Foundation Grant AST-1212115, by NASA Grant NNX-08AO29G, and by an American Astronomical Society Small Research Grant.

112.14 – Accurate orbit propagation of planet-encountering bodies: the case of (99942) Apophis

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We tackle the problem of accurately propagating the motion of those small bodies that undergo close approaches with a planet. The literature is lacking on this topic and the reliability of the numerical results is not sufficiently discussed. The chaotic motion of the close-encountering bodies makes their propagation particularly challenging both from the point of view of the dynamical stability of the formulation and the numerical stability of the integrator because of the high-frequency components of the perturbation. In this work the accuracy achievable in the orbit computation of a planet-encountering body is assessed by comparing different formulations of the perturbed two-body problem combined with the numerical methods most suitable to a stable integration. We consider three kinds of formulations to propagate the motion: the non-linear Newtonian equations integrated with respect to either the physical or a fictitious time, the Burdet-Ferrandiz and the Kustaanheimo-Stiefel regularizations which consist of perturbed harmonic oscillators, and several sets of generalized orbital elements, one of which has been recently developed by the author. In our study we take particularly care of the numerical stability of the integration process and describe the techniques that we have adopted for avoiding instability. We choose as a test-case the asteroid 99942 Apophis which represents a challenging example: as a consequence of the huge amplification of the orbit uncertainty after the 2029 Earth encounter we need to predict its position at the meter-level accuracy in the 2069 close approach. The Earth`s relativistic effect and the influence of the harmonics of the geopotential on the asteroid`s orbit will be included in the perturbation model applied during the close passages.

112.15 – Shape and Rotation Modeling and Thermophysical Analysis of Near-Earth Asteroid (1917) Cuyo

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We are conducting an ESO Large Program that includes optical photometry, thermal-IR observations, and optical-NIR spectroscopy of selected NEAs. Among the principal goals of the program are shape and spin-state modeling, and searching for YORP-induced changes in rotation periods. One of our targets is asteroid (1917) Cuyo, a near-Earth asteroid from the Amor group. We carried out an extensive observing campaign on Cuyo between April 2010 and April 2013, operating primarily at the ESO 3.6m NTT for optical photometry, and the 8.2m VLT at Paranal for thermal-IR imaging. Further optical observations were acquired at the ESO 2.2m telescope, the Palomar 200′ Hale telescope (California), JPL's Table Mountain Observatory (California) and the Faulkes Telescope South (Australia). We obtained optical imaging data for rotational lightcurves throughout this period, as the asteroid passed through a wide range of observational geometries, conducive to producing a good shape model and spin state solution. The preliminary shape and spin state model indicates a nearly spherical shape and a rotation pole at ecliptic longitude $\lambda = 53° \pm 20°$ and latitude $\beta = -37° \pm 10°$ (1-sigma error bars are approximate). The sidereal rotation period was measured to be 2.6899522 ± (3 × 10^-7) hours. Linkage with earlier lightcurve data shows possible evidence of a small change in rotation rate during the period 1989-2013. We applied the NEATM thermal model (Harris A., Icarus 131, 291, 1998) to our VLT thermal-IR measurements (8-19.6 μm), obtained in September and December 2011. The derived effective diameter ranges from 3.4 to 4.2 km, and the geometric albedo is 0.16 (+0.07, -0.04). Using the shape model and thermal fluxes we will perform a detailed thermophysical analysis using the new Advanced Thermophysical Model (Rozitis, B. & Green, S.F., MNRAS 415, 2042, 2011; Rozitis, B. & Green, S.F., MNRAS 423, 367, 2012). This work was performed in part at the Jet Propulsion Laboratory under a contract with NASA.

112.16 – Modeling the tangential YORP effect

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It has recently been shown that re-emission of absorbed solar light by centimeter- to decimeter-sized structures on the surface of an asteroid can create a component of the recoil force that is parallel to the surface (Golubov & Krugly 2012, ApJL 752: L11). Under certain conditions, the western sides of stones appear to be on average slightly warmer than their eastern sides, thus experiencing stronger recoil force and dragging the surface of the asteroid eastward. This force parallel to the overall surface of the asteroid is called the tangential YORP, or TYORP. It operates in concert with the normal YORP force, or NYORP, which acts normally to the overall surface. Even though the TYORP force is much smaller than the NYORP force, it has a bigger lever arm with respect to the rotation axis of the asteroid, and its torques tend to add up for opposite points on the asteroid's surface rather than to subtract, therefore the effects of TYORP and NYORP on the rotation rate of the asteroid can be comparable. In the talk I shall first discuss the effect qualitatively and make simple estimates for its magnitude, then study the effect in a simple model of 1-dimensional heat conductivity, then move to a 3-dimensional model, which realistically incorporates heat conductivity in stones and ray tracing of incoming and emitted light. In the end of the talk I shall discuss general trends of the effect, interplay between TYORP and NYORP, possibility of stable equilibrium between them, and possible implications for the discrepancy between observed and predicted YORP accelerations of Itokawa.

112.17 – A Statistical Analysis of YORP Coefficients

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The YORP (Yarkovsky–O'Keefe–Radzievskii–Paddack) effect is theorized to be a major factor in the evolution of small asteroids (<10 km) in the near-Earth and main belt populations. YORP torques, which originate from absorbed sunlight and subsequent thermal radiation, causes secular changes in an asteroid's spin rate and spin vector orientation (e.g. Rubincam, Journal of

Geophysical Research, 1995). This in turn controls the magnitude and direction of the Yarkovsky effect, which causes a drift in an asteroid's heliocentric semi-major axis (Vokrouhlicky and Farinella, Nature, 2000). YORP is also thought to be responsible for the creation of multiple asteroid systems and asteroid pairs through the process of rotational fission (Pravec et al, Nature, 2010). Despite the fact that the YORP effect has been measured on several asteroids (e.g. Taylor et al, Science, 2007 and Kaasalainen et al, Nature, 2007), it has proven very difficult to predict the effect accurately from a shape model due to the sensitivity of the YORP coefficients to shape changes (Statler, Icarus, 2009). This has been especially troublesome for Itokawa, for which a very detailed shape model is available (Scheeres et al, Icarus 2007; Breiter et al, Astronomy & Astrophysics, 2009). In this study, we compute the YORP coefficients for a number asteroids with detailed shape models available on the PDS-SBN. We then statistically perturb the asteroid shapes at the same resolution, creating a family of YORP coefficients for each shape. Next, we analyze the change in YORP coefficients between a shape model of accuracy obtainable from radar with one including small-scale topography on the surface as was observed on Itokawa. The combination of these families of coefficients will effectively give error bars on our knowledge of the YORP coefficients given a shape model of some accuracy. Finally, we discuss the statistical effect of boulder and craters, and the modification of these results due to recent studies on thermal beaming (Rozitis and Green, Mon. Not. R. Astron. Soc., 2012) and 'tangential' YORP (Golubov and Krugly, The Astrophysical Journal Letters, 2012).

112.18 – Quantifying Observational Selection Effects in Asteroid Surveys

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Asteroid orbital element distributions as observed in large scale surveys are biased as a result of selection effects caused by the detection efficiency that is a function of the objects's apparent brightness and rate of motion that in turn are determined by the object's orbital parameters, size, reflectivity, etc. To measure the actual distribution as a function of their absolute magnitude (H), semi-major axis (a), eccentricity (e) and inclination (i) (and any other parameters) requires correcting for the bias. We have developed an efficient technique for numerically calculating the survey bias as a function of (a,e,i,H) using an algorithm developed in Granvik et al. (2012, Icarus 218) to identify which orbits can appear in a field of view. We have applied our technique to eight years of data obtained with the Catalina Sky Survey (CSS) (Larson et al., 1998, BAAS 30) to calculate the bias in identifying near Earth objects (NEOs). We will provide an overview of our technique and illustrate the bias for the CSS NEO population. Our NEO bias will be applied by Granvik et al. (2013, Icarus) to obtain the actual NEO distribution from NEOs observed with CSS.

112.19 – A sensitive search for NEOs with the Dark Energy Camera

Lori Allen[1], David Trilling[2], Brian Burt[2], Frank Valdes[1], Ceasr Fuentes[2], David James[1], Steve Larson[3], Eric Christensen[3], Alissa Earle[5], David Herrera[1], Mike Brown[6], Tim Axelrod[4]
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We report on preliminary results from the DECam NEO Survey. DECam (Dark Energy Camera) is a 520 Megapixel optical imager with a 3 square degree field of view on the Blanco 4m telescope at the Cerro Tololo Inter-American Observatory. The combination of large field of view and 4 meter aperture yield an étendue that far surpasses those of previous NEO searches. Our goals are to obtain a census of NEOs down to a detection limit of V=23, to measure the size distribution of small NEOs, and to characterize the population of earth-crossing objects (ECOs). In this contribution we describe our 30-night survey, scheduled to begin in the 2014A semester and to extend over three 'A' (northern hemisphere Spring) semesters. We present preliminary results based on our pilot project conducted in January and April of this year and which resulted in our submitting approximately 100,000 astrometric measurements to the Minor Planet Center (observatory code W84), approximately 1% of which are NEOs. Details of extensive simulations and data processing performed with the Moving Object Processing System (MOPS) can be found in a separate contribution (Burt et al.) at this meeting.

112.20 – Applications of MOPS to NEO searches

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We are employing MOPS for two different NEO surveys. The first is a ground-based survey using the new Dark Energy Camera (DECam) on the CTIO 4-m Blanco telescope. We take transient source detections, create intra-night tracklets, and form inter-night tracks. We use find_orb to reject obviously bad orbits, and have successfully submitted over 100,000 measurements to the MPC. We have also adapted MOPS for use with a new Warm Spitzer NEO survey.

112.21 – Previously Unidentified Objects Found in MPC 'One Night Stands' File

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The MPC 'One Night Stands' file contains asteroid astrometry not associated with any identified object. This contains large amounts of astrometry for objects which are observed on one night and not believed to have been given followup on subsequent nights. Using a large computer cluster, we applied algorithms from Kubica et al. and our own software and found a variety of new linkages in this data set, including three new object identifications, all of which have been accepted into the MPC. Our current approach is extremely slow and computationally costly. We will report on our methods and their implications and discuss and more efficient approaches which we hope to test using this data set.

112.22 – Scientific Goals of Hayabusa-2 LIDAR Experiment

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Hayabusa-2 is the second asteroid mission of Japan to be launched between 2014 and 2015. LIDAR is one of five instruments onboard Hayabusa-2, and measures altitudes of the spacecraft from a surface of the asteroid, 1999JU3, by taking a time of flight of laser pulse. LIDAR is a part of attitude and orbit control subsystem and is designed for navigation of the spacecraft, in particular, during touch-down phase. Also the LIDAR data are scientifically important for analysis of the shape, mass, and surface properties of the asteroid. Hayabusa-2 LIDAR is an improved version of LIDAR onboard Hayabusa. We adopt Nd:YAG laser of which wavelength is 1.064 micro-m, and passive Q-switch. The size is 240 x 240 x 230 mm, and weighs 3.7 kg. To elucidate the nature and history of accretion and destruction of rubble pile body, we determine shape and mass of the asteroid 1999JU3. The model is developed basically from ONC images and LIDAR range data. Non dimensional shape is estimated using images taken from various configurations, and LIDAR range data determines its length scale. Mass is also essential for geodetic study of C-type asteroid. Because carbonaceous chondrites show wide variation of microscopic porosity, it is difficult to distinguish rubble pile and monolithic structures from either observation or theoretical analysis. Direct observation of mass and shape of C-type asteroid together with average density measurement of returned sample is necessary. We plan to let the spacecraft descent toward 1999JU3 from 20-km to 1-km altitude without orbital maneuvers, and also let the spacecraft ascend freely as well. Such experiments will be conducted 2 to 6 times depending on fuel left in the spacecraft. An accuracy of gravity estimate is improved as a number of free fall/rise experiments increases. LIDAR is an active sensor unlike other instruments on Hayabusa-2. Ratio of transmitting and receiving powers can be directly translated to geometric albedo at the surface of 1999JU3. In case of Hayabusa-1, the power meter could not measure both transmitting and receiving power at the same time. Then a design of Hayabusa-2 LIDAR is modified so that both transmitting and receiving powers can be measured simultaneously.

112.23 – Ejecta Behavior and Dynamics within the Proposed ISIS Kinetic Impactor Demonstration Mission

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Impactor for Surface and Interior Science (ISIS) is a proposed mission of opportunity which would demonstrate and test kinetic impact (KI) as a method of imparting a small ΔV to a hypothetical Near Earth Object (NEO) found in the future to be hazardous, i.e. have a non-negligible probability of Earth impact. In contrast to Deep Impact, 'test' here means having another spacecraft in rendezvous with the KI target, and accumulating sufficient tracking of that spacecraft, and target observations from it, both before and after the KI event, to measure the ΔV imparted to the target. A bounty of scientific information about cratering mechanics, geomorphology, and even internal structure of small asteroids would also result from in-situ observations of the event and its aftermath. For ISIS, the non-hazardous target and observing spacecraft would be respectively 1999 RQ36 (Bennu) and the OSIRIX-REx sample return mission. Motivated by a need to understand any hazard to OSIRIS-REx and any necessary changes to its plan of proximity operations, we embarked on a detailed study of the ejecta/debris that would be liberated by the KI event. For an event energy matching a 440 kg impactor at 13.43 km/s closing velocity, we modeled ejecta generation from the cratering itself, considering the on-surface net acceleration environment. We propagated the ejecta particles under all relevant dynamical effects, e.g. shape-model-derived full body gravity, differential solar tide acceleration, and solar radiation pressure accounting for particle size, optical properties, and shadowing. We present the proportion of particles reaching the dynamical fates of return impact or escape, and the time history of their doing so. We find clearing times from the system are nonlinearly dependent on particle size as expected. We present the size-frequency distribution of the population remaining at 1, 5, 10, etc. days post-impact, and where the re-accreted ejecta deposits on the surface. We also further explore the longest-lived population, visualizing its trajectories in several ways.

112.24 – A COMPOSITIONAL AND GEOLOGICAL VIEW ONTO THE EJECTA OF SMALL FRESH IMPACT CRATERS ON ASTEROID 4 VESTA

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In order to further understand the composition of the upper as well as lower parts of Vesta's crust, small impact crater (< 10km in diameter), which show distinct ejecta and thus represent unweathered surface areas, have been identified and their spectral properties investigated with respect to their geological and geomorphological context. The study was performed based on data acquired by the Visual and Infrared Spectrometer (VIR), which observed Vesta's surface between 0.25 and 5.1μm with a pixel ground resolution of ~60 m/pixel. The geological and geomorphological context is provided by images acquired by the Framing Camera (FC) with a pixel ground resolution up to 20 m/pixel. The spectral variations mirror the global trend with a more diogenitic composition in the Rheasilvia basin and an eucrite-/howardite-like composition in the geologically older densely cratered equatorial region. This points to the interpretation that the bright ejecta might be related to the Rheasilvia basin whereas the darker material resembles excavated in-situ subsurface material. This interpretation is strengthend by the fact that the bright ejecta were formed only in the western part of the small impact crater in the direction of slightly higher elevation possibly representing an addional upper surface layer of former ejecta of Rheasilvia newly excavated.

112.25 – Near Earth Asteroid Characterization: Challenges and Opportunities

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The current discovery rate of Near Earth Asteroids (NEAs) is set to increase dramatically in the next few years from ~900/year to 2,000-3,000/year thanks to new surveys coming online and equipment upgrades to current ones. Despite this, the rate of characterization is expected to remain the same: ~100 spectra and a few dozen light curves at best per year. At this rate it will take up to a century to characterize just the NEA population with sizes above 100m. Characterization is crucial to science, space missions and planetary defense and cannot be left by the wayside. Herein we discuss the challenges of, and opportunities for, optimal NEA characterization. In particular we find that immediate follow-up (within days) of discovery is essential: A dedicated 2m telescope could perform optical spectroscopy while a number of smaller telescopes would take light curves. Coordination could be performed by the Minor Planet Center as an extension of the services they provide through the NEO Confirmation Page.

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113.01 – Cold Friends of Hot Jupiters: AO Survey

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"Hot Jupiters" are a class of gas giant planets found in extrasolar systems at very small orbital distances (□0.05 AU). We know that these planets could not have formed at their present locations, but must instead have migrated in from beyond the ice line. One class of proposed migration mechanisms for these planets involve gravitational perturbations from a distant stellar companion. These same processes also provide a natural explanation for the existence of a subset of hot Jupiters that have been observed to have orbits that are highly misaligned with respect to their star's spin axis and/or have large orbital eccentricities.
In the 'Cold Friends' survey, we search for stellar companions around 51 stars known to host hot Jupiters in order to determine whether stellar companions play an important role in hot Jupiter migration. Our survey consists of a population of stars with planets that have eccentric and/or misaligned orbits as well as a control population of planets with well-aligned and circular orbits. This project searches for companion stars (the 'Cold Friends') in three detection modes: radial velocity monitoring, high resolution IR spectroscopy (presented by D. Piskorz et al. at this meeting), and adaptive optics (AO) imaging at infrared wavelengths (presented here). The AO mode is sensitive to the most distant companions (separations of 50-200 AU and beyond) while the other modes are effective at finding companions at smaller separations. We present the results of our AO survey and discuss the binary fraction found in our sample. Out of our total sample of 51 stars, 19 candidate companions (many of which have not been observed before) were directly imaged around 17 stars. We also describe follow-up photometry and astrometry of all detected companions to determine whether or not they are gravitationally bound to the primary planet-hosting star. If such companions are common, it would suggest that perturbations from stellar companions may play a significant role in the evolution of hot Jupiter systems.

113.02 – Cold Friends of Hot Jupiters: NIRSPEC Survey

Danielle Piskorz[1], Heather A. Knutson[1], Philip S. Muirhead[2], Konstantin Batygin[3], Justin R. Crepp[4], Sasha Hinkley[1], Andrew W. Howard[5], John A. Johnson[3], Timothy D. Morton[1]
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Previous surveys have shown that half of all stars occur in binary systems. Although most exoplanet surveys exclude systems with known binary companions, it is likely that many known planetary systems contain distant, low-mass stellar companions that went unnoticed in the initial survey selection. Such companions may have important effects on the formation and migration of planets (and especially hot Jupiters) around the primary star via three-body interactions such as Kozai-driven migration. The Cold Friends project uses three observing techniques to make a robust determination of the occurrence rate of exoplanets in binary systems: radial velocity monitoring, adaptive optics imaging (see presentation on the AO Survey by H. Ngo et al.), and near-infrared spectroscopy. In this presentation, we focus on the results of the spectroscopy portion of the Cold Friends project. Using NIRSPEC at Keck Observatory, we have obtained high-resolution spectra of roughly fifty exoplanet-hosting stars near 2.3 microns, where low-mass companions will show deep CO absorption features superimposed on the primary stellar spectrum. This method allows for the detection of binary companions located within 50 to 200 AU of the host star. At this location, such a binary companion could conceivably influence the formation and migration of exoplanets orbiting the main star. We describe our method for removing the signal due to the main-sequence FGK host stars and searching for the distinctive spectral features of a low-mass stellar companion.

113.03 – A Simple Model for Orbital Resonances with Dissipation and its Application to Multiple-Planet Systems

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Data from multi-planet systems discovered by Kepler show that most planets currently do not reside in or close to mean motion resonances. There is however a significant excess of planet pairs with period ratios close to but 1-2% larger than those of exact resonance. We present a simple model for orbital resonance including dissipation and apply it to exoplanet systems. Our results demonstrate that there are three possible outcomes for a pair of planets encountering a resonance. These three different outcomes are due to eccentricity damping that can drive an instability of the amplitude of libration about exact resonance. Damping promotes instability because the effective potential is maximal at exact resonance. The instability manifests itself in systems for which eccentricity damping occurs more rapidly than semi-major axis migration. Our results indicate that only about 10% of planet pairs should currently reside in or near mean motion resonances. Thus the small fraction of near commensurate orbits in multi-planet systems discovered by Kepler is fully consistent with disk migration of low mass planets. Furthermore, for planet pairs massive enough to be permanently captured into resonance, our model can account for the deficit of planet pairs at exact resonance and for the corresponding excess of pairs with slightly greater separation.

113.04 – Mass Growth and Evolution of Giant Planets on Resonant Orbits

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A pair of giant planets that tidally interact with a gaseous disk may undergo convergent orbital migration and become locked into a mean motion resonance (MMR). If the planet masses are similar to those of Jupiter and Saturn, typical after-formation conditions in protoplanetary disks lead to capture in the 2:1 MMR. Larger gas densities may cause capture in the 3:2 MMR instead. Here we present the results of hydrodynamical models of the evolution of a pair of planets, initially locked in the 2:1 or 3:2 MMR, as they interact with each other and the disk. We focus on the issue of ongoing gas accretion, the importance of which depends on the local disk mass. The high density required for capture in the 3:2 MMR causes a rapid change of the masses and mass ratio. Ensuing planet-planet interactions raises both orbital eccentricities and leads to scattering episodes and to the ejection of one of the planets from the system. Conditions compatible with 2:1 MMR locking can also lead to a more or less substantial growth of the planet masses, depending on the disk density. However, for planets orbiting in the 1 AU region, the resonant configuration appears stable up to masses of about 5 Jupiter's masses. Support from NASA Outer Planets Research Program and NASA Origins of Solar Systems Program is gratefully acknowledged.

113.05 – A Stable Configuration for the Upsilon Andromedae Planetary System

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Here we present a fully 3-dimensional, dynamically stable configuration for the 3 planets of the Upsilon Andromedae system. This work is a direct follow-up to McArthur et al (2010), which gave a 3-dimensional picture of the orbits of planets c and d but left the orbital plane of planet b unknown. Previous dynamical studies of the system found a stable configuration for planets c and d but failed to identify a stable solution for 3 planets. We searched for 3-planet configurations that are both consistent with the combined radial velocity and astrometric solution, and dynamically stable using N-body simulations. As planet b is not detected astrometrically, its inclination and longitude of ascending node are unconstrained by observations, but our stability analysis limits their ranges significantly. The system appears to be close to the stability boundary, as we find that only 10 trials out of 1000 are robustly stable. We find planet b's orbits must lie close to the fundamental plane of planets c and d, but can be either prograde or retrograde. These solutions predict b's mass is in the range 1.8 - 9 M_Jup. These results require planet b's orbit to lie very near the sky plane and hence when combined with the results of Crossfield et al (2010), predict that Ups And b is indeed an inflated hot Jupiter with a radius of >~ 1.5 R_Jup. This large radius would make the planet one of the largest known exoplanets and would require a large, continual heating source. In our solutions we find that the planet spends a significant amount of time with an eccentricity greater than 0.1, suggesting that tidal heating could be substantial. Using an equilibrium tidal model, we find that if Upsilon Andromedae b has a radius of 1.8 R_Jup and a tidal Q of 10^6, tides generate an average of ~2.5 x 10^19 W of power over the planet's eccentricity cycle. Our work presents the complete orbital architecture of this system, provides new constraints on planet b's interior, and lays a foundation for the interpretation and modeling of planetary systems that will be uncovered by the upcoming GAIA mission.

113.06 – LONG TERM DYNAMICAL STUDY OF KEPLER CIRCUMBINARY PLANETS SYSTEMS WITH ONE PLANET

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Currently, a number of circumbinary planets have been discovered. In this paper, we focus our attention on the long term stability (1Gyr) of the Kepler circumbinary planetary systems with only one planet, i.e. Kepler-16, Kepler-34, Kepler-35, Kepler-38 and Kepler 64. The investigation is done by means of numerical simulations. By using two different codes, we perform numerical integrations of the full equations of motion of each system with the aim of checking the long term stability of the planetary orbit. The integration time is set 1Gyr, which, for Kepler-16, Kepler-34, Kepler-35, Kepler-38 is much longer than any previous study (S\leqS10Myrs) and about the same for Kepler-64. Moreover, we look for the critical planetary semi-major axis, i.e. the smallest semi-major axis for which the planet is on a stable circumbinary orbit. Also, we investigate whether tidal friction, tidal deformation, deformation fue to rotation and general relativistic effects between the stellar bodies may play a role in the stability of the planetary orbit. For the time integrated, we find that all five planetary systems show no sign of instability. We also find the critical semi-major axis for each planetary system and most our results seem to be in good agreement with previous results in the literature, and we found for some systems our critical semi-major axis is closer to the nominal than previously reported. For the first time we find the critical semi-major axis for Kepler-64. Finally, tidal friction, tidal deformation, deformation due to rotation and general relativity do not seem to have an effect on the evolution of the systems.

113.07 – Analyzing the Orbits of Transiting Exoplanets Using Spitzer Secondary Eclipses

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Radial-velocity and transit-timing data can constrain the eccentricity, argument of periapsis, period, and other exoplanet orbital parameters. Including secondary-eclipse times can improve these parameters, especially eccentricity. We combined Spitzer secondary-eclipse data for HAT-P-16b and TrES-1b with existing radial-velocity and transit-timing data. For HAT-P-16b, we find that $e = 0.0435 \pm 0.0013$, reducing the uncertainty by a factor of 4. For TrES-1b, we find that $e \cos \omega = 0.002460 \pm 0.000814$, which is evidence of eccentricity not obtained by previous analyses of radial velocity data. We fit a Keplerian model to the data using Bayesian posterior sampling via a Markov-chain Monte Carlo (MCMC) algorithm to estimate the uncertainties. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA, which provided support for this work. This work was supported in part by NASA Planetary Atmospheres grant NNX13AF38G and NASA Astrophysics Data Analysis Program grant NNX12AI69G.

113.08 – Spitzer Secondary Eclipses of HAT-P-13b

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HAT-P-13 b is a transiting hot Jupiter with a slightly eccentric orbit (e = 0.010) inhabiting a two-planet system. The two-planet arrangement provides an opportunity to probe the interior structure of HAT-P-13b. Under equilibrium-tide theory and confirmation that the apsides of planets b and c are in alignment, a measurement of the planet's eccentricity can be related to the planet's tidal Love number k_2, which describes the central condensation of the planet's mass and its deformation under tidal effects. A measurement of k_2 could constrain interior models of HAT-P-13b. HAT-P-13b's orbit is configured favorably for refinement of the eccentricity by secondary eclipse timing observations, which provide direct measurements of ecos ω. In 2010, Spitzer observed two secondary eclipses of HAT-P-13b in the 3.6- and 4.5-μm IRAC bandpasses. We present secondary eclipse times and depths; joint models of the HAT-P-13 system that incorporate transit photometry and radial velocity data; and constraints on the atmospheric chemistry of HAT-P-13b that suggest solar-abundance composition without a thermal inversion. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA, which provided support for this work. This work was supported in part by NASA Planetary Atmospheres Grant NNX13AF38G.

113.09 – Dynamical Measurements of the Interior Structure of Exoplanets

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Giant gaseous planets often reside on orbits in sufficient proximity to their host stars for the planetary quadrupole gravitational field to become non-negligible. In presence of an additional planetary companion, a precise characterization of the system's orbital state can yield meaningful constraints on the transiting planet's interior structure. However, the applicability of this type of analysis can be limited by the configuration of the target system. Here, we explore the dynamical range in which these methods are valid while using HAT-P-13 as a case study. We determine that the interior structure determination method, despite being indirect, is surprisingly robust. As a result, we conclude that future efforts aimed at characterizing the interiors of giant exoplanets are likely to be fruitful.

113.10 – Are terrestrial exoplanets Earth-like, Venus-like, or the remnants of gas- or ice-giants?

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Since the discovery of the first exoplanet in the nineties, hundreds of candidates have been reported. Among them, some have densities that are close to the one expected for planets made of the same elements as Mars, Earth or Venus. Those planets are known as terrestrial exoplanets. For some of them, only the mass or the radius is known but their distance to the star suggests that they may also be terrestrial. Venus and Earth, although very close in density, have evolved on very different pathways: different atmospheric composition, lack of current plate tectonics on Venus, liquid water on the Earth's surface. Venus dynamics is in the so-called 'stagnant lid regime' whereas the Earth's surface is fractured into several plates which move relative to each other in relation with mantle convection. Parameters such as surface temperature, size, and atmospheric composition and density may influence the transition from one regime to the other. A few exoplanets are more massive than iron cores that would have the same size. The migration of gas giants and/or icy giants towards the star leads to atmospheric erosion. The present study investigates the deformation of theirs cores and the involved timescales as the atmosphere escapes. It suggests that the deformation of the inner parts of the core is so limited that the core remains very dense even though the surface pressure has greatly decreased. A very dense core surrounded by a tiny primitive atmosphere would mimic the mass and radius of a terrestrial planet. Searching for Earth-like planets where plate tectonics operates is a major endeavor in the field of exoplanets. The present study suggests that some terrestrial exoplanets may also be the remnant cores of giant planets that migrated towards their star while losing their atmosphere by escape processes. The discovery of Earth-like planets requires additional information such as the characteristics of their atmospheres. This work has been partly performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

113.11 – A Search for Transits of Radial Velocity Detected Super-Earths

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Unlike hot Jupiters or other gas giants, super-Earths (planets with masses between 1-10 times that of Earth) are expected to have a wide variety of compositions, ranging from terrestrial bodies like our own to more gaseous planets like Neptune. Observations of transiting systems, which allow us to directly measure planet masses and radii and constrain atmospheric properties, are key to understanding the compositional diversity of the planets in this mass range. Although Kepler has discovered hundreds of transiting super-Earths over the past four years, the majority of these planets orbit stars that are too far away and too faint to allow for detailed atmospheric characterization and reliable mass estimates. Ground-based transit surveys focus on much brighter stars, but most lack the sensitivity to detect planets in this size range. One way to get around the difficulty of finding these smaller planets in transit is to start by choosing targets that are already known to contain super-Earth sized bodies detected using radial velocity techniques. Two of the three currently known transiting super-Earths around bright stars were discovered first by RV and then subsequently found to transit their host stars (55 Cnc e and HD 97658 b). Radial velocity measurements can be used to forecast expected transit times to within a ten to twenty hour window for many of the published super-Earth systems. Spitzer is an ideal platform for observing these targets, as it can observe the entire transit window in a single continuous span with enough sensitivity to detect transits for the full range of plausible planet sizes and compositions, many of which would be challenging to detect with typical ground-based facilities. We present results from a Spitzer program to observe six of the most favorable RV detected super-Earth systems: HD 1461, HD 7924, HD 97658, HD 156668, HIP 57274, and GJ 876. We find no evidence for transits in any of their 4.5 μm flux light curves, but place limits on the allowed transit depths and corresponding planet radii that rule out even the most dense and iron-rich compositions for these objects.

113.12 – Constraining the Magnetic Field of HAT-P-16b via Near-UV Photometry

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We present the first primary transit light curve of the hot Jupiter HAT-P-16b in the near-UV photometric band. We observed this object on December 29, 2012 in order to update the transit ephemeris, constrain its planetary parameters and search for magnetic field interference. Vidotto et al. (2011a) postulate that the magnetic field of HAT-P-16b can be constrained if its near-UV light curve shows an early ingress compared to its optical light curve, while its egress remains unchanged. However, we did not detect an early ingress in our night of observing when using a cadence of 60 seconds and an average photometric precision of 2.26 mmag. We find a near-UV planetary radius of Rp = 1.274 ± 0.057 RJup which is consistent with its near-IR radius of Rp = 1.289 ± 0.066 RJup (Buchhave et al., 2010). We developed an automated reduction pipeline (ExoDRPL) and a modeling package (EXOMOP) to process our data. The data reduction package synthesizes a set of IRAF scripts to calibrate images and perform aperture photometry. The modeling package utilizes the Levenberg-Marquardt minimization algorithm to find a least-squares best fit and a differential evolution Markov Chain Monte Carlo algorithm to find the best fit to the light curve. To constrain the red noise in both fitting models we use the residual permutation (rosary bead) method and time-averaging method.

113.13 – Constraining the Magnetic Fields of Transiting Exoplanets through Ground-based Near-UV Observations

Jake Turner[1,2], Brianna M. Smart[1,3], Kyle A. Pearson[1], Lauren I. Biddle [1], Ian T. Cates[1], Micheal Berube[1], Robert M. Thompson[1], Carter-Thaxton W. Smith[1], Johanna K. Teske[1], Kevin K. Hardegree-Ullman[4], Amy N. Robertson[1], Benjamin E. Crawfod[1], Robert Zellem[1], Megan N. Nieberding[1], Brandon A. Raphael[1], Ryan Tombleson[1], Kendall L. Cook[1], Shelby Hoglund[1], Ryan A. Hofmann[1], Christen Jones[1], Allison P.M. Towner[1], Lindsay C. Small[1], Amanda M. Walker-LaFollette[1], Brent Sanford[1], Caitlin C. Griffith[1], Thomas A.G. Sagan[1]

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We observed the primary transits of the exoplanets CoRoT-1b, HAT-P-1b, HAT-P-13b, HAT-P-22b, TrES-2b, TrES-4b, WASP-12b, WASP-33b, WASP-44b, WASP-48b, and WASP77A-b in the near-ultraviolet photometric band in an attempt to detect their magnetic fields and update their planetary parameters. Vidotto et al. (2011) suggest that the magnetic fields of these targets could be constrained if their near-UV light curves show an early ingress compared to their optical light curves, while their egress remain unaffected. We do not observe this effect in any of our targets, however, we have determined an upper limit on their magnetic field strengths. Our results are consistent with observations of TrES-3b and HAT-P-16b which both have had upper limits on their magnetic fields found using this method. We find abnormally low field strengths for all our targets. Due to this result we advocate for follow-up studies on the magnetic fields of all our targets using other detection methods (such as radio emission and magnetic star-planet interactions) and other telescopes capable of achieving a better near-UV cadence to verify our findings and the techniques of Vidotto et al. (2011). We find that the near-UV planetary radii of all our targets are consistent within error of their optical radii. Our data includes the only published near-UV light curves of CoRoT-1b, HAT-P-1b, HAT-P-13b, HAT-P-22b, TrES-2b, TrES-4b, WASP-33b, WASP-44b, WASP-48b, and WASP77A-b. We used an automated reduction pipeline, ExoDRPL, to perform aperture photometry on our data.
In addition, we developed a modeling package called EXOMOP that utilizes the Levenberg-Marquardt minimization algorithm to find a least-squares best fit and a differential evolution Markov Chain Monte Carlo algorithm to find the best fit to the light curve. To constrain the red noise in both fitting models we used the residual permutation (rosary bead), time-averaging, and wavelet method.

113.14 – Testing a Method of Detecting a Magnetic Field of Transiting Hot-Jupiter CoRot-1b

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In October of 2011 and December of 2012, exoplanet CoRot-1b was observed on the Steward Observatory 1.55m Kuiper Telescope using the Bessel-U filter to detect a possible magnetic field. It is suggested by Vidotto et. al. (2011), that it is possible to detect a magnetic field of a transiting exoplanet in the near-UV photometric band by comparing asymmetry between the ingress and egress of the light curve. This effect is believed to be caused by a bow shock being formed in front of a closely orbiting planet as it transverses through the coronal plasma of its host star. CoRot-1b is a candidate for demonstrating this effect. We do not observe an early ingress in our near-UV broad-band light curves from the 61′ Kuiper Telescope. We find an unexpected upper limit of 0.087-1.4 Gauss for the magnetic field strength of CoRoT-1b. This result is consistent with the near-UV observations by Turner et al. (2013) of another exoplanet predicted to show this effect, TrES-3b. It was suggested by Vidotto et al. (2011) and the finding of Turner et al. (2013) that an early ingress observed in the near-UV might only happen at certain spectral resonance lines. To find the best fit to the light curves we used a modeling package called EXOMOP that uses the analytic equations of Mandel & Agol (2002) to generate a model transit, the Levenberg-Marquardt non-linear least squares minimization algorithm to find the best fit, the bootstrap Monte Carlo technique to calculate robust errors of the fitted parameters, and the residual permutation "rosary bead" method to access the importance of red noise. Several other parameters to confirm and amend can be derived from the light curve including the planet's mass, radius, density, surface gravity, distance, and orbital inclination.

113.16 – Debris Disks around Nearby Late-type Stars: Combined Studies with Herschel and HST

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Contributing teams: Herschel SKARPS Project Team

While hundreds of debris disks (extra-solar Kuiper Belts) are known from far-IR excess emission around main sequence stars, the best-understood ones are those that are spatially resolved. Disk images establish the size scale of an exoplanetary system. They can reveal central holes, rings, and asymmetries in the dust distribution which can indicate the presence of planetary perturbers. With its unsurpassed spatial resolution, the Herschel Space Observatory has resolved numerous debris disks for the first time in the far-infrared. We report on these results for six debris disks around nearby late-type stars. An outstanding object is the large eccentric ring of HD 202628, in which the PACS images clearly show asymmetric emission consistent with pericenter glow and thus bolster the case for a perturbing planet orbiting near 100 AU. The Herschel images and photometry are combined with Spitzer and HST measurements to infer grain sizes and albedos using thermal emission models.

113.17 – Just How Earth-like are Extrasolar Super-Earths? Constraints on H+He Envelope Fractions from Kepler's Planet Candidates

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Contributing teams: Kepler Team and the SAMSI Bayesian Characterization of Exoplanet Populations Working Group

With 3500 planetary candidates discovered in its first 3 years of data, the Kepler Mission promises to answer one of the most fundamental questions posed in exoplanetary research: what kinds of planets occur most often in our Galaxy? As Kepler primarily yields planetary radii and orbital periods, it has enabled numerous studies of the occurrence rate of planets as a function of these variables. Unfortunately, the full mass distribution, and thus a direct measure of these planets' possible compositions, remains elusive due to the unsuitability of these faint targets for radial velocity follow-up and the relative rareness of transit timing variations. We show, however, that relatively straightforward models of planetary evolution in an irradiated environment can make some progress without this full mass distribution towards understanding bulk compositions of the abundant Super-Earth/Sub-Neptunes that Kepler has discovered. In particular, we constrain the distribution of envelope fractions, i.e. the fraction of a planet's mass that is in a gaseous hydrogen and helium envelope around its rocky core, for this exoplanet population that has no analogs in our Solar System.

114 – Mercury Posters

114.01 – Instrumental modelling of PHEBUS/Bepi-Colombo

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Probing the Hermean Exosphere By Ultraviolet Spectroscopy (PHEBUS) is a double EUV (55-155 nm) and FUV (145 – 320 nm) spectrometer aboard Mercury Planetary Orbiter (MPO) one of the two spacecrafts of the Bepi-Colombo ESA mission. The goal of this instrument is to study the composition; structure and dynamics of the exosphere of Mercury as well as measure the UV albedo of the surface to caracterize water ice deposits in permanently shaded regions. In this presentation, we will present modelling of the instrument performances of exospheric observations and stellar observations needed for in-flight calibration. A new model coupling MPO trajectory and ephemeris, as well as atomic and molecular lines and radiometric model of the instrument has been developped to prepare future data inversion to derive densities and/or upper limits of large number of species. In-flight calibration during the cruise as well as in orbit will be done by observing as many stars as possible. Integration time needed to achieve a signal to noise equal to 10 for different stars from FONDUE database is computed at each wavelength to prepare a strategy of observations. Finally a radiometric model of the instrument taking into account the instrumental defects (mirror's scattering, baffle's surface and edge scattering, ...) is used to estimate the pollution by light inside and outside the guard angle on the observations.

114.02 – Kinetic modeling of the sodium distribution in the Hermean surface-bound exosphere

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Because of its bright emission that allows ground-based observations, the existence of a sodium exosphere on Mercury has been known for more than 20 years. Produced by photo-ionization, Na^+ is the most abundant heavy ion species of the exospheric origin entering the magnetosphere. As a result, the study of the exospheric sodium distribution (both neutral and ionized) can help to link the dynamical processes occurring in the exosphere and magnetosphere and sources on the surface to in situ, remote sensing and ground-based observations. Because collisions are negligible in Mercury's exosphere, groups of atoms can maintain energy distributions characteristic of their sources. As the result, the relative rates of the source processes can have a significant impact on the volatile distribution in the exosphere. In our simulations, we account for the micrometeorite impact vaporization, thermal and photon stimulated desorption, and sputtering, the rates of which are obtained by reproducing the ground-based observations. The surface abundance of sodium is calculated by balancing the recycling and ejection fluxes by accounting for the planet's rotation and surface sticking. The radiation pressure and the brightness of the exosphere and tail are calculated by accounting for the velocity dependence of the g-factor. Photoionization of the exospheric neutral sodium is the source of the Hermean ions detected in situ. In our model the ions are produced from the modeled neutral exospheric sodium population. We follow their trajectories in the ambient electric and magnetic fields extracted from our global model of the solar wind interaction with Mercury's magnetosphere at the conditions that correspond to those during MESSENGER/FIPS measurements. In this presentation we show the results of our simulations and comparisons with the according observations.

114.03 – Mercury's Sodium Exosphere: Up-Close with MESSENGER

Timothy A. Cassidy[1], Aimee W. Merkel[1], William E. McClintock[1], Matthew H. Burger[2], Rosemary M. Killen[3], Ronald J. Vervack[4], Menelaos Sarantos[5]
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The Mercury Atmospheric and Surface Composition Spectrometer (MASCS) UltraViolet and Visible Spectrometer (UVVS) on the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft orbiting Mercury provides the first up-close look at the planet's sodium exosphere. We have observed the exosphere from orbit almost daily for more than 9 Mercury years and have used these data to make estimates of sodium density and temperature for the equatorial dayside and south pole. We find that the density varies over time but that this variability repeats itself: the density and temperature at a given local time and true anomaly (time of year) are nearly identical from one Mercury year to the next. The bulk of the exosphere has a temperature of around 1200 K, consistent with photon-stimulated desorption, although a more energetic and as-yet uncertain mechanism populates the relatively tenuous high altitudes and tail. The density varies in a manner consistent with transport caused by radiation pressure, which acts to push sodium away from noon and toward the terminators. Radiation pressure transport is one aspect of the exosphere identified by ground based observers over the last three decades. Some interpretations of their data, however, are inconsistent with our analysis of the orbital data. For example, they conclude that the exosphere has a persistent dawn/dusk asymmetry with more sodium at dawn, while we see a dawn/dusk asymmetry only during half of Mercury's year. Many ground-based observers also reported frequent brightenings of polar sodium emissions and attributed them to episodic ion flux. Our limited observations of the south polar region show primarily seasonal, rather than episodic, variability.

114.04 – MESSENGER Observations of Calcium in Mercury's Exosphere

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The Ultraviolet and Visible Spectrometer (UVVS) channel of the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) on the MESSENGER spacecraft has made near-daily observations of calcium in Mercury's exosphere since orbital observations began in March 2011. UVVS is a scanning grating monochrometer that measures resonantly scattered emission from Ca at 422.7 nm. The data have shown that the principal source of atomic Ca in the exosphere is located in the dawn equatorial sector. Calcium is seen to originate from a small region at high temperature (~50,000 K), possibly as a product of the dissociation of calcium-bearing molecules ejected from the surface. Data collected over 8 Mercury years during MESSENGER's 1-year primary and 1-year first extended missions have indicated that the source strength varies with Mercury's true anomaly. The Ca flux from the surface is greatest near perihelion and weakest near aphelion, but there is little year-to-year variation in the source strength. The expected calcium source mechanisms, including micrometeoroid impact vaporization, ion sputtering, and dawn vaporization of material deposited on the nightside, do not appear to be consistent with the observations.

115 – Moon Posters

115.01 – Selenodesy from SELENE(KAGUYA) to Future Lunar Missions

Sho Sasaki[1], Hiroshi Araki[2], Hideo Hanada[2], Yoshiaki Ishihara[3], Fuyuhiko Kikuchi[2], Yusuke Kono[2], Koji Matsumoto[2], Hirotomo Noda[2], Sander J. Goossens[4], Takahiro Iwata[5], Ryuhei Yamada[2], Noriyuki Namiki[6], Qinghui Liu[7], Hiroo Kunimori[8], Shoko Oshigami[2], Tomokatsu Morota[9]
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KAGUYA(SELENE) was launched in 2007 with 14 science instruments. KAGUYA obtained the first precise global gravity field inclluding lunar farside, using 4-way Doppler tracking with a relay satellite OKINA. Multi-frequency differential VLBI observation using OKINA and OUNA improved the accuracy of gravity, through precise determination of OKINA's orbit. Spherical harmonic solution of the lunar gravity field to order 150, SGM150j, is finally obtained. Laser altimeter (LALT) obtained the first precise global topography of the Moon. The correlation of spherical harmonics coefficients between gravity and topography became higher than that of the previous model. Circular gravity signatures of far-side impact basins are mostly explained by topography. The farside interior was cooler than that of the nearside, which was confirmed by visco-elastic numerical studies. Combined with topography data, we estimate Bouguer anomaly and the crustal thickness of the Moon. The thinnest crust beneath Moscoviense basin can be explained by the double impact model. Topography and gravity data of the Moon were revised by LRO (Lunar Reconnaissance Orbiter) and GRAIL missions of NASA. The Moon with synchronous rotation is tidally deformed by the Earth. In lunar rotation, irregular motions with small amplitude, which is called forced librations, are excited. Lunar rotation parameters have been obtained by LLR. Dissipation of the librations of lunar rotation depends on the interior of the Moon, especially on the state of the core and lower mantle. One important scale of tidal deformation is degree 2 potential Love number k2, which could constrain the state of the core and lower mantle of the Moon. Liquid metallic core should imply significant amount of sulfur in the core, whereas low-viscosity lower mantle should suggests the presence of water. The result might modify the evolution scenario of the Moon. Deployment of a new LLR reflector or ILOM may improved lunar rotation parameters. Long-term precise observation of low order gravity would improve k2. Simultaneous geodetic (selenodetic) and seismic measurements are preferable. These measurements will be fit into future lunar missions such as SELENE-2.

115.02 – Science Highlights from the LRO/LAMP Mission and Future Plans

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The Lyman Alpha Mapping Project (LAMP) is an ultraviolet (UV) spectrograph on the Lunar Reconnaissance Orbiter (LRO) that is currently mapping the lunar albedo and studying the lunar exosphere at far-UV wavelengths. LAMP primarily measures faint interplanetary HI Lyman-alpha sky-glow and far-UV starlight reflected from the nightside lunar surface pioneering an innovative technique for studying the permanently shadowed regions (PSRs) near the poles. At the same time, far-UV reflectance measurements of the bright lunar dayside are also frequently obtained through the pinhole aperture in LAMP's aperture door reducing the throughput by a factor of 736 in order to keep the detector safely away from saturation. Off nadir observations are also performed in short intense campaigns to derive information on the global distribution of the helium exosphere and to search for lunar dust and other elements. We present a set of science highlights over the mission thus far, a description of the current state of LAMP, and future observations planned through the end of the Extended Science Mission in September 2014.

115.03 – The Far-UV Albedo of the Moon Determined from Dayside LAMP Observations

Mark A. Bullock[1], Kurt D. Retherford[2], Randall Gladstone[2], Thomas K. Greathouse[2], Kathleen E. Mandt[2], Amanda R. Hendrix[3], Paul D. Feldman[4], Paul F. Miles[2], Anthony F. Egan[1]
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The Lyman Alpha Mapping Project (LAMP) onboard the Lunar Reconnaissance Orbiter (LRO) has been recording far-UV photons reflected from the lunar surface almost continuously since December 2009 (Gladstone et al., 2010). One photon at a time, LAMP builds up spectra from 575 to 1965 Å with a resolution of 26 Å. We will present 3 years of accumulated LAMP lunar dayside spectral maps and derive the lunar geometric albedo spectrum for a range of phase angles. These LAMP observations can thus be used to reconstruct the lunar far-UV photometric function and refine photometric models of the lunar surface (Hapke, 1963; Lucke et al., 1976). We will also compare LAMP lunar dayside albedo with the albedo from 820-1840 Å obtained by the Hopkins Ultraviolet Telescope (HUT) on the March 1995 Astro-2 Space Shuttle mission (Henry et al., 1995). The improved lunar photometric functions from our analysis of LAMP albedo spectra will enable a better quantitative assessment of how phase angle and composition affect the Moon's reflectance in the far-UV. Gladstone, G. R., Stern, S. A., Retherford, K. D., Black, R. K., Slater, D. C., Davis, M. W., Versteeg, M. H., Persson, K. B., Parker, J. W., Kaufmann, D. E., Egan, A. F., Greathouse, T. K., Feldman, P. D., Hurley, D., Pryor, W. R., Hendrix, A. R., 2010. LAMP: The lyman alpha mapping project on NASA's lunar reconnaissance orbiter mission. Space Science Reviews. 150, 161-181. Hapke, B. W., 1963. A theoretical photometric function for the lunar surface. Journal of Geophysical Research. 68, 4571-4586. Henry, R. C., Feldman, P. D., Kruk, J. W., Davidsen, A. F., Durrance, S. T., 1995. Ultraviolet Albedo of the Moon with the Hopkins Ultraviolet Telescope. The Astrophysical Journal Letters. 454, L69. Lucke, R. L., Henry, R. C., Fastie, W. G., 1976. Far-ultraviolet albedo of the moon. The Astronomical Journal. 81, 1162-1169.

115.04 – CONSTRUCTION OF A SMALL AUTOMATED CORONAGRAPH FOR OBSERVATIONS OF THE LUNAR Na EXOSPHERE

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We report on the final optical and mechanical design and the construction and initial testing of a small coronagraph at the Winer Observatory, near Sonoita, Arizona. The coronagraph includes a narrow band filter and low-light level camera to observe lunar exospheric sodium in the resonance lines of that element near 590 nm. Without the use of a coronagraph, the signal from sodium would be lost against light scattered by the Earth's atmosphere and scattered light in the telescope. The design uses Commercial Off the Shelf Technology (COTS), and our goal is to obtain observations while the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission is still in orbit.

115.05 – Velocity Scaling of Neutral Gas Generation from Hypervelocity Dust Impact

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We present direct laboratory measurement of vapor produced by simulated micrometeoroid bombardment. New in-situ observations from the Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER) spacecraft, and the anticipation of results from the Lunar Atmosphere and Dust Environment Explorer (LADEE), have highlighted the uncertainty surrounding the role of micrometeoroid impacts in sustaining planetary exospheres. In a recent series of experiments, the quantity of neutral molecules generated by impacts of simulated micrometeorids of 0.1-1 micron radius was measured using a fast ion gauge, over a speed range of 1-10 km/s. The quantity of neutrals released per unit projectile mass, N/m, is consistent with a power law N/m = v^b in the projectile speed v, with b ~ 2.4. At the highest speeds tested, the number of neutrals liberated is equivalent to a few percent of the atoms in the projectile; near-complete vaporization is projected at speeds exceeding 20 km/s.

115.06 – Effects of Lunar Topography on the Near-Surface Dusty-Plasma Environment

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Due to interactions with the solar wind and solar ultraviolet radiation, the lunar surface develops a complex plasma environment, especially around geological features like craters. Various phenomena have been observed taking place in this dusty plasma environment, including dust levitation and even horizontal dust transport. The Surveyor 5, 6 and 7 cameras have recorded such phenomena including what has been dubbed 'horizon glow'. This glow has been explained as forward-scattered light off of levitating dust particles. Dust levitation and transport could also result in dust ponding, as has been observed on asteroid 433 Eros. To understand these phenomena a three-dimensional particle-in-cell (PIC) code was ran using the commercial code, VORPAL© . The plasma environment was modeled above various topographies with changing solar angles to simulate a full days worth of plasma conditions. Dust dynamics were modeled with the development of a three-dimensional dust tracing code where individual dust grains are introduced into the PIC-modeled plasma environment. To detect net dust transport or time variability we simulated multiple lunar days of dust dynamics. We did this by interpolating between the modeled plasma environments and allowed charged dust grains to be continuously ejected off the surface and dynamically interact with the resulting electric fields.

116 – Historical Astronomy Division Posters

116.01 – A Review of Historical Naked-Eye Sungrazing Comets

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With the upcoming perihelion passage of Comet ISON (C/2012 S1) in November 2013, there is considerable interest in sungrazing comets at present. However, given the infrequency with which such comets appear, there have been few systematic studies of their behavior near perihelion. Bright, sometimes even daytime-observable comets have been recorded by observers around the world for more than 2000 years. A number of authors have compiled records of possible historical sungrazing comets, e.g., Hasegawa 1979, Kronk 1999, Hasegawa & Nakano 2001, England 2002, and Strom 2002. We review this literature to estimate the frequency of arrival of naked-eye sungrazing comets and investigate if there are any trends in their behavior, such as between peak brightness and length of time a comet is observable. We will also review the "modern" observations of naked-eye sungrazing comets (primarily Kreutz group comets observed since 1800) to investigate the frequency of fragmentation near the Sun and the dependence of survivability on size (as inferred from brightness) and/or perihelion distance.

117 – Education Posters

117.01 – A Big Year for Small Bodies

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2013 is a watershed year for celestial events involving the solar system's unsung heroes, small bodies. The Cosmic Valentine of Asteroid 2012 DA14 which passed within ~ 3.5 Earth radii of the Earth's surface (February 15, 2013), Comet C/2011 L4 PANSTARRS and the Thanksgiving 2013 pass of Comet ISON, which will pass less than 0.012 AU (1.8 million km) from the solar

surface and could be visible during the day. All this in addition to Comet Lemmon and a host of meteor showers makes 2013 a landmark year to deliver the excitement of planetary science to the audiences worldwide. To deliver the excitement and wonder of our solar system's small bodies to worldwide audiences, NASA's JPL and GSFC education teams in partnership with NASA EDGE will reach out to the public through multiple venues including broadcast media, social media, science and math focused educational activities, observing challenges, interactive visualization tools like "Eyes on the Solar System" and more culminating in the Thanksgiving Day Comet ISON perihelion passage. This talk will highlight NASA's focused education effort to engage the public in small bodies science and the role these objects play in our understanding of the formation and evolution of the solar system.

117.02 – The Student Spaceflight Experiments Program: Access to the ISS for K–14 Students

Timothy A. Livengood[1, 2], Jeffrey J. Goldstein[1], Stacy Hamel[1], Jeffrey Manber[3], Michael Hulslander[4]
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The Student Spaceflight Experiments Program (SSEP) has flown 53 experiments to space, on behalf of students from middle school through community college, on 4 missions: each of the last 2 Space Shuttle flights, the first SpaceX demonstration flight to the International Space Station (ISS), and on SpaceX-1 to ISS. Two more missions to ISS have payloads flying in Fall 2013. SSEP plans 2 missions to the ISS per year for the foreseeable future, and is expanding the program to include 4-year undergraduate college students and home-schooled students. SSEP experiments have explored biological, chemical, and physical phenomena within self-contained enclosures developed by NanoRacks, currently in the form of MixStix Fluid Mixing Enclosures. 21,600 students participated in the initial 6 missions of SSEP, directly experiencing the entire lifecycle of space science experimentation through community-wide participation in SSEP, taking research from a nascent idea through developing competitive research proposals, down-selecting to three proposals from each participating community and further selection of a single proposal for flight, actual space flight, sample recovery, analysis, and reporting. The National Air and Space Museum has hosted 3 National Conferences for SSEP student teams to report results in keeping with the model of professional research. Student teams have unflinchingly reported on success, failure, and groundbased efforts to develop proposals for future flight opportunities. Community participation extends outside the sciences and the immediate proposal efforts to include design competitions for mission patches, which also fly to space. Student experimenters have rallied around successful proposal teams to support a successful experiment on behalf of the entire community. SSEP is a project of the National Center for Earth and Space Science Education enabled through NanoRacks LLC, working in partnership with NASA under a Space Act Agreement as part of the utilization of the International Space Station as a National Laboratory.

117.03 – Studying the Jovian System with small telescopes

Agustin Sanchez-Lavega[1], Teresa del Rio Gaztelurrutia[1], Ricardo Hueso[1]
1. Universidad del Pais Vasco, Bilbao, Spain.

We describe a learning activity performed at the Aula Espazio Gela UPV/EHU in which students of the Master of Space Science and Technology study the Jovian System (Jupiter and satellites) and deduce some of its parameters using their own images obtained with telescopes ranging from 11 to 20 inch in diameter by means of the lucky-imaging technique.

117.04 – PDS and NASA Tournament Laboratory Progress in Engaging Developers to Provide New Access to the Nation's Planetary Data

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The Planetary Data System (PDS), working through the NASA Tournament Lab (NTL) and TopCoder®, used challenge-based competition to generate an optimized data base and API for comet data at the PDS Small Bodies Node (SBN). Additional, follow-on contests challenged the competitors to create new, transparent, agile tools for public access to NASA's planetary data, where "public" includes not just researchers, but also students and educators. Since the initial start-up last year, the installation at SBN now provides ready access to the comet data holdings of the SBN, and has introduced new users and new developers to PDS data. We report on recent developments arising from that first success. Specifically, the experience gained in that process is being applied to establishing a second installation at the PDS Planetary Rings Node (Rings), to serve as the basis for a new series of challenges – this time to develop similar access tools at Rings to make the growing archive of CASSINI images available through the API; and to develop a crowd-sourcing project with eventual application across the PDS holdings.

117.05 – Scientists and Educators Working Together: Everyone Teaches, Everyone Learns

Larry A. Lebofsky[1, 4], Nancy R. Lebofsky[1], Donald W. McCarthy[1], Thea L. Canizo[2], William Schmitt[3], Michelle L. Higgins[4]
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The primary author has been working with three of the authors (Lebofsky, McCarthy, and Cañizo) for nearly 25 years and Schmitt and Higgins for 17 and 8 years, respectively. This collaboration can be summed up with the phrase: "everyone teaches, everyone learns." What NASA calls E/PO and educators call STEM/STEAM, requires a team effort. Exploration of the Solar System and beyond is a team effort, from research programs to space missions. The same is true for science education. Research scientists with a long-term involvement in science education have come together with science educators, classroom teachers, and informal science educators to create a powerful STEM education team. Scientists provide the science content and act as role models. Science educators provide the pedagogy and are the bridge between the scientists and the teacher. Classroom teachers and informal science educators bring their real-life experiences working in classrooms and in informal settings and can demonstrate scientists' approaches to problem solving and make curriculum more engaging. Together, we provide activities that are grade-level appropriate, inquiry-based, tied to the literacy, math, and science standards, and connected directly to up-to-date science content and ongoing research. Our programs have included astronomy camps for youth and adults, professional development for teachers, in-school and after-school programs, family science events, and programs in libraries, science centers, and museums. What lessons have we learned? We are all professionals and can learn from each other. By engaging kids and having them participate in activities and ask questions, we can empower them to be the presenters for others, even their families. The activities highlighted on our poster represent programs and collaborations that date back more than two decades: Use models and engage the audience, do not just lecture. Connect the activity with ongoing science and get participants outside to look at the real sky: do a Moon journal, measure shadows, observe constellations, and look through a telescope—the sky is more than just string, balls, or a computer program.

117.06 – DPS Listing of Planetary Science Graduate Programs: A Resource for Students and Advisors

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Planetary science is a dynamic and diverse discipline that is not a stand alone department at most institutions. Nor is there any one discipline that can said to be the 'home' for planetary science. Typically, research scientists earn a PhD in a field such as geology, chemistry, astronomy, physics, etc. while focusing their research in that area to planetary or solar system oriented topics. While this inherent diversity in our field is one of its greatest strengths, it can be a source of great confusion to undergraduates considering our field for advanced study. Because of this, we have attempted to compile a list of the graduate programs which can lead to a PhD with a planetary science focus. The list is meant to be a first-stop shop for undergraduate students and undergraduate advisors where they can find programs, compare them across some very basic informational categories, and follow links to the programs' web sites for further information. While the list is extensive, it is most likely not comprehensive and we will continue to add programs as we find out about them. In addition, we will continue reaching out to programs and admissions chairs to help complete the current entries and keep them up-to-date. We preset here the background work that went into compiling and sorting the list of programs, the data fields recorded for each program, and some notes on future directions. Additionally, we call upon those mentoring and advising undergraduate to use this resource and program admission chairs to review their entry and provide us with the most up-to-date information.

117.07 – Tools You Can Use! E/PO Resources for Scientists and Faculty to Use and Contribute To: EarthSpace and the NASA SMD Scientist Speaker's Bureau

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The Planetary Science Education and Public Outreach (E/PO) Forum has helped to create two tools that are designed to help scientists and higher-education science faculty make stronger connections with their audiences: EarthSpace, an education clearinghouse for the undergraduate classroom; and NASA SMD Scientist Speaker's Bureau, an online portal to help bring science – and scientists – to the public. Are you looking for Earth and space science higher education resources and materials? Come explore EarthSpace, a searchable database of undergraduate classroom materials for faculty teaching Earth and space sciences at both the introductory and upper division levels! In addition to classroom materials, EarthSpace provides news and information about educational research, best practices, and funding opportunities. All materials submitted to EarthSpace are peer reviewed, ensuring that the quality of the EarthSpace materials is high and also providing important feedback to authors. Your submission is a reviewed publication! Learn more, search for resources, join the listserv, sign up to review materials, and submit your own at http://www.lpi.usra.edu/earthspace. Join the new NASA SMD Scientist Speaker's Bureau, an online portal to connect scientists interested in getting involved in E/PO projects (e.g., giving public talks, classroom visits, and virtual connections) with audiences! The Scientist Speaker's Bureau helps educators and institutions connect with NASA scientists who are interested in giving presentations, based upon the topic, logistics, and audience. The information input into the database will be used to help match scientists (you!) with the requests being placed by educators. All Earth and space scientists funded by NASA – and/or engaged in active research using NASA's science – are invited to become part of the Scientist Speaker's Bureau. Submit your information into the short form at http://www.lpi.usra.edu/education/speaker.

117.08 – Educational Opportunities for the 2014 Opposition of Mars

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Mars reaches opposition and is well placed for public viewing on April 8, 2014 at 20:57 UT. The opposition timeline and educational opportunities are considered, with emphasis on programs presented at the Fernbank Science Center in Atlanta, Georgia. Educational programs include a planetarium presentation, observations of Mars through telescopes, and activities associated with the ongoing Curiosity Rover (MSL) / anticipated Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft. When at opposition in 2014, Mars will have an apparent diameter of 15.1 arcseconds and will be visible in the evening sky for a little over a year until it is lost in the glare of the Sun in late April 2015. At closest approach, the planet will be a bit more than 57 million miles (92 million kilometers) from the Earth. Mars is especially well placed in the evening sky for viewing between the months of March and May of 2014. During this period, the planet can be found in retrograde motion within the constellation pattern of Virgo. Fernbank Science Center will offer public viewing of Mars through the observatory's 36-inch (0.9 meter) reflecting telescope on Thursday and Friday evenings. The observatory is open immediately after the evening planetarium program. We anticipate showing a fulldome planetarium presentation about Mars entitled, 'Mars Quest,' which includes a live update about the Red Planet and how to find it among the stars in the current evening sky.

117.09 – Make Movies out of Your Dynamical Simulations with OGRE!

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We have developed OGRE, the Orbital GRaphics Environment, an open-source project comprising a graphical user interface that allows the user to view the output from several dynamical integrators (e.g., SWIFT) that are commonly used for academic work. One can interactively vary the display speed, rotate the view and zoom the camera. This makes OGRE a great tool for students or the general public to explore accurate orbital histories that may display interesting dynamical features, e.g. the destabilization of Solar System orbits under the Nice model, or interacting pairs of exoplanets. Furthermore, OGRE allows the user to choreograph sequences of transformations as the simulation is played to generate movies for use in public talks or professional presentations. The graphical user interface is coded using Qt to ensure portability across different operating systems. OGRE will run on Linux and Mac OS X. The program is available as a self-contained executable, or as source code that the user can compile. We are continually updating the code, and hope that people who find it useful will contribute to the development of new features.

118 – Venus Posters

118.01 – Coordinate Transformations of Low Beta Regions in the Nightside Venus Ionosphere

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Pioneer Venus Orbiter discovered regions of localized low plasma pressure and high magnetic pressure, or low beta regions, in the nightside ionosphere of Venus during its 14-year mission. These regions contain a magnetic field oriented nearly parallel to the sun-Venus line, where the pressure due to the magnetic field buildup is equal to the outside plasma pressure. The low beta regions are the result of ionospheric currents induced by the solar wind electric field and interplanetary magnetic field (IMF) with a configuration consistent with field-like draping of the IMF. Previous results using a coordinate system based on the IMF direction showed that the polarities of the radial-like fields were consistent with the IMF direction. However, that study reversed the magnetic longitude according to the IMF Y coordinate, which was not consistent with the local time variation of the regions. We look at the distribution of these events using a magnetic latitude based on the IMF direction but maintain the local time coordinate which is assumed to order the direction of ionospheric flows from the day into the night. Further, the magnetic fields at the edges of these low beta region are analyzed through Maxwell's equations to examine the source and direction of the electric current flows that create the magnetic fields, showing horizontal currents perpendicular to the sun-Venus line present outside the regions.

118.02 – Characteristics of Ionospheric Magnetic Flux Ropes on Venus

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Because Venus has no intrinsic magnetic field, its atmosphere is more directly exposed to the solar wind than an atmosphere of a magnetized planet such as Earth. One observed consequence of this solar wind-atmosphere interaction is the presence of magnetic flux ropes, approximately cylindrical structures consisting of twisted magnetic field lines. The central region of a flux rope contains current that can transport charged particles and may therefore aid in atmospheric escape from Venus. Flux ropes in the ionosphere are observed more often during solar maximum periods, when increased photoionization creates an ionospheric thermal pressure sufficient to exclude the solar wind magnetic field. Despite the discovery of flux ropes more than 30 years ago and the availability of new observations since the arrival of Venus Express (VEX) in 2006, the formation mechanism for ionospheric flux ropes is still unresolved. We present the results of a manual survey of magnetic field data from the VEX magnetometer (MAG) for magnetic flux ropes, which present as localized peaks in magnetic field strength with field rotations consistent with flux rope geometry. We survey data from evenly spaced month-long time intervals from 2006 – 2012 to examine the effects of different stages of the solar cycle on flux rope properties such as location, half-length, and orientation relative to the planet. We present trends in the properties of observed flux ropes, how they are affected by the solar wind, and how they compare to previous results. This research is supported by a NASA Venus Express Supporting Investigator grant.

118.03 – Properties of the V1 layer in the Venus ionosphere using VeRa observations from Venus Express

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The Venus Radio Science Experiment (VeRa) on the Venus Express spacecraft sounds the Venus atmosphere during Earth occultations to obtain vertical profiles of electron density in the ionosphere. The resultant profiles reveal the vertical structure of the Venus ionosphere from the topside down to below the lower layers (< 115 km). On the dayside, the dominant plasma layer is the V2 layer at ~142 km, which is produced primarily by photoionization of CO2. Embedded on the bottomside of the V2 layer is the less prominent, and much less studied, V1 layer at ~127 km. The V1 layer is also produced by photoionization of CO2, but secondary ionization due to energetic photoelectrons is much more important. Here we investigate properties of the V1 layer using VeRa profiles from 2006 to 2012 during which the Sun went from the deep solar minimum of Solar Cycle 23 to the rising solar activity levels of Solar Cycle 24. We investigate how the peak electron density and peak altitude of the V1 layer depend on solar zenith angle. We also characterize the shapes of the V1 layer and show how they are related to the solar activity level. Solar spectra from the Solar EUV Experiment (SEE) on the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) spacecraft are used to characterize the shapes of the V1 layer with solar activity.

118.04 – Waves in the Mesosphere of Venus as seen by the Venus Express Radio Science Experiment VeRa

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The Venus Express Radio Science Experiment (VeRa) has retrieved more than 700 profiles of the mesosphere and troposphere of Venus. These profiles cover a wide range of latitudes and local times, enabling study of atmospheric wave phenomena over a range spatial scales at altitudes of 40–90 km. In addition to quasi-horizontal waves and eddies on near planetary scales, diurnally forced eddies and thermal tides, small-scale gravity waves, and turbulence play a significant role in the development and maintenance of atmospheric super-rotation. Small-scale temperature variations with vertical wavelengths of 4 km or less have wave amplitudes reaching TBD km in the stable atmosphere above the tropopause, in contrast with much weaker temperature perturbations observed in the middle cloud layer below. The strength of gravity waves increases with latitude in both hemispheres. The results suggest that convection at low latitudes and topographical forcing at high northern latitudes—possibly in combination with convection and/or Kelvin-Helmholtz instabilities—play key roles in the genesis of gravity waves. Further, thermal tides also play an important role in the mesosphere. Diurnal and semi-diurnal wave modes are observed at different latitudes and altitudes. The latitudinal and height dependence of the thermal tide modes will be investigated.

118.05 – Photochemical Distribution of Venusian Sulfur and Halogen Species

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Recent observations of enhanced amounts of SO2 at 100 km by Venus Express (Bertaux et al, 2009; Marcq et al, 2012) suggest that there is a hitherto unknown source of gaseous sulfur species in the upper atmosphere of Venus. The observations of Sandor and Clancy (2010) also show short and longterm variations in mesopause-level (90-100 km) SO and SO2. Zhang et al (2010) argue that the photolysis of H2SO4 vapor derived from evaporation of H2SO4 aerosols provides a source of SO3, which upon photolysis yields SO2. In this study, the photochemistry and dynamics of Venus' atmosphere from the cloud tops to 110 km has been modeled using an updated/expanded chemical scheme, with the view to improving our understanding of the vertical and global distributions of sulfur and halogen species by application of the 1-D Caltech/JPL KINETICS chemistry tracer species profiles to the Venus Thermospheric General Circulation Model (VTGCM) (Bougher et al, 1997) for comparison to VEx and ground-based datasets. Specifically, we compare our model results with the SO2 observations of Bertaux et al (2009), Sandor and Clancy (2010), and Marcq et al (2012) in our analysis. We mainly follow Yung and DeMore (1982), Mills (1998), Pernice et al. (2004), Krasnopolsky (2010), and Zhang et al. (2010) in our choice of chemical reactions, chemical rate constants, and boundary conditions for 38 species. We will examine a model with an HCl mixing ratio of 1E-7 corresponding to Venus Express observations made at high northern latitudes. Our modeling agrees satisfactorily with stratospheric observations of key species such as CO, O2 and SO2, and we better quantify the implications of the different HCl mixing ratios observed. As well, we also include other tunable parameters in our study such as considering a range of eddy diffusion profiles that vary by a factor of 10 and other sensitivity studies such as wave drag using Rayleigh friction parameters.

118.06 – Microphysical Model of the Venus clouds between 40km and 80km.

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I am continuing to adapt the Community Aerosol and Radiation Model for Atmospheres (CARMA) to successfully simulate the multi-layered clouds of Venus. The present version of the one-dimensional model now includes a simple parameterization of the photochemicial production of sulfuric acid around altitudes of 62km, and its thermochemical destruction below cloud base. Photochemical production in the model is limited by the availability of water vapor and insolation. Upper cloud particles are introduced into the model via binary homogeneous nucleation, while the lower and middle cloud particles are created via activation of involatile cloud condensation nuclei. Growth by condensation and coagulation and coalescence are also treated. Mass loadings and particle sizes compare favorably with the in situ observations by the Pioneer Venus Large Probe Particle Size Spectrometer, and mixing ratios of volatiles compare favorably with remotely sensed observations of water vapor and sulfuric acid vapor. This work was supported by the NASA Planetary Atmospheres Program, grant number NNX11AD79G.

118.07 – Bimodal Distribution of Sulfuric Acid Aerosols in the Atmosphere of Venus

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Observations by the SPICAV/SOIR instruments aboard Venus Express have revealed that the upper haze of Venus, between 70 and 90 km, is variable on the order of days and that it is populated by two particle modes. In this work, we posit that the observed phenomena are caused by the transient mixing of the clouds and the haze, as well as another source of sulfuric acid aerosols in the upper haze that nucleate on meteoric dust. We test this hypothesis by simulating a column of the Venus atmosphere from 40 to 100 km above the surface using a model based upon the Community Aerosol and Radiation Model for Atmospheres and consider the effects of meteoric dust and polysulfur acting as condensation nuclei in the upper haze and upper cloud, respectively, as well as transient winds at the cloud tops caused by subsolar convection. Our aerosol number density results are consistent with Pioneer Venus data from Knollenberg and Hunten (1980), while our gas distribution results match the Magellan radio occultation data as analyzed by Kolodner and Steffes (1998) below 55 km. The size distribution of cloud particles shows two distinct modes in the upper clouds region and three distinct modes in the middle and lower clouds regions, qualitatively matching the observations of Pioneer Venus. The UH size distribution shows one distinct mode that is likely an upwelled cloud particle population with which an in situ meteoric dust condensation particle population has coagulated. The results of the transient wind simulations yield a variability timescale that is consistent with Venus Express observations, as well as a clear bimodal size distribution in the UH.

118.08 – Aqueous Chemistry in the Clouds of Venus: A Possible Source for the UV Absorber

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The identity and cause of the UV absorber near the Venusian cloudtops (~62-70 km altitude) has been an enduring mystery. Given the role of sulfur in Venus's atmosphere, where, somewhat analogous to water on Earth, it cycles through gas, liquid, and (possibly) solid phases in the atmosphere, it has been a prime suspect as at least a key component, perhaps as long-lived solid poly-sulfur aerosols, S_n, where n > 4. However, the narrow range of altitudes inhabited by the UV absorber (thought to form and reside primarily above 62 km altitude) seems incompatible with Sn, which should vertically disperse after formation. Here, we point to another process that could lead to somewhat more exotic chemistries that favor formation and sequestration at high altitudes: Aqueous chemistry within H_2SO_4-nH_2O cloud particles. Due to (1) the decrease of temperature and (2) the increase in the fraction of water ("n" in the previous formula) of each cloud droplet with altitude, high-altitude particles near the cloudtops are – via the "heterogeneous uptake" process – significantly more capable of capturing and concentrating trace gases, in particular HCl. For example, the heterogeneous uptake of HCl in H_2SO_4 droplets near the 65-km cloudtops is at least three times greater than that found in the middle of the clouds near 55 km altitude. Other factors such as local mixing ratios and the concentration of other solvents in the droplet also modify the uptake. Within the cloud droplets, solution chemistry between HCl and H_2SO_4 may lead to the formation of chlorosulfonic acid, $ClSO_3H$, which is a weak acid that readily breaks down into other species, such as SO_2Cl_2 (sulfuryl chloride) and $SOCl_2$ (thionyl chloride). Together, these three materials have UV-blue absorptions at 0.21, 0.29, 0.39 and 0.47 micron. Thus, H_2SO_4 aerosols at high altitudes may take on lasting UV absorption characteristics, dependent on temperature (altitude) and other conditions, Balloons floating at benign Earth-surface-like temperature/pressure conditions near 56-km altitude may be able to sample such aerosols and their complex contents as measured in periodic downdrafts of materials from higher altitudes.

118.09 – Laboratory Studies of O_2 Excited States Relevant to the CO_2 Planets

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Knowledge of the details relevant to the production of excited O_2 is critical for the study and modeling of composition, energy transfer, airglow, and transport dynamics in CO_2 planetary atmospheres. Significant gaps and uncertainties exist in our understanding of the above processes, and often the relevant input from laboratory measurements is missing or outdated. We are performing laser-based laboratory experiments to investigate the O-atom three-body recombination responsible for the generation of oxygen airglow in the upper atmosphere of Venus and Mars. In the laboratory, an ultraviolet light pulse from a laser photoinitiates O-atom recombination in a CO_2 environment. Spectroscopic techniques are used to probe the excited O_2 molecules produced following recombination and subsequent relaxation in CO_2. We present our latest laboratory results and discuss their atmospheric implications. This work is supported by the National Science Foundation's (NSF) Planetary Astronomy Program under grant AST-1109372. K. Storey-Fisher participated at a Research Experiences for Undergraduates (REU) site at SRI International, co-funded by the Division of Physics of the NSF and the Department of Defense in partnership with the NSF REU program (PHY-1002892).

118.10 – Influence of Asteroid and Comet Impacts on Atmospheric Abundances at Venus, Earth, and Mars

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Asteroid and comet impacts have undoubtedly altered the atmospheres of the terrestrial planets over billions of years. Impacts are capable of either delivering or removing atmospheric particles from a planet depending upon the characteristics of the impact. With many thousands of impacts large enough to alter the atmospheres of each terrestrial planet, all with varying compositions, velocities, impact angles, and sizes, it is not entirely clear how impacts have contributed to changes in atmospheric abundance over time. Some theoretical and numerical work has been undertaken in the past for generic individual impacts, and several studies have considered the net effect of impacts on the atmospheres of Mars and Earth over time. However, the full parameter space of atmospheric impact calculations remains unexplored, particularly in regards to Venus and the effect of oblique impacts on atmospheres. This work uses Monte Carlo simulations to model atmospheric erosion and delivery from impacts at Venus, Earth, and Mars. Flexibility in the code allows us to examine the effects of changing impactor populations (i.e. size and composition), velocity distributions, and angles of impact on the resultant atmospheric pressure, as well as the different sensitivities to these factors between the planets. The work we present relies on published analytic expressions for the effects of individual impacts. However, the results of detailed simulations of individual impacts (e.g. using the RAGE hydrocode) can be incorporated into our future modeling efforts to help validate these expressions.

118.11 – Characterization of a transiting exo-Venus : lessons from the 2012 Transit

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The transit of Venus in June 2012 provided a unique chance to view a well studied planetary atmosphere as we might see that of a transiting exoplanet, through scattered and refracted illumination of its parent star. We report on mesospheric temperature at Venus' morning terminator using SDO/HMI aureole photometry and comparison with Venus Express. Close to ingress and egress phases, we have shown that the aureole photometry reflects the local density scale height and the altitude of the refracting layer (Tanga et al. 2012). The lightcurve of each spatial resolution element of the aureole is compared to a two-parameter model to constrain the meridional temperature gradient along the terminator. Our measurements are in agreement with the VEx/SOIR temperatures obtained during orbit 2238 at evening terminator during solar ingress (46.75N - LST = 6.075PM) and solar egress (31.30N - LST = 6.047PM) as seen from the orbiter. Imaging data using IBIS/ROSA on the Dunn Solar Telescope in the G-band (430 nm) are also presented. We also performed spectroscopy and polarimetry during the transit of Venus focusing on extracting signatures of CO2 absorption. Observations were taken during the first half of the transit using the Facility InfraRed Spectropolarimeter on the Dunn Solar Telescope. Although the predicted CO2 transmission spectrum of Venus was not particularly strong at 1565 nm, this region of the H-band often used in magnetic field studies of the Sun's photosphere provides a particularly flat solar continuum with few atmospheric and molecular lines. Sun-subtracted Venus limb observations show intensity distribution of vibro-rotational CO2 band 221 $2\nu + 2\nu 2 + \nu 3$ at 1.571µm allowing for an additional constraint on Venus' thermospheric temperature.

118.12 – Venus Terminator Temperature Structure: Venus Express SOIR and VTGCM Comparisons

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Venus Express SOIR terminator profiles of CO2 densities and temperatures have been organized and presented for 100+ selected orbits obtained between 2006-2011. The SOIR instrument measures CO2 absorption across a broad spectral window. The observed atmospheric transmittance spectra are subsequently inverted to obtain vertical density (and inferred temperature) profiles at the Venusian terminator over approximately 70 to 160 km. These recently recalibrated measurements continue to show a striking permanent temperature minimum (at 125 km) and a weaker temperature maximum (over 100-115 km). These features are reflected in the corresponding CO2 density profiles, and provide detailed constraints for global circulation models of the upper atmosphere. New Venus Thermospheric General Circulation Model (VTGCM) simulations are conducted for conditions appropriate to these SOIR measurements. In particular, solar minimum fluxes are specified and mean values of eddy diffusion and wave drag parameters are utilized. Recent upgrades to the VTGCM code now include more realistic lower boundary conditions at 70 km near cloud tops. Model temperature profiles are extracted from the terminators that correspond to five latitude bins presently used in the SOIR data analysis. Averaging of VTGCM temperature profiles in each of these bins (at each terminator) is conducted to match

SOIR sampling. Comparisons of these SOIR and VTGCM temperature profiles are made. Most notably, the observed temperature minimum near 125 km and the weaker temperature maximum over 100-115 km are generally reproduced by the VTGCM at the correct pressure level. However, magnitudes of simulated and measured temperatures are somewhat different. In addition, VTGCM evening terminator (ET) temperatures are simulated to be modestly warmer than corresponding morning terminator (MT) values, a result of stronger ET than MT zonal winds at/above about 130 km. The SOIR terminator temperatures thusfar only reveal rather weak ET versus MT asymmetries above 140 km. Details of the underlying thermal balance processes are identified that give rise to these VTGCM simulated temperatures.

118.13 – Venus' 5577 Å Oxygen Green Line: An Auroral Process?

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Venus' oxygen green line at 5577 Å is a highly variable feature on the Venusian nightside. It was first seen in 1999 by Slanger et al. (Science 291, 463, 2001) and found to be stronger than the terrestrial green line. It subsequently decreased in strength and was undetectable after 2004. It was seen again in 2012 by Gray et al. (Icarus, submitted, 2013) after a coronal mass ejection (CME) impacted Venus in April 2012 and after an X-flare and CME impact in July 2012. They found that for every detection from 1999 - 2004, a high energy flare, CME, or strong solar wind stream occurred within one week prior to each observation. For observations where the green line was not detected, there were no solar flares or CMEs. They propose that solar flares and/or CMEs are responsible for green line emission. The process for emission is still unknown, but they suggest two possibilities. First, increased levels of EUV photons from flares may increase photodissocation of dayside molecules, which are then transported to the nightside, to a large enough level where green line emission becomes detectable. Second, electron precipitation from solar flares and CMEs may have a high enough energy and density to penetrate deep in atmosphere (<150km) in order to produce green line emission without producing oxygen red lines 6300, 6364, and 7600 Å. Gray detected the green line immediately after a CME impact on April 22, 2012 but was not able to detect the feature after two separate solar flare events not associated with a CME. We propose that electron precipitation is the main process responsible for green line emission and suggest that electrons are penetrating deeper in the atmosphere and with higher density than previously believed or modeled. To test this hypothesis, we compare electron density profiles on the Venusian nightside, obtained by the Venus Radio Science Experiment on Venus Express, before and after solar flares and CMEs. Here we present the result of these comparisons. This research is funded by NASA's Earth and Space Science Fellowship, NNX12AM70H.

119 – Sagan Medal Public Talk: Near-Earth Objects: Finding Them Before They Find Us, Don Yeomans (JPL)

200 – Exoplanets 3: Atmospheres, Interiors, and Composition

200.01 – 3.6 and 4.5 micron Full-orbit Phase Curves of the Hot-Saturn HD 149026b

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The extrasolar planet HD 149026b, discovered in 2005, was among the first to be observed to transit its host star as seen from earth. Since its discovery, several observational campaigns have targeted HD 149026b in wavelengths from the visible to the infrared to obtain both transmission and emission broadband measurements. These measurements have revealed that HD 149026b has a radius similar to that of Saturn, but a density more akin to that of Neptune. This suggest that HD 149026b is enriched in heavy elements much like the ice giants of our solar system. Half-orbit phase curve observations of HD 149026b at 8 microns (Knutson et al., 2009) suggest that the day-to-night transport of heat is fairly efficient for this planet. However, further phase curve observations at other infrared wavelengths are needed to better constrain the planet's energy budget, location of hot and cold regions, as well as possible chemical gradients in the planet's atmosphere. Here we present an analysis of the full-orbit phase-curves of HD 149026b at 3.6 and 4.5 microns. We discuss the implications of the combined phase-curve information at 3.6, 4.5, and 8 microns and compare the observations to theoretical phase curves derived from three-dimensional atmospheric models that consider a range of possible heavy element enrichments in HD 149026b's atmosphere.

200.02 – Updating the SPARC/MITgcm to model the atmospheric circulation of super Earths and terrestrial exoplanets

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While many of the exoplanets detected thus far have been hot Jupiters and hot Neptunes (Jovian- and Neptunian-sized planets within 0.1 AU of their host stars), ground- and space-based surveys will continue to see a growth in the detection of so-called super Earths, that is, exoplanets with masses less than 10 times that of Earth. This class of objects will include not only planets with thick fluid envelopes but also traditional terrestrial planets with solid surfaces and thinner atmospheres. To that end, we present results from studies investigating the atmospheric circulation of these latter classes of planets using the SPARC/MITgcm, a state-of-the-art model which couples the MIT General Circulation Model with a plane-parallel, two-stream, non-gray radiative transfer model. We will describe the many updates that have been included to investigate these classes of planets. We will also present select results from these studies, focusing on the circulation of GJ 1214b, a super-Earth detected by the MEarth survey, and on general terrestrial exoplanets orbiting M-dwarfs.

200.03 – Atmospheric Heat Redistribution on Hot Jupiters

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Infrared lightcurves of transiting hot Jupiters present a trend in which the atmospheres of the hottest planets are less efficient at redistributing the stellar energy absorbed on their daysides—and thus have a larger day-night temperature contrast—than colder planets. To this day, no predictive atmospheric model has been published that identifies which dynamical mechanisms determine the atmospheric heat redistribution efficiency on tidally locked exoplanets. We present a two-layer shallow water model of the atmospheric dynamics on synchronously rotating planets that explains why heat redistribution efficiency drops as stellar insolation rises. Our model shows that planets with weak friction and weak irradiation exhibit a banded zonal flow with minimal day-night temperature differences, while models with strong irradiation and/or strong friction exhibit a day-night flow pattern with order-unity fractional day-night temperature differences. To interpret the model, we develop a scaling theory that shows that the timescale for gravity waves to propagate horizontally over planetary scales, τ_{wave}, plays a dominant role in controlling the transition from small to large temperature contrasts. This implies that heat redistribution is governed by a wave-like process, similar to the one responsible for the weak temperature gradients in the Earth's tropics. When atmospheric drag can be neglected, the transition from small to large day-night temperature contrasts occurs when $\tau_{wave} \sim (\tau_{rad}/\omega)^{1/2}$, where τ_{rad} is the radiative relaxation time, and ω is the planetary rotation frequency. Alternatively, this transition criterion can be expressed in terms of τ_{vert}, the timescale for a fluid parcel to move vertically over the difference in day-night thickness. The transition then occurs when $\tau_{rad} \sim \tau_{vert}$. These results subsume the more widely used timescale comparison for estimating heat redistribution efficiency between τ_{rad} and the timescale for large-scale horizontal advection, τ_{adv}. Only because $\tau_{adv} \sim \tau_{vert}$ for hot Jupiters does the commonly assumed timescale comparison between τ_{rad} and τ_{adv} yield approximately correct predictions for the heat redistribution efficiency.

200.04 – Atmospheric Dynamics of Brown Dwarfs and Directly Imaged Giant Planets

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A variety of observations provide evidence for vigorous motion in the atmospheres of brown dwarfs and directly imaged giant planets. Motivated by these observations, we examine the dynamical regime of the circulation in the atmospheres and interiors of these objects. Brown dwarfs rotate rapidly, and for plausible wind speeds, the flow at large scales will be rotationally dominated. We present 3D, global, numerical simulations of convection in the interior, which demonstrate that, at large scales, the convection aligns in the direction parallel to the rotation axis. Convection occurs more efficiently at high latitudes than low latitudes, leading to systematic equator-to-pole temperature differences that may reach ~1 K near the top of the convection zone. The interaction of convection with the overlying, stably stratified atmosphere will generate a wealth of atmospheric waves, and we argue that, as in the stratospheres of planets in the solar system, the interaction of these waves with the mean flow will cause a significant atmospheric circulation at regional to global scales. At large scales, this should consist of stratified turbulence (possibly organizing into coherent structures such as vortices and jets) and an accompanying overturning circulation. We present an approximate analytic theory of this circulation, which predicts characteristic horizontal temperature variations of several to ~50 K, horizontal wind speeds of ~10-300 m/sec, and vertical velocities that advect air over a scale height in ~10^5-10^6 sec. This vertical mixing may help to explain the chemical disequilibrium observed on some brown dwarfs. Moreover, the implied large-scale organization of temperature perturbations and vertical velocities suggests that, near the L/T transition, patchy clouds can form near the photosphere, helping to explain recent observations of brown-dwarf variability in the near-IR.

200.05 – A Novel Diagnosis of Chemical Disequilibrium in Extrasolar Planet and Substellar Object Atmospheres

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With recent advancements in spectroscopic capabilities, characterization of the temperatures and compositions of extra-solar planets is becoming more prevalent. One outstanding issue one can address with temperature and abundance determinations is the role that disequilibrium plays in sculpting the atmospheric compositions. A variety of disequilibrium models now exist in the literature to explore various planets and the effects that photochemistry and vertical mixing have on the molecular abundances. In this investigation we introduce a novel approach to diagnosing disequilibrium without the need of sophisticated photochemical/kinetics models. In short, we define an "equilibrium" line as a function of a representative planet temperature. If we can determine the abundances of H2O, CH4, CO, and H2, we can evaluate a simple analytic formula to quickly assess whether or not the atmospheric composition is in disequilibrium. We verify the usefulness of this approach with state-of-the-art chemistry-transport models and find that, as expected, cooler planets tend to show the strongest signs of disequilibrium.

200.06 – Constraints on Elemental Abundances in Hot Jupiter Atmospheres and Implications for Their Formation Conditions

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Spectroscopic observations of hot Jupiters in the past few years have led to the possibility of determining elemental abundance ratios in their atmospheres. It has been demonstrated that the O/H and C/O ratios in hot Jupiters can be measured more easily than those for giant planets in the solar system where temperatures are too low for water to be accessible to spectroscopic observations. Nominal constraints on atmospheric C/O ratios have already been reported for a few hot Jupiters (Madhusudhan 2012). In the present work, we combine existing data, from the Spitzer space telescope and from ground-based facilities, with new data obtained using the Hubble space telescope to place new constraints on the C/H, O/H, and C/O ratios in five hot Jupiters. The systems considered in our study span a wide range of incident irradiation and, hence, equilibrium temperatures. We use our estimates of the elemental abundance ratios in the hot Jupiters to constrain the range of volatile compositions of their formation environments and their subsequent evolution.

200.07 – Characterizing the Demographics of Exoplanet Bulk Compositions

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The Kepler Mission has discovered thousands of sub-Saturn-sized transiting planet candidates. Using planet interior structure models, we constrain the bulk compositions of the more than 50 known sub-Saturn-sized transiting planets with measured masses. Our model considers fully differentiated planets comprised of up to four layers: an iron core, a silicate mantle, a water mantle, and a gas envelope. We calculate the planet interior structure by integrating the coupled differential equations describing an evolving self-gravitating body, employing modern equations of state for the iron, silicates, water, and gas. For any individual planet, a wide range of compositions is consistent with the measured mass and radius. We consider the planets as an ensemble, and discuss how thermal evolution, mass loss, and observational biases sculpt the observed planet mass-radius-insolation distribution. Understanding these effects is crucial for constraining the demographics of small planet bulk compositions and for extracting signatures of the planet formation process from the accumulating census of transiting planets with dynamical confirmation.

200.08 – How Thermal Evolution and Photo-Evaporation Sculpt Kepler's Sub-Neptunes and Super-Earths.

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NASA's Kepler mission has discovered a large new population of super-Earth and sub-Neptune sized planets. Although we have no analogous planet in our own solar system, such planets are incredibly common. Understanding the nature and formation of systems of these planets is one of the key challenges for theories of planet formation. We use models of thermal evolution and photo-evaporation to examine the structure, composition, and evolution of low-mass planets. Over time Neptune like planets with large H/He envelopes can be transformed into rocky super-Earths. We show that differences in mass loss history provide a natural explanation for many features of the Kepler multi-planet systems, such as large density contrast between Kepler-36b and Kepler-36c. For the broader population of Kepler planets, we find that there is a threshold in bulk planet density, mass, and incident flux above which no low-mass transiting planets have been observed. We suggest that this threshold is due to XUV-driven photo-evaporation and show that it is well reproduced by our evolution models.

201 – Asteroids 3: Potpourri

201.01 – Volatiles in the M-class Population: A Lesson from Vesta?

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Using the S-band radar at Arecibo Observatory, we have observed 27 main-belt M-class asteroids, including 12 which display a 3 micron absorption feature often attributed to the presence of hydrated minerals (Rivkin et al, Icarus 145, 2000). Five of these "W-class" objects – 40% of our sample – have a mean radar albedo of 0.39 which is usually interpreted to mean a composition dominated by metals. Traditionally, high radar albedos and metal compositions have been thought to be inconsistent with hydrated minerals in the regolith; metal formation requires either high temperatures or greatly reducing environments that would remove volatiles. The simultaneous spectral evidence of hydrated silicates and the apparent lack of FeO (0.7 micron absorption feature) make aqueous alteration of a metal-rich composition difficult to reconcile (Rivkin et al. Asteroids III, 2002). Recent observations of Vesta have shown that primitive objects (CI or CM analog objects) collide with and implant volatiles on otherwise volatile-poor surfaces (e.g. Reddy et al. Icarus 221, 2012; Prettyman et al. Science 338, 2012; McCord et al. Science 338, 2012; Denevi et al. Science 338, 2012). Additional evidence that this may be happening within the M-class is that all of the high-radar albedo W-class

objects have bifurcated radar echoes, suggesting large structural or compositional anomalies; collisions are one way to generate such echoes. The fact that half of our high-radar albedo sample displays a 3 micron feature is also consistent with the stochastic nature of the proposed process. Similar features of anomalous hydration in the E-class (Rivkin et al. Icarus 117, 1995) suggest this process may be ubiquitous throughout the main-belt. Acknowledgements: This work was funded by NSF grant AST-0908098 to MKS and AST-0908217 to BEC.

201.02 – The Water Regime of Dwarf Planet (1) Ceres

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The traditional view of minor bodies in the (inner) Solar System being divided into icy comets and rocky asteroids has been challenged by recent results, such as the discovery of comets on asteroidal orbits and the detection of water ice frost on the surface of asteroid (24) Themis. The discovery of water ice on the surface of asteroids has profound implications for how the Solar System formed, and challenges our ideas about the stability of ice in the inner Solar System. The study of volatiles in the asteroid belt places strong constraints on the temperature and composition distribution in the proto-planetary disk,and on possible sources of terrestrial water, and strongly constrains formation models of the early Solar System. Water may have played a significant role in the evolution of Ceres. Despite the mostly featureless spectrum of Ceres in the visible and near-infrared (NIR), the weak but mysterious absorption features in the 3-5 μm region have been repeatedly interpreted as water ice frost or hydrated silicates. Thermal evolution models of Ceres suggested liquid water in the mantle in the past and perhaps even today. HST images and NIR observations of Ceres showed a remarkably homogeneous surface, possibly a consequence of relatively recent or even current global scale resurfacing driven by liquid-phase activity and/or volatile sublimation. While the results of surface spectra are ambiguous, detections of water vapour or its dissociation products around Ceres are a clear proof of a wet Ceres. Theoretical studies suggested that water ice could remain stable at shallow depths over the age of the solar system on MBAs. As the largest MBA and a dwarf planet, Ceres accounts for ~1/4 of the total mass in the main belt, and has a much larger surface area than any single small main-belt comet. In 1992, a 3 sigma detection of OH was reported based on IUE observations. So far, attempts at confirming that detection failed We will report on observation of Ceres we performed on Nov. 2011, Oct. 2012 and March 2013 with the ESA Herschel Space Observatory. We used the Heterodyne Instrument for the Far Infrared (HIFI) to search for the water ground state line at 557 GHz.

201.03 – Thermal and Structural Evolution of Asteroid (4) Vesta

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Placing the formation and evolution of a large differentiated planetesimal like asteroid (4) Vesta into a broader context of Solar System chronology has important implications for our understanding of planetary formation. Vesta is here assumed to form instantaneously at t=1.0 Myr after CAI by low-velocity contraction of a boulder swarm created by streaming instabilities. A novel computer code tracks the last phase of formation, from a radius R=564 km swarm with 90% porosity, via cold-pressing, to hydrostatic equilibrium at R=314 km, porosity above 42% and bulk density d=2.00 g/cc. The code then calculates temperature versus depth and time for an initially homogeneous mixture of metal and rock which contains radioactive Al-26 and Fe-60. Heat conductivities and specific heat capacities are functions of temperature and porosity. The porosity profile is updated continuously as a result of hot-pressing. When the first sign of metal melting occurs at t=1.68 Myr, the core porosity is 35%, R=310 km and d= 2.20 g/cc. The gradual melting of metal and its flow towards the center is modeled. Initially only void spaces are filled out, but as the liquid fraction reaches a threshold, silicate grains migrate upward, thus finalizing the differentiation. Around this time, efficient hot-pressing of weakened warm rock leads to substantial shrinking. By t=1.9 Myr, R=270 km, d=3.14 g/cc, and a compact solid rock mantle separates a ~110 km liquid metal core from a ~10km porous metal/rock crust. At t=2.1 Myr rock melting is initiated, and is completed 0.8 Myr later. The densities of metal and rock are considered temperature dependent, resulting in swelling or shrinking of the body, as well as density gradients within core and mantle. Efforts are ongoing to allow the resulting buoyancy to drive convection, with the corresponding energy transport accounted for. This will allow for studies of the duration of the magnetic dynamo, and more realistic changes of temperature, radius, and density as the body heats further and eventually cools and solidifies, thereby approaching the current R=263km and d=3.46 g/cc.

201.04 – Constraints on planetesimal formation from asteroid compositions

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Ordinary chondrite meteorites (OCs) are by far the most abundant meteorites (80% of all falls). Their study along with that of other chondrite classes has provided numerous constraints on the formation and early evolution of the solar system, including a) the migration processes that occurred in the protoplanetary disk prior to primary accretion (i.e. planetesimal formation) and their associated timescales, b) the post- (and syn-) accretional heating events, and c) the collisional events that occurred since 4.6 Gyrs. Although petrologic, chemical and isotopic studies of OCs and meteorites in general have largely helped establish a chronology of the earliest events of planetesimal formation, there are several questions that cannot be resolved via laboratory measurements and/or experiments only. These include the formation location of the different classes of ordinary chondrites (and meteorites in general); the initial average size of their parent bodies; the amplitude of the bias in our collections with respect to the compositional distribution of OC-like material in the Asteroid Belt; the number of parent bodies for a given meteorite class (it is typically proposed that each meteorite class has only one parent body); the level of radial mixing experienced by parent bodies after their formation; and their accretion timescale. To investigate answers to these questions, we conducted an extensive spectroscopic survey of 83 main belt S-type asteroids and 5 S-type families as it was recently established unambiguously that these asteroids encompass the parent bodies of OCs. In parallel, we also obtained for the first time spectral measurements for a representative number (53) of unequilibrated ordinary chondrites (UOCs) as those were lacking in current databases (e.g. RELAB; http://www.planetary.brown.edu/relab/). We will present evidence for establishing several new constraints on the planetesimal formation process from our broadened spectral survey.

201.05 – Discovery of the Dust Tail of Asteroid (3200) Phaethon

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We report the discovery of a comet-like tail on asteroid (3200) Phaethon when imaged at optical wavelengths near perihelion. In both 2009 and 2012, the tail appears about 350 ′ ′ (2.5×10^8 m) in length and extends approximately in the projected anti-solar direction. We interpret the tail as being caused by dust particles accelerated by solar radiation pressure. The sudden appearance and the morphology of the tail indicate that the dust particles are small, with an effective radius of 1 micron and a combined mass about 3×10^5 kg. These particles are likely products of thermal fracture and/or desiccation cracking under the very high (1000K) surface temperatures experienced by Phaethon at perihelion. The existence of the tail confirms our earlier inferences about activity in this body based on the detection of anomalous brightening. Phaethon, the presumed source of the Geminid meteoroids, is still active. The relation between the observed particles and those constituting the Geminid meteoroid stream will be discussed.

201.06 – NEOWISE: Recent Results and Observations of Tiny Near-Earth Objects

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Contributing teams: NEOWISE Team

The minor planet-hunting portion of the Wide-field Infrared Survey Explorer mission (Wright et al. 2010), known as NEOWISE, has resulted in the creation of an archive of single exposure images and extracted sources collected by this infrared all-sky survey (Mainzer et al. 2011). All data products have now been publicly released through NASA's Infrared Science Archive (Cutri et al. 2012). Along with the single exposure images and source databases, the NEOWISE project supported the development of tools for solar system-friendly queries of the data. We have used these tools to extract mid-infrared observations of near-Earth objects that make extremely close approaches to the Earth. Using these observations, we have computed physical properties for these objects. An overview of these derived properties as well as other recent results and status from the project will be presented.

201.07 – New Heating Mechanism of Asteroids in Protoplanetary Disks

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Heating of asteroids in the early solar system has been mainly attributed to two mechanisms: the decay of short-lived radionuclides and the unipolar induction mechanism originally proposed in a classic series of papers by Sonett and collaborators. As originally conceived, unipolar induction heating is the result of the dissipation of current inside the body driven by a "motional electric field", which appears in the asteroid's reference frame when it is immersed in a fully-ionized, magnetized T-Tauri solar wind. However we point out a subtle conceptual error in the way that the electric field is calculated. Strictly speaking, the motional electric field used by Sonett et al. is the electric field in the free-streaming plasma far from the asteroid. For realistic assumptions about the plasma density in protoplanetary disks, the interaction between the plasma and asteroid cause the formation of a shear layer, in which the motional electric field decreases and even vanishes at the asteroid surface. We reexamine and improve the induction heating mechanism by: (1) correcting this conceptual error by using non-ideal multifluid MHD to self consistently calculate the velocity, magnetic, and electric fields in and around the shear layer; and (2) considering more realistic environments and scenarios that are consistent with current theories about protoplanetary disks. We present solutions for two highly idealized flows, which demonstrate that the electric field inside the asteroid is actually produced by magnetic field gradients in the shear layer, and can either vanish or be comparable to the fields predicted by Sonett et al. depending on the flow geometry. We term this new mechanism "electrodynamic heating", calculate its possible upper limits, and compare them to heating generated by the decay of short-lived radionuclides.

201.08 – WE'RE GOING TO NEED A BIGGER BOAT- SOFTWARE TO THERMOPHYSICALLY MODEL ASTEROIDS OBSERVED BY NEOWISE

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NEOWISE, the NASA planetary-funded extension of the Wide-field Infrared Survey Explorer (WISE) mission, observed over 150,000 minor planets over four infrared wavelength bands (Mainzer et al. 2011). Many of these observed asteroids have associated shapes and spin states derived by the radar community (see current list maintained by L. Benner at http://echo.jpl.nasa.gov/~lance/shapes/asteroid_shapes.html). Combined, these resources represent a valuable dataset for thermophysical modeling, a technique that combines shape models and infrared observations to determine the thermal inertia of an asteroid, which can indicate composition. However, the large number of objects within this dataset, as well as the detail of the radar shape models (which can be composed of thousands of surface facets), presented a computational challenge. In response, we employ advanced thermal modeling software which allows for full three-dimensional heat conduction, self-heating (via Monte Carlo ray tracing), and surfaces with variable reflective properties. We present thermophysical models using this software, and compare these results to more traditional thermophysical modeling techniques used in the asteroid community.

202 – Venus

202.01 – Submillimeter spectroscopy of Venus's atmosphere with ALMA: CO, HDO and sulfur species

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The study of the composition of the upper mesosphere of Venus is necessary to characterize several atmospheric processes such as photochemistry, condensation and dynamics. At this altitude level (80-110 km), several species have been detected thanks to their (sub)millimeter rotational lines, in particular sulfur species SO_2 and SO, that may be indicative of Venus' volcanic activity, and showed an abundance increase with altitude suggesting a local sulfur-bearing aerosol source[1,2]. H_2O, which takes part in the formation of H_2SO_4 clouds, was also detected as well as its isotope HDO; their analyses revealed significant diurnal and long-term temporal variations [3,4]. To explore this case in greater detail and better assess local, diurnal and temporal variations of minor species, heterodyne spectroscopic observations were obtained in November 2011 during the first Early Science observation cycle of the Atacama Large Millimeter Array (ALMA), the largest (sub)millimeter interferometer, which at the time offered 16 12-m large antennas. These observations allowed us to map the day side of Venus with a spatial resolution down to 1.2-2.4'' (for a disk of 11'), targeting SO_2, SO, HDO and CO transitions around 0.85mm (335-346 GHz). All of these transitions were well detected and their modeling yielded abundances consistent with previous single-dish assessments. We will present a detailed analysis of the data in terms of spatial distribution (horizontal and vertical) and temporal variations, and we will discuss their interpretation with regard to the efficiency of photochemical destruction in the mesosphere and aerosol sources. In addition, by mapping the CO(3-2) line's Doppler-shifts, we have been able to derive the wind field near the upper boundary of the mesosphere, whichs corresponds to a region of dynamic transition between the retrograde zonal wind regime of the troposphere and the subsolar-to-antisolar flow that dominates at higher altitudes. [1] Sandor et al., 2010, Icarus 208, p.49-60 [2] Sandor et al., 2012, Icarus 217, p. 239-244 [3] Gurwell et al., 2007, Icarus 188, p.288-304 [4] Sandor and Clancy, 2005, Icarus 177, p.129-143

202.02 – First Measurements of ClO in the Venus Mesosphere

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The first measurements of ClO in the Venus mesosphere are presented, based upon submm (352.88 GHz) spectroscopic observations in Oct-Dec 2010 (made with JCMT - the James Clerk Maxwell Telescope, Mauna Kea, Hawaii). CO2 is photolyzed to CO+O in the Venus thermosphere. If 3-body recombination were the only mechanism for regenerating CO2, models show the equilibrium Venus atmosphere would have large (10s of percent) abundances of CO and molecular oxygen. Three catalytic recombination mechanisms for stabilizing the atmosphere as CO2 have been proposed (Yung and Demore, 1982). The three suggested mechanisms involve hydrogen chemistry, nitrogen chemistry, and chlorine chemistry, respectively. Our ClO measurement confirms for the first time that chlorine catalysis indeed does play a large role in stabilizing the bulk atmosphere as CO2. This result neither requires nor rules out the possibility that hydrogen and/or nitrogen catalysis may also contribute to CO2 recombination. Altitude distribution, retrieved based upon shape of the pressure- broadened ClO absorption line, indicates there is more ClO in the upper mesosphere (above ~85 km) than at lower altitudes. The possibility that ClO abundance may be time variable will be discussed. [We acknowledge NASA for their funding of this project.]

202.03 – Models for the Centimeter-Wavelength Opacity of Sulfur Dioxide and Carbon Dioxide based on Laboratory Measurements Conducted under Simulated Conditions for the Deep Atmosphere of Venus

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In the past two decades, multiple observations of Venus have been made at X band (3.6 cm) using the Jansky Very Large Array (VLA), and maps have been created of the 3.6 cm emission from Venus. Since the emission morphology is related both to surface

features and to deep atmospheric absorption from CO2 and SO2 (see, e.g., Butler et al., Icarus 154, 2001), knowledge of the microwave absorption properties of sulfur dioxide in a carbon dioxide atmosphere under conditions for the deep atmosphere of Venus is required for proper interpretation. Initial measurements of the centimeter-wavelength (3.7-20 cm) of SO2 and CO2 under simulated conditions for the deep atmosphere of Venus, conducted using a new high-pressure system operating at 430 K and at pressures up to 92 Bars, were presented by Steffes and Barisich (DPS-2012, B.A.A.S., v.44, p.241). Over the past year, we have completed this measurement campaign for temperatures up to 550 K, so as to better understand the effects of SO2 and CO2 on the microwave emission from the Venus boundary layer. Results indicate that the model for the centimeter-wavelength opacity from pure CO2 (developed over 40 years ago – Ho et al., JGR 71, 1966), is valid over the entire centimeter-wavelength range under simulated conditions for the deep atmosphere of Venus. Additionally, the laboratory results indicate that the model for the centimeter-wavelength opacity of SO2 in a CO2 atmosphere from Suleiman et al. (JGR-Planets, 101, Feb. 1996) can reliably be used under conditions of the deep atmosphere of Venus with the modifications described in this paper . This work is supported by the NASA Planetary Atmospheres Program under Grant NNX11AD66G.

202.04 – Spatially-Resolved Measurements of H_2O, HCl, CO, OCS, SO_2, and cloud opacity in the Venus Near-Infrared Windows

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We present new ground-based measurements of the Venus atmosphere below the lower cloud deck (from 0-45 km in altitude) using the Venus nightside spectral windows between 1.0 and 2.5 μm. The Venus nightside spectral windows are sensitive to minor gas abundances, cloud opacity variations, and surface thermal emission. We observed Venus over six nights in late 2010 using the Apache Point Observatory 3.5 m telescope TripleSpec spectrograph (resolution of 3500). Combining our observations with simulated spectra generated with the 1-D line-by-line multiple scattering Spectral Mapping and Atmospheric Radiative Transfer (SMART) model, we produced the first simultaneous spatially-resolved maps of the mixing ratios of H_2O, HCl, CO, OCS, and SO_2 in the Venusian lower atmosphere. To understand how gas mixing ratios correlate with cloud opacity, spatially-resolved maps of the lower cloud deck opacity were generated by measuring the relative peak radiances of the 1.74 μm and 2.3 μm spectral windows, which are sensitive to variations in cloud thickness. H_2SO_4 droplets are the chief constituents of the Venus cloud particles, and water vapor and SO_2 are chemically linked to the production of H_2SO_4. Accordingly, water vapor and SO_2 are measured at lower abundances in regions where cloud opacity is high. There are also possible correlations between CO, OCS, and cloud opacity. To better understand the temperature structure of the near-surface environment, we measured the radiance in the 1.0 μm window, which is 96% surface thermal emission. The brightness temperature at 1.0 μm was measured on Aphrodite Terra, a highland plateau, and nearby on the lowland plains. Aphrodite Terra is 4 km higher than the nearby plains and was found to be approximately 30 K cooler, consistent with a -7.5 K/km adiabatic lapse rate.

202.05 – Experimental Aerobraking with Venus Express

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Venus Express has successfully orbited Venus in its polar 24 hour, 250km by 66000 km, orbit since April 2006 and has provided a wealth of new data from our sister planet. Approaching the end of the mission we are now planning an experimental campaign dedicated to aerobraking at altitudes down to as low as about 130km. These low pericentre passes will provide direct measurements of density, temperature, magnetic field and energetic particles in a region not accessible by other methods. Experience of operations and studies of spacecraft responses will be valuable knowledge for possible future missions that might need this techniques as a part of its nominal operations. Aerobraking was considered in the early design phase of the mission but it was fairly soon realised that the nominal mission would not need this. However, a few important design features were maintained in order to allow for this in case it should be needed at a later stage. The inherently stable geometry of the spacecraft configuration and the inclusion of a software mode for aerobraking are the two most important elements from this early design phase. An recent study by industry has determined the constraints for the spacecraft and identified several potential scenarios. The present highly elliptical orbit has as one of its inherent features a downward drift of the pericentre altitude of between 1 and 4 km/day. However, at certain times, when the Sun is in the orbital plane, this drift disappears for a period of up to two weeks. This is a very well suited time to carry out these initial experiments as it is makes operations safer and it reduces the heat input on the spacecraft as the solar panels will be edge-on towards the sun during the aerobraking. Already a number of low altitude operations have been carried out during the so called atmospheric drag campaigns. The spacecraft has then dipped down to altitudes as low as 165 km and a good characterisation of this region has been performed. This collected information will be helpful for the planning of the aerobraking itself.

202.06 – Oxygen Escape from Venus During High Dynamic Pressure ICMEs

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Previous studies using data from Pioneer Venus suggested that oxygen ion escape flux may be enhanced by orders of magnitude during Interplanetary Coronal Mass Ejections. However, this large enhancement has been ambiguous in Venus Express ion data – with some analyses showing no flux enhancement or a small enhancement (within 2 times undisturbed cases). One possible explanation is that high escape flux may be due to high dynamic pressure in the solar wind, and the dynamic pressure has been lower during the VEX time period. So, we focus on ICMEs with the largest dynamic pressure and with VEX sampling of the escaping ions during the sheath of the ICMEs (during which the highest dynamic pressures in the solar wind occur). We will show the characteristics of these large events measured by VEX, and compare them to the largest ICMEs measured by PVO. We will then discuss estimates of the oxygen ion escape flux during these events.

202.07 – High variability of the Venus mesosphere and lower thermosphere

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The wavelength range probed by SOIR/VEX allows a detailed chemical inventory of the Venus atmosphere. Several trace gases, such as H2O/HDO, HF, HCl, CO, or SO2, are observed together with CO2, leading to the derivation of their vertical density profiles. Temperature and total density profiles are deduced from the CO2 density profiles and VMR are obtained for all trace gases. The measurements all occur at the Venus terminator, morning and evening sides, covering all latitudes from the North Pole to the South Pole. The vertical resolution is between 100 and 500 m in the Northern hemisphere, and is poorer at southern latitudes (between 1 and 2.5 km). The typical vertical extent of the profiles ranges from 70 to 120 km but depends strongly on the targeted species: for CO2, it ranges from 70 to 170 km and for CO, from 70 to 140 km. Aerosols extinctions are also obtained from the SOIR spectra from above the cloud deck up to 90-100 km altitudes. The sounded region encompasses thus the mesosphere and the lower thermosphere of the planet's atmosphere. The Venus atmospheric region probed by SOIR is very special as it acts as a transition region between two distinct dynamic regimes characterized by different flow patterns: the zonal retrograde flow below 70 km and the subsolar to antisolar circulation above 100 km. Some of the trace gases detected play important roles in the chemistry of the atmosphere. The study of CO, mainly produced through the photodissociation of CO2 at high altitudes by solar ultraviolet radiation, can lead to significant information on the dynamics taking place in this region. Results from SOIR observations will be presented and discussed in view of demonstrating the high variability of the Venus atmosphere. This high variability is observed both on molecular species and aerosols, both on temporal and spatial scales. We will report and analyze short and long term time variations. The latitudinal dependency will also be investigated.

202.08 – Venus winds from ultraviolet, visible and near infrared images from the VIRTIS instrument on Venus Express

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After more than 6 years orbiting Venus the Venus Express mission has provided the largest database of observations of Venus atmosphere at different cloud layers with the combination of VMC and VIRTIS instruments. We present measurements of cloud motions in the South hemisphere of Venus analyzing images from the VIRTIS-M visible channel at different wavelengths sensitive to the upper cloud haze at 65-70 km height (dayside ultraviolet images) and the middle cloud deck (dayside visible and near infrared images around 1 μm) about 5-8 km deeper in the atmosphere. We combine VIRTIS images in nearby wavelengths to increase the contrast of atmospheric details and measurements were obtained with a semi-automatic cloud correlation algorithm. Both cloud layers are studied simultaneously to infer similarities and differences in these vertical levels in terms of cloud morphologies and winds. For both levels we present global mean zonal and meridional winds, latitudinal distribution of winds with local time and the wind shear between both altitudes. The upper branch of the Hadley cell circulation is well resolved in UV images with an acceleration of the meridional circulation at mid-latitudes with increasing local time peaking at 14-16h. This organized meridional circulation is almost absent in NIR images. Long-term variability of zonal winds is also found in UV images with increasing winds over time during the VEX mission. This is in agreement with current analysis of VMC images (Kathuntsev et al. 2013). The possible long-term acceleration of zonal winds is also examined for NIR images. References Khatuntsev et al. Icarus 226, 140-158 (2013)

202.09 – Temperature retrieval at the southern pole of the Venusian atmosphere

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Venus' thermal radiation spectrum is punctuated by CO_2 bands of various strengths probing into different atmospheric depths. It is thus possible to invert measured spectra of thermal radiation to infer atmospheric temperature profiles. VIRTIS-M observations of Venus in the 3-5 μm range allow us to study the night time thermal structure of the planet's upper troposphere and lower mesosphere from 50 to 105 km [1, 2]. Building a forward radiative transfer model that solves the radiative transfer equation for the atmosphere on a line-by-line basis, we confirmed that aerosol scattering must be taken into account and we studied the impact of factors such as cloud opacity, and the size, composition and vertical distribution of aerosols [3]. The cloud top altitude and aerosol scale height have a notable impact on the spectrum. However, their weighting function matrices have similar structures contributing to the degeneracy of the temperature retrieval algorithm [2]. Our retrieval code is focused on the strong 4.3μm CO_2 band, which enables the determination of the thermal profile above the cloud top, and based on the algorithm proposed by Grassi et al. (2008) in their equation (2). We present temperature maps for the south pole of Venus, where a highly variable vortex is observed. We aim to combine these maps with our previously measured velocity fields from the same VIRTIS-M infrared images [4], in order to infer the potential vorticity distribution for different vortex configurations and to improve the understanding of its unpredictable character and its role in the general atmospheric circulation. Acknowledgements This work was supported by the Spanish MICIIN projects AYA2009-10701 and AYA2012-36666 with FEDER funds, by Grupos Gobierno Vasco IT-765-13 and by Universidad País Vasco UPV/EHU through program UFI11/55. IGL and AGM gratefully acknowledge ESA/RSSD for hospitality and access to 'The Grid' computing resources. References [1] Roos-Serote, M., et al. Icarus (1995). [2] Grassi, D., et al J Geophys Res-Planet (2008). [3] García Muñoz, A., et al. Planet Space Sci (2013). [4] Garate-Lopez, I., et al. Nat Geosci (2013).

204 – Exoplanets 4: Planet Finding

204.01 – Three New Planetary Systems Orbiting Metal-Poor Thick Disk Stars

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We report the detection of Jovian mass planets orbiting three nearby metal-poor thick disk stars. These discoveries were all made using precise radial velocity measurements from the High Resolution Spectrograph of the Hobby-Eberly Telescope. All of the planets are of Jovian mass or larger, with orbital periods ranging from about a year to over six years. HIP 14342 shows two planetary companions with orbital periods near a 2:1 resonance. The other planets detected orbit HIP 13366 and HIP 109384. All three of these stars are kinematic members of the galactic 'thick disk', which is a population of stars with a larger vertical scale height and a larger velocity dispersion that the thin disk to which the Sun belongs. The thick disk stars are of lower total metallicity than the Sun, and are also chemically different than thin disk stars, having the abundances of their alpha-capture elements (e.g. O, Ne, Mg, Si, S, Ca, Ti) enhanced by 0.2 to 0.4 dex over those of thin disk stars of the same [Fe/H]. The majority of planets found among stars with [Fe/H] < ~-0.2 orbit thick disk stars, even though thin disk stars significantly outnumber thick disk stars in this metallicity range. Thus, the enhanced abundance of the alpha-capture elements, which are also key elements in the chemistry of planet-forming materials, may be responsible for the large fraction of low-metallicity thick-disk stars with planetary companions.

204.02 – Precision Near-Infrared Radial Velocities

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We have built a single gas absorption cell for precision spectroscopic radial velocity measurements in the near-infrared. We will present radial velocity time-series from a 2.3 micron pilot survey with the CSHELL spectrograph at the NASA InfraRed Telescope Facility to detect exoplanets around red, low mass, and young stars. We will present first light data at 1.6 microns from a near-infrared fiber scrambler used in tandem with our gas cell and CSHELL at IRTF. The fiber scrambler makes use of non-circular core fibers to stabilize the illumination of the slit and echelle grating against changes in seeing, focus, guiding and other sources of systematic radial velocity noise, complementing the wavelength calibration of a gas cell.

204.03 – A Survey for Very Short-Period Planets in the Kepler Data

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Most gas giant exoplanets with orbital periods less than or equal to a few days are unstable against tidal decay and may be tidally disrupted before their host stars leave the main sequence. These gas giants may contain rocky and icy solid cores, and tidal disruption of the gas giants could strand these cores near their progenitors' Roche limits (in orbital periods of a few to several hours). Whatever their origins, such short-period objects will evade the Kepler mission's transit search because it is focused on periods > 0.5 days. Motivated by these considerations, we conducted a search for very short-period transiting objects in the publicly available Kepler dataset. Our preliminary survey has revealed about a dozen planetary candidates, with periods ranging from 3.3 to 10 hours. We have analyzed the data for these candidates using photometric models that include transit light curves, as well as ellipsoidal variations and secondary eclipses, to constrain the candidates' radii, masses, and brightness temperatures. Even with masses of only a few Earth masses, the candidates' short periods mean they may induce stellar radial velocity signals (~ 10 m/s) detectable by currently operating facilities. In this presentation, we will describe our survey, constraints from Kepler photometry, and plans for follow-up observations. If confirmed, these planets would be among the shortest-period planets ever discovered, and if common, such planets would be particularly amenable to discovery by the planned TESS mission, which is specifically designed to find short-period rocky planets.

204.04 – Current State of the Statistics of Exoplanet Occurrence Rates

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Large numbers of planetary candidates have become available from Kepler and other surveys of exoplanets. As the number of candidates increase, estimates of their occurrence rates proliferate. The current state of the statistics is reviewed as well as the varying assumptions and corrections that are critical to the reliability of these estimates.

204.05 – An Analysis and Implications of Kepler's Photometric Uncertainties

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The photometric uncertainties of the Kepler targets carry important information on the intrinsic limitation of the Kepler survey regarding small planets in long-period orbits, precisely the corner of the period-radius diagram where the key information is located on the frequency of terrestrial, habitable-zone planets. An analysis of these uncertainties shows that they can be relatively well approximated by an analytical function, but that there are numerous outliers, both real and artificial. The application to estimating eta-sub-Earth will be shown.

204.06 – Likely Planet Candidates Identified by Machine Learning Applied to Four Years of Kepler Data

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Contributing teams: Kepler SOC, Kepler SO

Over 3,200 transiting planet candidates, 134 confirmed planets, and ~2,400 eclipsing binaries have been identified by the Kepler Science pipeline since launch in March 2009. Compiling the list of candidates is an intensive manual effort as over 18,000 transit-like signatures are identified for a run across 34 months. The vast majority are caused by artifacts that mimic transits. While the pipeline provides diagnostics that can reduce the initial list down to ~5,000 light curves, this effort can overlook valid planetary candidates. The large number of diagnostics (~100) makes it difficult to examine all the information available in identifying planetary candidates. The effort required for vetting all threshold-crossing events (TCEs) takes several months by many individuals associated with the Kepler Threshold Crossing Event Review Team (TCERT). We have developed a random-forest classifier that decides whether a TCE should be called ` planet candidate', ` astrophysical false positive', or ` non-transiting phenomena'. Ideally a machine learning algorithm will generate a list of candidates that approximates those generated by human review, thereby allowing the humans to focus on the most interesting cases. By using a machine learning-based auto-vetting process, we have the opportunity to identify the most important metrics and diagnostics for separating signatures of transiting planets and eclipsing binaries from instrument-induced features, thereby improving the efficiency of the manual effort. We report the results of a applying a random forest classifier to four years of Kepler data. We present characteristics of the likely planet candidates identified by the auto-vetter as well as those objects classified as astrophysical false positives (eclipsing binaries and background eclipsing binaries). We examine the auto-vetter's performance through receiver operating characteristic curves for each of three classes: planet candidate, astrophysical false positive, and artifact. Funding for this mission is provided by NASA's Science Mission Directorate.

204.07 – Increasing the sensitivity of the Kepler legacy archive to transiting planets

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All legacy light curves archived by the Kepler project are available to the community. They are based upon simple aperture extractions from time-tagged pixel data. We demonstrate that this photometry method works well for the bright end of the Kepler target sample yet there is enormous scope for further gains in sensitivity to planet transits of faint stars in the sample. To this end, all pixel data have been made available in the archive. Methods for the user community to optimize aperture photometry and exploit point spread function modeling are being developed. Exploiting existing Kepler planet candidates, we showcase the signal-to-noise to be gained by these methods. We argue that at the faintest end of the candidate distribution, optimization provides a factor two improvement in sensitivity to transits.These methods can provide potentially significant improvement to a number of facets of the Kepler mission: 1. Sensitivity to new planet candidates residing currently below the signal-to-noise detection threshold; 2. Characterizing known transit profiles to higher precision; 3. Identifying contamination from nearby sources and removing contamination bias from transit depths; 4. Mitigating focus and pointing systematics within the Kepler data, and 5. Allowing the direct characterization of time-dependent physical and detector biases within the image background. These methods are equally applicable to data from the upcoming TESS mission.

205 – Asteroids 4: Composition

205.01 – A Comprehensive Study of Chelyabinsk Meteorite: Physical, Mineralogical, Spectral Properties and Solar System Orbit

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On February 15, 2013, at 9:22 am, an exceptionally bright and long duration fireball was observed by many eyewitnesses in the Chelyabinsk region, Russia. A strong shock wave associated with the fireball caused significant damage such as destroyed windows and parts of buildings in Chelyabinsk and the surrounding territories. A number of video records of the event are available and have been used to reconstruct atmospheric trajectory, velocity, deceleration rate, and parent asteroid Apollo-type orbit in the Solar System. Two types of meteorite material are present among recovered fragments of the Chelyabinsk meteorite. These are described as the light-colored and dark-colored lithology. Both types are of LL5 composition with the dark-colored one being an impact-melt shocked to a higher level. Based on the magnetic susceptibility measurements, the Chelyabinsk meteorite is richer in metallic iron as compared to other LL chondrites. The measured bulk and grain densities and the porosity closely resemble other LL chondrites. Shock darkening does not have a significant effect on the material physical properties, but causes a decrease of reflectance and decrease in silicate absorption bands in the reflectance spectra. This is similar to the space weathering effects observed on asteroids. However, no spectral slope change similar to space weathering is observed as a result of shock-darkening. Thus, it is possible that some dark asteroids with invisible silicate absorption bands may be composed of relatively fresh shock darkened chondritic material.

205.02 – Composition of Chelyabinsk Meteorite: Identifying its Parent Body in the Main Belt

Vishnu Reddy[1], Ed Cloutis[2], Matthew Cuddy[2], William Bottke[3], Juan Sanchez[4], Paul Mann[2], Matthew Izawa[2], Gary Fujihara[5], Michael Gaffey[6], Lucille Le Corre[1]
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On February 15, 2013 a colossal fireball was observed over the Chelyabisnk region of Russia, which caused widespread damage across the region (Brown 2013). Subsequently, thousands of stones rained on villages south of Chelyabinsk. Here we report near-IR spectra properties of the Chelyabinsk meteorite samples in an effort to identify its parent body in the main belt. Chelyabinsk is an LL5 ordinary chondrite with olivine and pyroxene as major mineral phases. Our samples also included a dark-colored fine grain impact melt component, which is a significant portion (1/3rd) of the meteorite apart from light-colored lithology typical of ordinary chondrites (2/3rd) (Vernad, 2013). Laboratory measurements suggest an olivine composition of Fa28 (mol. %) and pyroxene composition of Fs23 (mol. %). Spectrally derived olivine and pyroxene composition using equations from Dunn et al.

(2010) are Fa25+/-1.3 and Fs21+/-1.4, respectively. While spectrally derived values are lower than those directly measured from the samples (possibly due to compositional heterogeneity), they are consistent with LL chondrites, which have an olivine and pyroxene composition of Fa26-31 and Fs22-26. The impact melt component is spectrally distinct from the light-color lithology with lower albedo (~9% vs. 32% at 0.55 microns), weaker absorption band I depth (4% vs. 30%) and steeper spectral slope. Works of Vernazza et al. (2008) and Dunn et al. (2013) have shown that a majority of the NEAs (~60%) have an LL chondrite type composition. Dynamical modeling (Bottke et al. 2002) has shown that these LL chondrite NEAs are preferentially derived (83 percent) from the nu6 resonance (Dunn et al. 2013). The Flora family, which lies near the nu6 resonance, is dominated by S-type asteroids and has been hypothesized as the primary source region for LL chondrite meteorites and NEAs. Our spectrally derived olivine and pyroxene composition for Flora (Fa29+/-1.3 and Fs24+/-1.4) is consistent with Chelyabinsk (Fa28 and Fs23). Based on the spectral and mineralogical similarities, and supported by previous dynamical studies, we hypothesize that the parent body of the Chelyabinsk meteorite was a member of the Flora family.

205.03 – On the metal-rich surfaces of (16) Psyche and other M-type asteroids from interferometric observations in the thermal infrared.

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Asteroids belonging to the spectroscopic M-type exhibit a quasi featureless and moderately red reflectance spectrum and a geometric visible albedo between 0.1 and 0.3. These asteroids were initially thought to be metallic cores of differentiated asteroids that were exposed to space by a catastrophic disruption by impacts. Later, this view has been challenged by the detection of silicates and hydration spectroscopic bands on these bodies. Unveiling the physical properties of the surfaces of these asteroids, and identifying their meteorite analogs is a challenge from remote-sensing observations. Nevertheless, these are crucial problems, important for estimating the number of asteroids that underwent differentiation in the early phases of the formation of our solar system. The thermal inertia is a sensitive indicator for the presence of metal in the regolith on the surfaces of asteroids. We developed a new thermophysical model that allow us to derive the value of the thermal inertia from interferometric observations in the thermal infrared. We report on our investigation of the thermal inertia of M-type asteroids, including the asteroids (16) Psyche, for which we obtained a thermal inertia value anomalously high compared to the thermal inertia values of other asteroids in the same size range. From the thermal inertia and model of heat conductivity that accounts for different values of the packing fraction (a measure of the degree of compaction of the regolith particles) the regolith grain size is derived.

205.04 – Reflectance Properties and Age of the Baptistina Family

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The Baptistina asteroid family resides in the same portion of orbital element space as the larger Flora family, and complete membership lists for both families cannot be obtained via common clustering methods due to cross-contamination and nonuniform phase space density. Here we use restrictive cuts in orbital element space to select out enhanced samples from both families to determine their color and albedo characteristics. We find the Baptistina family to have an average SDSS (a^*, i-z) color of (-0.028 ± 0.006, -0.005 ± 0.015) and an average WISE visual albedo of 0.171 ± 0.006, distinguishing it as the only inner main belt family occupying this region of color-albedo parameter space. Having established the distinct reflectance properties, we next use cuts on color and albedo to select out a Baptistina-enhanced sample for further dynamical study. We determine the age of the family via two standard independent methods: 1) observations of the size-dependent drift in semimajor axis due to the combined influences of the Yarkovsky and YORP effects, and 2) observations of the spread in proper eccentricity and inclination due to chaotic diffusion. For method 1, we calibrate the Yarkovsky drift by scaling from clusters with similar physical parameters for which we have obtained independent measurement of the Yarkovsky drift rates, as an alternative to estimation of all of the physical parameters that affect the drift rates. We further estimate the magnitude of the influence on the drift rates due to obliquity changes caused by both "variable YORP" (Bottke et al., this meeting) and spin-orbit resonances in the Flora and Baptistina region (Rubincam et al. 2002, JGR 107; Vokrouhlicky et al. 2006, Icarus 184), which can affect estimates of the family's age by up to a factor of two. For the Baptistina family, this work extracts reflectance properties, orbital distribution and age from the complex mix of families in this region of the main belt. This work was supported by an NSF GRF (MJD) and a Michigan Space Grant Consortium undergraduate fellowship (SJV).

205.05 – A Map Of The Asteroid Belt By Taxonomic Class, Mass, Distance, And Size

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The distribution of asteroids across the Main Belt has been studied for decades to understand the current compositional distribution and what that tells us about the formation and evolution of our solar system. In this work, we reexamine the architecture of the asteroid belt by determining the bias-corrected distribution of 99.99% of its mass based on compositional information provided by ground-based and space-based measurements. The main belt's most massive classes are C, B, P, V and S in decreasing order. Excluding the four most massive asteroids, (1) Ceres, (2) Pallas, (4) Vesta and (10) Hygiea that heavily skew the values, primitive material (C-, P-types) account for more than half main-belt and Trojan asteroids by mass, most of the remaining mass being in the S-types. All the other classes are minor contributors to the material between Mars and Jupiter. Additionally, we present the taxonomic distribution of asteroids as a function of size. The relative mass contribution of each class changes as a function of size in each region of the Main Belt. We report an updated view of the distribution of asteroid compositions according to distance and size.

205.06 – Building Blocks of the Terrestrial Planets: Mineralogy of Hungaria Asteroids

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Deciphering the mineralogy of the Hungaria asteroids has the potential to place constraints on the material from which the terrestrial planets accreted. Among asteroids with semi-major axes interior to the main-belt (e.g., Hungarias, Mars-crossers, and near-Earth asteroids), only the Hungarias are located in relatively stable orbital space. Hungaria asteroids have likely resided in this orbital space since the planets completed their migration to their current orbits. The accretion and igneous differentiation of primitive asteroids appears to be a function of chronology and heliocentric distance. However, differentiated bodies that originated in the terrestrial planet region were either accreted or scattered out of this region early in solar system history. Thus, the Hungaria asteroids represent the closest reservoir of in situ material to the terrestrial planet region from early in solar system history. We present VISNIR (~0.45-2.45 μm) and NIR spectra (~0.65-2.45 μm) spectra of 24 Hungaria group (objects in similar orbital space) asteroids. Our NIR data (17 objects) were acquired using the InfraRed Telescope Facility and was supplemented with available visible data. Spectra of seven objects were obtained from the MIT-UH-IRTF survey. We distinguish our sample between Hungaria family (presumed fragments of parent 434 Hungaria; 2 objects) and Hungaria background (group minus family; 22 objects) asteroids using proper orbital elements. The classification of each asteroid is determined using the taxonomy of Bus-DeMeo.
We find that S- and S-subtypes are prevalent among the Hungaria background population (17/22). Spectral band parameters measurements (i.e., Band I and Band II centers and depths, and Band Area Ratio) indicate that eight of these S-types are analogous with undifferentiated ordinary chondrites (SIV "boot" of S-subtypes plot). Mafic silicate mineral abundances and compositions derived for these SIV asteroids mainly correlate with L chondrites. However, one object is an SIII subtype (possible ureilite analog), while two asteroids are SVI subtypes (possible primitive achondrite analog). Family member 6447 Terrycole is a Xe-type, consistent with the taxonomic classification of the parent 434 Hungaria.

205.07 – Near-Infrared Spectroscopy of Warm Spitzer-observed Near-Earth Objects

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We have completed a spectroscopic observing campaign to complement the ExploreNEOs Warm Spitzer program. ExploreNEOs or "The Warm Spitzer NEO Survey: Exploring the history of the inner Solar System and near-Earth space" was allocated 500 hours over two years (2009-2011) to determine diameters and albedos for approximately 600 near-Earth objects using the 3.6 and 4.5 micron IRAC bands. We present the results of the SpeX component of our campaign. In order to increase our sample size we also include all near-infrared observations of ExploreNEOs targets in the MIT-UH-IRTF Joint Campaign for Spectral Reconnaissance. Our complete dataset includes 125 observations of 92 objects from our survey and 213 observations of 154 objects from the MIT survey. The combination of the two surveys includes near-infrared spectroscopy of 187 ExploreNEOs targets. We find no correlation between spectral band parameters and ExploreNEOs albedos and diameters. We identified all potential ordinary chondrites within our sample and determined likely ordinary chondrite types using the equations derived by Dunn et al. 2010. Our resulting proportions of H, L, and LL ordinary chondrites are different than those previously calculated for ordinary chondrite-like near-Earth objects and meteorite falls.

205.08 – Combining visible-to-near-infrared spectra and WISE data of Hildas and Jupiter Trojans: preliminary results.

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The Hilda asteroid group and Jupiter Trojans (JTs) are populations of primitive minor bodies whose origins have not been conclusively determined. In the framework of the so-called Nice Model, they are icy bodies scattered from the Kuiper Belt in an early epoch of the Solar System (the Late Heavy Bombardment) and finally trapped in the stable regions in which they are located today, in 3:2 and 1:1 resonances with Jupiter. Comparing detailed compositional and physical studies of these populations can thus help constrain dynamical models and provide clues about several key aspects of planetary science. However, because their visible and near-infrared spectra are featureless, the diagnostic spectral information available is scarce and has been obtained in different wavelength ranges, e.g., 10-micron emission plateaus characteristic of fine-grained silicates detected on JTs [Emery et al. 2006. Icarus 182, 496E], or the 3-micron features detected on four Hildas: three of them associated with water ice, one related to hydrated silicates [Takir & Emery 2012. Icarus, 219 641T]. Studying the 3-micron region from ground-based facilities is complicated, particularly for these distant populations, and no such bands have been detected on JTs within the achieved signal-to-noise ratios. But if these objects share a common origin and similar evolution, they should show similar properties. Now, the space-based Wide-field Infrared Survey Explorer (WISE) has provided infrared data of hundreds of JTs and Hildas [Grav et al. 2012. ApJ 744, 197G, Grav et al. 2012. ApJ, 759 49G]. To take advantage of WISE 3.4-micron (W1) broad-band data, Ali-Lagoa et al. [2013. A&A 554A, 71A] combined them with complementary spectral data from the literature and showed that they can be used to detect the presence of the water-related 3-micron absorption features in a sufficiently numerous group of objects. We present the results of applying the same method to Hildas and JTs.

205.09 – Statistical study of aqueous alteration on primitive asteroids

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The study of aqueous alteration is particularly important for unraveling the thermal and chemical conditions existing during the earliest times in Solar System history. The process consists in the low temperature (< 320 K) chemical alteration of materials by liquid water which acts as a solvent and produces hydrated materials. Hydrated minerals have been detected on main belt C, G, P, B and F-types asteroids as defined by Tholen taxonomy. Studying visible spectra of primitive bodies, one can detect signatures of phyllosilicates like the Fe^{2+}-Fe^{3+} transition band centered around 0.7 microns. We have investigated 600 spectra of these primitive bodies available in the literature (Vilas observations 1982-1992, Sawyer PhD thesis 1991, Xu et al. 1995, Fornasier et al. 1999, Bus & Binzel 2002 and Lazzaro et al. 2004) and from our own observations, and we have characterized the 0.7 microns band when present. We have examined all the possible relationships between the aqueous alteration process and asteroid taxonomic classes, orbital elements, heliocentric distances, albedo and sizes of these objects. We find that the percentage of hydrated asteroids is 5% for the P, 8% for the F, 10% for the B, 51% for the C, and 100% for the G-type asteroids. The process seems to be mostly active on primitive asteroids located between 2.3 and 3.2 AU. The number of hydrated asteroids increases with the size and dominates for bodies larger than 100km. We also compare the properties of the 0.7 microns absorption band seen on asteroids with the one seen on CM carbonaceous chondrites spectra (from RELAB data): aqueous altered asteroids are the plausible parent bodies of CM2 meteorites, but we see a systematic difference in the band center position.

205.10 – Composition and Degree of Alteration of Dark Asteroids

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Spectral classification schemes of asteroids are typically based on visible and near-infrared measurements made from both Earth- and space-based observatories. Some asteroids have spectral features that readily indicate their composition and can be used to relate them to laboratory spectral measurements of meteorites. However, asteroids with characteristically low visible light albedos (e.g. C- and B- types) have few features, if any, in this wavelength region. The absence of strong spectral features makes the determination of surface composition and the connection to meteorite groups difficult. In CM/CI group meteorites, a strong mid-infrared feature at 10-12 μm (1000-800 cm-1) has been found to correlate with composition and degree of alteration (McAdam et al., LPSC, 2013). A similar feature, but weaker in strength, has also been found in the spectra of some dark asteroids. Seven asteroids from the Themis family and Cybele group (C-types) have spectral features that are consistent with iron-rich clays indicating a low degree of alteration. Three Trojan asteroids (D-types) studied do not exhibit this feature, which may suggest a different origin for these bodies. We present the preliminary results from a survey of dark asteroids using archived data from mid-infrared space telescopes. The 10-12-μm (1000-800 cm-1) feature is used to characterize the surface composition of dark asteroids in the context of the alteration trends seen in meteorites.

205.11 – The Ch asteroids: Connecting a Visible Taxonomic Class to a 3-μm spectral shape

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The Ch-class asteroids in the Bus and Bus-DeMeo classifications are characterized by an absorption near 0.7-μm, first described in a series of papers by Vilas and her co-workers, and associated with phyllosilicates. We have known for some time that the presence of this band is correlated with the presence of the 3-μm absorption band diagnostic for OH/H2O in asteroids and meteorites (Howell, Vilas et al.). In the meteorite collection, the 0.7-μm band seems to be limited to a particular subset of carbonaceous chondrites, the CM group (Cloutis et al.). The difference in 3-μm band shape between Ceres and Pallas has been recognized since the 1980s from work by Lebofsky, Feierberg et al.. Several surveys in this spectral region have established that on the order of 3-4 different spectral shapes exist in the asteroid population (Takir et al., Rivkin et al.). One group, the largest member of which is Pallas, has spectral shapes similar to what is seen in the carbonaceous chondrite meteorites. At this writing, the L-band Mainbelt/NEO Observing Program (LMNOP) has obtained spectra for 25 asteroids classified as Ch by the SMASS surveys. Of the 20 objects that can be unambiguously assigned a 3-μm spectral type, all 20 have a Pallas-type spectral shape. An additional 6 objects in the LMNOP without SMASS classifications are classified as Ch by the S3OS2 survey. Only one of these 6 objects is not obviously Pallas-like, 791 Ani, and inspection of the S3OS2 spectrum leads to doubt that it is actually a Ch-class object. The assignment of at least 80% and perhaps 100% of Ch-class asteroids to the Pallas 3-μm type (depending on how ambiguous objects are treated) serves as evidence for a specific tie between the visible-region and infrared spectral regions, and that the 0.7-μm band can be used not only

as a proxy for the presence of a 3-μm band but for a specific band shape and mineralogy. We will present our spectral results and analysis.

205.12 – Surface composition of low delta-V near-Earth asteroids, a survey of future targets for space missions

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Near-Earth asteroids (NEAs) are attracting nowadays more and more attention from the scientific community, because of their constant threat to human civilization, their increasing feasibility for future space missions and the opportunity to investigate pristine material. The classical 'accessibility' of a celestial body can be defined in terms of the velocity change (delta-V) applied to an already free-flying spacecraft needed to realize a rendez-vous mission. It is possible to show that NEAs can be more accessible than the Moon or as difficult to reach as Jupiter and beyond (Perozzi et al. 2010). Due to their low delta-V and short mission duration, these objects could be therefore suitable targets for space missions. Unfortunately only 10% of discovered NEAs have been physically characterized. So, in order to guarantee both technical feasibility and high scientific return, we perform spectroscopic observations of 13 low delta-V NEAs. The taxonomic classification of the observed NEAs has been obtained by performing a best fit between our data and the mean spectra of each spectral class proposed by Bus & DeMeo (DeMeo et al. 2009). We also compared our observational data with laboratory spectra, searching for a possible meteorite analogue. Finally we investigate mineralogy by sampling the prominent bands in the NIR, typical of pyroxene and olivine assemblages.

206 – Rings

206.01 – The Neptune System Revisited: New Results on Moons and Rings from the Hubble Space Telescope

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We report on observations of Neptune's rings, arcs and inner moons as obtained by the Hubble Space Telescope during 2004-2009. These are the only Earth-based observations of the ring system obtained at visual wavelengths, permitting direct photometric comparison with the Voyager images. This allows us to determine quantitatively how the arcs have evolved from the time they were first imaged. Of the four arcs identified in 1989, the leading two have vanished, but the trailing two appear to have remained quite stable. New analysis of the images has also revealed a small moon, S/2004 N 1, orbiting between Proteus and Larissa. The body has a mean motion of 378.907 +/- 0.001 degrees per day, corresponding to semimajor axis 105,283 km. Its V magnitude is 26.5 +/- 0.3, suggesting a radius of ~ 10 km if its albedo is ~ 10%, comparable to that of the other inner moons. Tentative detections of Naiad, the smallest moon discovered by Voyager, will also be discussed.

206.02 – Enceladus' Influence on the Vertical Structure of Saturn's E Ring

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Within ~+/- 20,000 km of Enceladus' orbit, Saturn's tenuous E ring has a double-banded appearance, with the number of particles depleted by a few percent within +/- 1000 km of the planet's equatorial plane (Hedman et al. 2012). We wish to understand this vertical structure, to learn if it might indicate launch speeds or a sweeping effect of Enceladus. We have combined order-of-magnitude analytical estimates and numerical simulations that include Enceladus and Saturn's gravity up to J6 in short-term (1-2 days) and longer-term (~ 200-yr) integrations. Because most particles emanating from the surface geysers will fall back on the moon, the E ring must be dominated by particles that barely escaped. Hence we follow the orbits of many hundreds of particles launched near Enceladus' southern pole with speeds between ~ 0.8 to 2 times the nominal escape speed (i.e., that from an isolated sphere). We illustrate some contorted trajectories within the three-body problem for such launch conditions. Typically, gravitational deceleration after launch followed by a few gravitational kicks from the moon induce many particles to attain orbital inclinations corresponding to a maximum height of ~4rE (rE = radius of Enceladus = 250 km), or about one Hill radius for Enceladus. The vertical epicyclic motions of such inclined orbits account the observed two-banded structure. Simultaneous gravitational interactions will scatter particles to produce a two-banded, radially extended (+/-10,000km) Gaussian core on either side of Enceladus, as observed. In our simple model, particles are lost by collisions into Enceladus in ~ 100 yrs; mutual impacts are ignored. Since gravity alone can generate in short order the most prominent features in the observed structures, non-gravitational forces (cf. Kempf et al. 2010) mostly affect other aspects of the E ring structure and evolution.

206.03 – Saturn's ring temperatures at equinox

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Modeling the thermal emission of Saturn's rings is challenging due to the numerous heating sources as well as the structural properties of the disk and of the particles that are closely related. At equinox, however, the main rings are externally heated by Saturn alone and the problem is somewhat simplified. We test the abilities of our current models to reproduce the temperatures observed with the Cassini CIRS instrument around equinox in August 2009. A simple semi-analytic model which includes mutual shadowing effects can mostly explain the radial profile of the equinox ring temperatures, except the model predicts lower temperatures than those observed for the A ring. The temperature variation at a given saturnocentric radius is primarily caused by observational geometry variations relative to Saturn. The observed temperature increases with decreasing Saturn-ring-observer angle. In addition, we found evidence that the leading hemispheres of particles are warmer than the trailing hemispheres at least for the C ring and probably for the A and B rings as well. This is explained if some fraction of particles has spin rates lower than the synchronous rotation rate as predicted by N-body simulations. The spin model for a monolayer ring (Ferrari, C., Leyrat, C., 2006, Astron. Astrophys. 447, 745–760) can fit the temperature variations with spacecraft longitude observed in the C ring with currently known thermal properties and a mixing of slow and fast rotators. The multilayer model (Morishima, R., Salo, H., Ohtsuki, K., 2009, Icarus 201, 634–654) can reproduce the temperatures of the B and C rings but gives A ring temperatures that are significantly lower than those observed as does the simple semi-analytic model. More advanced models which take into account self-gravity wakes may explain the A ring temperature behavior.

206.04 – Spectral properties and temperature radial profiles of Saturn's main rings by Cassini-VIMS: variability with solar phase and elevation

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We report about Saturn's rings average spectral properties and temperature as retrieved from ten Cassini VIMS radial mosaics acquired between october 2004 and january 2010. The dataset includes observations taken with solar phase running between 12° to 136° and elevation angle between -21° to +5°. These observations, after being reduced in spectrograms, e.g. 2D arrays containing the VIS-IR spectral (0.35-5.0 μm) and spatial (from 73.500 to 141.375 km) information, allow us a direct comparison of the derived spectral properties on a common spatial scale. Significant changes in VIS reddening, water ice abundance and grain sizes are observed across different rings radial regions. When observed at high solar phases, a remarkable increase of VIS reddening and water ice band depths is found, as a consequence of the presence of a red contaminant intimately mixed within water ice grains. Ring's particles temperature is retrieved by using the wavelength of the 3.6 μm continuum peak on reflectance spectra as a marker. For pure water ice the position of the peak, as measured in laboratory, shifts towards shorter wavelengths when temperature decreases, from about 3.65 μm at 123 K to about 3.55 μm at 88 K. When applied to VIMS rings observations,

this method allow us to infer the average temperature across ring regions sampled with 400 km-wide radial bins. VIMS temperature radial profiles are compared with similar CIRS measurements acquired at the same time. We have found a substantial agreement between VIMS and CIRS results for the A and B ring while VIMS measures higher temperatures than CIRS across C ring and CD as a consequence of the lower optical depth and deviation from pure water ice composition. In summary, VIMS results show that 1) across C ring and CD the 3.6 μm peak wavelength is always higher than across B and A rings: C and CD are warmer than A and B rings; 2) when the solar elevation angle decreases to 0° (equinox) the peak's position shifts at shorter wavelengths: rings become colder; 3) when both afternoon and morning ansae observations are available, we have measured higher temperature across the afternoon ansa

206.05 – Observing Saturn's Rings in the Microwave with Cassini

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We will present calibrated, high (~2.0×10³ km)- and low (~8.0×10³ km)-resolution maps of Saturn's rings at 2.2-cm wavelength acquired by the Cassini radar radiometer. Microwave emission is the ideal waveband for studying the scattering properties of cm-scale ring particles and for constraining the thermal emission from (possibly buried) rocky ring contaminants, which, unlike water ice, behave like blackbodies at cm- wavelengths. While occultation observations are necessarily restricted to near-forward scattered light, scattered emission from Saturnshine (an extended source) can be viewed at a wide range of geometries. In order to successfully remove energy contributed by the radar's extensive side-lobes, we use an iterative self-calibration process. The current calibration reaches an RMS residual of 0.18 K (about 2% ring brightness temperature). The observed microwave brightness temperature of Saturn's rings is dominated by scattered Saturnshine and intrinsic thermal emission from the ring disk. We will present a single scattering model for the low optical depth C ring that treats intrinsic ring particle emission as an isothermal dielectric slab. Our results predict that the non-icy component of the C ring, assuming that contaminants emit with the dielectric properties of silicate rock, reach a maximum of ~6% at the center of C ring and decreases toward its edges. These implications of these results for the origin and evolution the Saturn's rings will be discussed.

206.06 – Saturn Ring Seismology: Interpreting the Seismogram

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Marley (1990) and Marley and Porco (1993) proposed that f-mode oscillations of Saturn could excite resonant density and bending waves in the inner C-ring. They hypothesized that certain wave features discovered by Rosen et al. (1991) that were not associated with known satellite resonances could be the result of such resonant interactions with the planetary oscillation modes. They also predicted that if this was the case the waves would be found to be density (and not bending) waves by Cassini and predicted the azimuthal wave number of the C-ring waves m. Employing Cassini VIMS stellar occultation data Hedman and Nicholson (2013) have now confirmed the predictions and demonstrated that at least some of the C-ring features identified by Rosen et al. are indeed likely caused by resonant oscillation modes of Saturn. Given this context we have taken a fresh look at the Saturn ring seismology. First we propose that an apparent bending wave denoted 'j' by Rosen may be a second order outer vertical resonance with the l=3, m=2 f-mode of Saturn and discuss the locations of other plausible second order resonances in the rings. Since only a handful of ring resonances have been identified, measuring even one or two additional planetary mode frequencies would substantially assist the process of inverting mode frequencies to constrain Saturn interior's structure. Using the available mode frequencies, modern inversion technique employed in stellar seismology, and a recent set of Saturn interior models we provide an initial estimation of what available mode frequencies are telling us about the interior structure of the planet. Since the f-modes are confined relatively closely to the planetary surface, most of the observed modes probe only the outermost layers of the planet that are already comparatively well understood. However the l = 2 mode does probe relatively deeply into the planet and we will discuss the potential the measurement of this mode frequency has for placing new constraints on the interior structure.

206.07 – Normal Modes in Saturn's Rings

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Careful study of the edges of many of the gaps and narrow ringlets in Saturn's rings has revealed not only eccentric and resonantly-perturbed features (Spitale & Porco 2009, 2010; French etal. 2011; Nicholson etal. 2011), but a wide variety of what appear to be spontaneously-generated radial distortions with a range of azimuthal wavenumbers, m, and corresponding pattern speeds or angular rotation rates. Using data from over 150 stellar and radio occultation observations by the Cassini spacecraft, we have searched for normalmodes with values of $|m|$ up to 9 on most of the known gap and ringlet edges in the C Ring and Cassini Division, and determined their amplitudes and pattern speeds. Radial amplitudes range from as little as 100 m to a maximum of 3.8 km, while the number of different modes on a single edge varies from 0 to 6. Although their numbers and amplitudes appear to be unpredictable, a consistent overall pattern emerges from our results which supports the idea that the modes represent standing density waves trapped in a form of 'resonant cavity' near sharp edges. Modes with positive values of m have pattern speeds which match those at inner Lindblad resonances, and appear exclusively on the outer edges of ringlets or the inner edges of gaps. Modes with negative values of m have pattern speeds which match those at outer Lindblad resonances, and appear exclusively on the inner edges of ringlets or the outer edges of gaps. In each case, the pattern speed is such that the 'resonant radius' of the mode falls within the ring material, rather than in the adjacent gap. In the caseof extremely narrow ringlets, such as the uranian γ and Δ rings, the same mode may manifest itself on both edges, as observed by French etal. (1988).

206.08 – Mapping radial features in Saturn's rings

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We have carried out a comprehensive survey of the best Cassini ISS data of Saturn's main rings for the purpose of cataloguing all observed spiral density waves, spiral bending waves, and other radial and quasi-radial ring structure. Our survey has revealed a number of new features, including the first known resonant waves raised by Enceladus and Hyperion, thus increasing the number of points at which the local surface density and viscosity of the rings can be measured (cf. Tiscareno et al. 2007, Icarus). We also catalogue several wave-like features whose cause is unknown. Although images of the rings taken by the Imaging Science Subsystem (ISS) are not nominally as high-resolution as the best stellar and radio occultations, they are capable of superior signal-to-noise because of the co-adding inherent in converting a 2-D image into a 1-D 'radial scan.' In this common technique, as many as a thousand pixels at a given radial distance from Saturn are combined to produce a single characteristic brightness for each radial location. This process suppresses local structure, azimuthal structure, and random noise, all of which commonly decrease the sensitivity of high-resolution occultations, and causes ISS to be the optimal Cassini instrument for detecting a certain class of low-amplitude features. Finally, we employ wavelet techniques (cf. Tiscareno et al. 2007, Icarus) to elucidate subtle periodic and quasi-periodic features in the radial scan data. We will present our results in the context of a ranking of known perturbations in the rings by their resonant torque (updating Lissauer and Cuzzi 1982, AJ). We will identify the strongest expected perturbations that do not appear, and discuss whether the absence is likely to reflect a real limit of ring responsiveness, or (as with previous observations) to reflect sensitivity limits.

206.09 – Analysis of Clumps in Saturn's F Ring from Voyager and Cassini Observations

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Saturn's F ring is well known for its unique and dynamic features that change on timescales from hours to months. Among these features are clumps, localized bright areas spanning ~3-30 degrees in longitude. 34 clumps tracked in Voyager images (Showalter 2004, Icarus, 171, 356-371) were found to live for several months and have a ~100 km spread in semi-major axis around the F ring core. Several clumps appeared to 'split' during their lifetimes. Unfortunately, the poor resolution of the Voyager images and limited temporal and longitudinal coverage prevented a more detailed analysis. In this study, we performed a similar analysis using six years' worth of images from the Cassini Orbiter. We tracked 96 clumps and found similar angular widths, lifetimes, and semi-major axes to those observed by Voyager. However, the number of clumps present at one time appears to have decreased and the clumps are generally less bright; there are also many fewer extremely bright clumps. The better quality images allowed us to investigate five 'splitting' clumps and we found that the apparent splits were often caused by the passage of the inner shepherd moon Prometheus. We further found that the birth and death of clumps appears uncorrelated with the position of Prometheus or with other features such as 'mini-jets' or 'jets' often found in the ring. We speculate on the changes in the population of embedded moonlets that may have resulted in these changes.

206.10 – Cassini Imaging of Saturn's Huygens Ringlet

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We present the results of an examination of Saturn's Huygens ringlet, 250 km exterior to the B-ring, based on ISS observations spanning an eight-year interval from 2005 – 2013. The Huygens ringlet is a narrow eccentric ringlet in the classical shape of a ~28-km amplitude Keplerian ellipse with the apses of the inner and outer edges nearly locked. However, unlike most narrow eccentric ringlets, the Huygens ringlet has a nearly uniform width at all longitudes, which is inconsistent with the classical theory for gravitating ringlets, so new ringlet physics is implicated. The Keplerian shape is perturbed by higher-order structure with amplitudes in the 1–2-km range. The outer edge shows two superimposed m=2 patterns, one moving at Mimas's rate, implying that it is forced by the nearby 2:1 Lindblad resonance, and the other moving at a rate consistent with a free normal mode. The forced and free m=2 modes on the outer edge have amplitudes of about 1 and 2.3 km respectively. The inner edge shows a single m=2 pattern forced by the Mimas resonance, with an amplitude of about 2 km. Patterns with higher wavenumbers appear in individual data sets and do not appear to be long-lasting. Additional stochastic structure is prevalent in the ringlet and cannot be modeled using a simple superposition of low-wavenumber Fourier modes. The stochastic structure may reflect gravitational unevenness within the ring, and the the higher-order transient normal modes may be a response to stochastic perturbations arising from those clumps.

206.11 – Measuring Particle Sizes from Diffraction Spikes at Saturn's Ring Edges with Cassini UVIS Stellar Occultations

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The sharp edges that define many of the boundaries in Saturn's rings enable the detection of diffracted starlight by small particles during stellar occultations. As the occulted star is revealed in a gap or beyond the outer edge of the rings, the direct stellar signal is augmented by an additional signal due to the scattered light from the particles in the nearby edge. The Ultraviolet Imaging Spectrograph (UVIS) on Cassini has detected strong diffraction signals throughout Saturn's A ring in 50-75% of the one hundred and thirty stellar occultations analyzed thus far. We measure the radial extent and the strength of the diffraction signals at the Encke Gap edges, the Keeler Gap edges, and the outer edge of the A ring in the UVIS occultation data. The radial extent of the signal is determined by the size of the smallest particles and the number of those particles determines the amplitude of the signal. We therefore use the measurements to place a lower limit on the particle size and to constrain the fractional optical depth due to these small particles. The diffraction signals extend radially from several meters to tens of kilometers beyond the ring edges, indicating significant populations of centimeter and millimeter-sized particles. We find more prominent diffraction signals in the Keeler Gap edges and the outer edge of the A ring than in the Encke Gap edges which suggests a decrease in particle size toward the outer edge of the A ring. We will present the results of a study of the small particle population at ring edges with azimuthal distance from the embedded ringmoons Pan (Encke Gap) and Daphnis (Keeler Gap) and the conclusions from our analysis of the size and abundance of particles in these three regions of the outer A ring.

206.12 – Stellar Occultation Measurements of Particles in Saturn's Rings.

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Occultations of rings have proven to be a useful way to measure the particle-size distribution of the bodies making up the ring. During stellar occultations of Saturn's rings observed by Cassini, we have observed 'gap overshoots' or 'horns': places near a sharp edge of the rings, such as the gaps of A Ring, where the transmission of starlight appears to exceed unity. This excess light is due to starlight forward-scattered from the nearby ring into the detector. In this work, we model these ` horns' in terms of a truncated power law particle-size distribution. Due to the geometry of the observations and the observation wavelength of 2.92 microns, chosen to minimize reflected ringshine, our observations are sensitive to the distribution of ring particles from the millimeter to decimeter range. We model this using a truncated power law size distribution. We are able to model power law indices within the C Ring and Cassini Division, but low optical depths in the C Ring and a shallow power law of around 2.8 in the Cassini Division prevent meaningful constraints on minimum particle size. We also show that the outer A ring has some significant trends, going from a power law index of 2.9 and a minimum particle size of 2 cm at the inner edge of the Encke Gap to a power law index of above 3.5 and a minimum particle size of 6 mm at the edge of the A Ring. Finally, we are able to show that the outer edge of the B Ring looks much like the outer edge of the A Ring in terms of a steep power law index and small minimum particle size, in contrast to other studies of the B Ring interior.

207 – Titan 1: From the Ground Up

207.01 – Probing Titan's North Polar Atmosphere using a Specular Refection of the Sun

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On T85 Cassini VIMS observed a spectacular specular reflection of the Sun off Titan's Kivu Lacus (87.5N). This sunglint was so bright that it was observable not just at 5 microns, but also within the 2.7/2.8 and 2.0 micron windows as well. Because the specular reflectivity off of methane/ethane liquid is independent of wavelength in the VIMS range, the specular reflection allows us to infer Titan's atmospheric transmission spectrum. We will discuss the results of our opacity analysis with regard to Titan's atmospheric absorption and scattering. Empirical knowledge of the normal optical depth will directly enable us to disentangle surface from atmospheric effects, with the eventual goal of generating of absolute surface albedo spectra. This novel technique complements existing methods, occultations and radiative transfer analyses, and will enable identification of changes to Titan's polar atmosphere through the end of the Cassini mission.

207.02 – Titan's Haystack: the 220 cm^{-1} ice cloud feature

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More than thirty years have passed since Voyager 1 rendezvoused with Titan. At that time, the onboard InfraRed Interferometer Spectrometer (IRIS) discovered an ice cloud in Titan's winter polar stratosphere with a very intense and broad emission feature that peaks at 220 cm^{-1}. This ice cloud spectral feature, which we call the "Haystack," continues to persevere, having been observed continuously at high northern latitudes by Cassini's Composite InfraRed Spectrometer (CIRS) since the beginning of the Mission in early 2005. The Haystack radiates very strongly, and is 50 times a better emitter than Titan's aerosol in this part of the far-IR spectrum. The magnitude of the haystack dominates everything in terms of opacity and it radiates most efficiently where the Planck intensity is a maximum. This suggests that there may be a physical correlation between Titan's vertical temperature structure and the location where the Haystack exists spatially. The Haystack may contribute to the complex structure of the temperature profiles that is observed in the lower stratosphere at high northern winter latitudes (see for example, Schinder et al., 2012, Icarus 221, 1020–1031). Contrary to the sheer strength of the Haystack, its identity continues to elude us. With CIRS, however, we have the ability to derive several physical properties of the Haystack independently of knowing its composition. In this presentation, we will review the high northern latitude decline in the Haystack's intensity throughout most of northern winter and on into northern spring. We will then discuss the recent debut of the Haystack near Titan's south pole, with an emphasis on the recently observed strong variation in the Haystack's emission strength at latitudes poleward of 70°S. The decline in the Haystack's emission at high northern latitudes, combined with recent CIRS observations showing a strong latitudinal dependence in the Haystack's strength near Titan's south pole, reinforces our notion that the formation of the Haystack is highly correlated with Titan's polar shadow. Once photolysis is turned off, various organics build up that would otherwise be destroyed, and ultimately these gases condense to form the mysterious Haystack.

207.03 – Modeling Photochemical Processes on Titan: Comparison to Cassini Observations

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The recent data from the Cassini/CIRS soundings (Vinatier et al., 2010), the Cassini/UVIS stellar occultations (Koskinen et al., 2011, Kammer et al. 2013) and the Cassini/INMS in situ measurements (Westlake et al., 2011) revealed vertical profiles of minor species from 100 to 1500 km in the atmosphere of Titan. In this study, we introduce a new optimization method of deriving the best-fit eddy diffusivity profile. We also make systematic revisions of the rate coefficients for the chemistry of hydrocarbons within the uncertainties of laboratory measurements. After a careful search, we found that reproducing the abundance profile of C2H2 is the best strategy for retrieving the eddy diffusivity profile. We verify the validity of the eddy diffusivity profile though its application to the modeling of other tracers. We found that our objectively derived new eddy profile is consistent with that from Lavvas et al. (2008), but differs significantly from those used by other groups. We re-examined the chemistry of C2H4. The results suggest a revision of rate coefficients for three-body reactions related to C2H4 so as to keep the simulated profile close to the observation. The rate coefficients for reactions that control the abundance of C2H6, C3H8, CH3C2H and C4H2 are also modified in the model to provide better fit to Cassini observations. We identified the rate coefficients that need improved laboratory data appropriate for the conditions of Titan's atmosphere.

207.04 – Atmospheric Gravity Waves in Titan's Troposphere and Stratosphere

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The Cassini/Huygens in situ measurements of the structure of Titan's lower atmosphere are analyzed for presence of small-scale variability. An atmospheric gravity wave model is used to simulate wave generation and propagation in an atmosphere with variable temperature and wind conditions. We use the wavelength, the amplitude, and the phase of the simulated waves to compare with the observations and to constrain the wave period. We investigate the effect of topography on the generated wave spectrum and their impact on the background atmosphere.

207.05 – Non-LTE diagnostics of CIRS observations of the Titan's mesosphere

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Above about 400-450 km in Titan's atmosphere, the assumption of local thermodynamic equilibrium (LTE) breaks down for molecular vibrational levels of methane and various trace gases. Above this altitude non-LTE significantly impacts the formation of mid-infrared ro-vibrational band emissions of these species observed in the limb viewing geometry. Due to the limb geometry this impact also propagates down to lower tangent heights. We studied retrievals of temperature and trace gas abundances from the CIRS limb observations of Titan's atmosphere with the help of an iterative retrieval algorithm applied earlier by Vinatier et al, (2007, 2010), which was modified to account for the non-LTE source functions for each gas. We demonstrate that accounting for the non-LTE significantly affects the retrieval results: it leads to higher temperature values (up to 10 K at altitudes of about 550 km). It also leads to substantially higher vertical gradients of volume mixing ratio (VMR) profiles and, as a result, to higher VMR values for some trace gases at high altitudes (e.g., up to about 6 time higher C2H2 mixing ratio at 550 km) compared to those obtained with the LTE assumption. The non-LTE impact on retrievals also propagates down to the altitudes of 350 km.

208 – Asteroids Posters 2: Second Helping

208.01 – Olivine or Impact Melt: Origin of the "Orange" Material on Vesta

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NASA's Dawn spacecraft entered orbit around asteroid (4) Vesta in July 2011 for a year-long mapping orbit, which allowed for complete imaging of the surface with the Dawn Framing Camera (FC). During the approach phase, enigmatic "orange" material was discovered on Vesta (Reddy et al. 2012). This "orange" material exhibits a red spectral slope and therefore is seen in FC ratio images (with red=0.75/0.45 microns, green=0.75/0.92 microns, and blue=0.45/0.75 microns) as orange. Here the green channel helps quantify the pyroxene band depth at 0.90 microns (greener areas have higher ratio, i.e. deeper band). The two other channels depend on the visible spectral slope (redder areas have positive visible slope; bluer areas have negative visible slope). FC images revealed diffuse "orange" ejecta around three impact craters: 34-km diameter Oppia, 30-km diameter Octavia, and 11-km Arruntia as well as numerous lobate "orange" deposits distributed around Rheasilvia's basin rim. Additionally, some fresh-looking craters (like Cornelia or Rubria) display impact ejecta rays made of "orange" material. Even though some of the "orange" deposits are not directly linked with nearby impact craters, these observations suggest an impact related origin. The distribution of all of the lobate "orange" material is constrained to outside Rheasilvia, which suggests a link with the basin's formation. Interestingly, as noted in Reddy et al. (2013) and Le Corre et al. (2013), the "orange" ejecta around Oppia corresponds to the olivine-rich unit that was postulated by Gaffey (1997). We will present our study of the geomorphology and composition of this material and explore meteoritical analogs (Le Corre et al. 2013). Several possible options for the composition are investigated in-depth including a cumulate eucrite layer exposed during impact, metal delivered by impactors, an olivine-orthopyroxene mixture, and impact melt. Combining all our analyses, the most probable analog for the orange material on Vesta appears to be impact melt. This work is supported by Dawn UCLA subcontract# 2090-S-MB170, NASA Dawn Participating Scientist Program Grant NNH09ZDA001N-DAVPS, and NASA Planetary Geology and Geophysics Grant NNX07AP73G.

208.02 – Indication of Melt Sheets on Vesta from Thermal Inertia Calculations

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Contributing teams: The Dawn VIR Team

We combined data from Dawn Framing Camera (FC) and Visual and Infrared Spectrometer (VIR) to identify possible melt sheets in the Cornelia crater on Vesta. First, we extracted the thermal spectra from four VIR cubes of Cornelia and matched a thermal curve to get a spatially resolved surface temperature for each observation. Second, we used stereophotoclinometry (SPC) to derive high resolution (16 m) topography and surface reflectance using FC images (Gaskell, et al., 2010). We calculated the absorbed thermal flux over the course of a full rotation that also included shadowing. Third, we ran a suite of diurnal 1-D thermal models with thermal inertia values of 21, 50, 100, 200, 357, 715 [J m-2 K-1 s-1/2] for every pixel of the crater. Then, we remapped the results to match the exact location and resolution of the VIR data so we could compare the data sets directly. We fit a thermal inertia value for each pixel using the observed surface temperature and the different model simulations. Finally, we grouped pixels with similar thermal inertia values to define different units. Higher thermal inertia units indicate more coherent rock (less porous) that could be melt sheets (such as on the crater rim) or exposed bedrock (rock ledges in the crater).

208.03 – Vesta - A Tale of Two Craters

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Two craters in the Rheasilvia basin of the south pole region of the asteroid Vesta, 51 km apart. The larger crater @29E_69.5S (Tarpeia) has a diameter of 41km, and the second crater @1.5E_64S (unnamed) has a diameter of 21km. Both craters and the area between them are part of a region geologically classified as "undifferentiated crater material" [1], extending, in a wedge form, between longitude 0deg.E and 50deg.E and in latitude between 80deg.S and 20deg.S. Data from the Dawn mission Low Altitude Mapping Orbit (LAMO) imaging sessions [2,3,4] enable us to study the surface of Vesta at a spatial resolution of 20m per pixel. We are using the imaging data to identify surface features down to the 30m size range, and also measure their diameter starting at the 60m - 70m size range. The smaller unnamed crater at 1.5E and 64S is surrounded by a boulder field. We identified 280 boulders in the size range between the detection limit of 30m and 200m, with few boulders larger than 140m. The spatial distribution is almost circular but, with a deficiency of boulders in the S-S/E area (5 o'clock) followed by an enhancement in the number of crater diagonally opposite at 11 o'clock. It suggests a central source for the ejected boulders. A hypothetical field of secondary craters around this crater will have to follow the same spatial distribution. We, however, did not detect any. The terrain between the 2 craters is populated by small (less than 1km diameter) and very small craters in the 100m range. We detected visually 2 groups of craters with a linear spatial distribution arranged as Crater Chains. We measured the size and positions of the craters in the chains and of the context craters around them. Our study includes the size distribution as well as the spatial distribution of the Crater Chains. We intend to test few statistical methods for verifying the membership in a crater chain. The presence of the boulder field and the crater (pit?) chain is likely indicative of a highly fractured terrain (bed-rock). [1] Mest at al. JGR in review, [2] Russell, C.T. Raymond, C.A. Space Sci. Rev. 163, 3-23 (2011), [3] Jaumann, R. et al. Science 336, 687-690 (2012), [4] Russell et al. (2012) Science 336, 684-686 (2012)

208.04 – Vesta's Crustal Properties from the Dawn Gravity Measurements

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Vesta's internal structure has been investigated via gravity and shape models derived from the Dawn mission data. A 20th degree and order spherical harmonic gravity field solution by Konopliv et al (2013) has been available for geophysical analysis and interpretation and various internal structure models have been considered (Russell et al. 2012, Asmar et al. 2011). Spectral and statistical analyses of the gravity and topography by Bills et al. (2013) have revealed that the observed gravity is highly correlated with the observed topography suggesting little lateral variation in density and that lateral mass variations associated with surface topography is the dominant cause of the observed gravity. The Bouguer anomaly is generally much smaller than the free-air anomaly. Vesta's variance spectra of gravity and topography are similar to those seen on other silicate bodies, including Moon, Mars, Venus, and Earth. The gravity/topography admittance spectrum follows the trend for homogeneous density except for a notable dip at harmonic degrees 5-8. Also, the gravity and topography are both significantly non-isotropic, with larger variations in the north-south direction than in the east-west direction. These two features may both be explained by large scale fracturing of the body, and displacements along those fractures, associated with the impacts, which formed Veneneia and Rheasilvia. More recent modeling of multi-layered Vesta demonstrated that there are many different internal density models that satisfy all the observational constraints, the well-known non-uniqueness issue with gravity solutions. This paper will present details of these topics as well as selected possible models constraining Vesta's crustal thickness and densities.

208.05 – A Record of Multiple Cratering Events in the Vesta Asteroid Family

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The Vesta asteroid family has been the focus of many detailed spectroscopic studies that have shown its members belong to the taxonomic V-class, as well as providing evidence that link Vesta and its family to the HED meteorites. Most recently, results from the Dawn mission have revealed an impact history on Vesta that is consistent with the formation of the Vesta asteroid family through large cratering events. I present results from an ongoing study of spectro-dynamical asteroid families that show the Vesta family may still contain a remnant record of multiple impact events. This work combines proper orbital elements and Sloan Digital Sky Survey Moving Object Catalog (SDSS-MOC) colors for over 2000 asteroids that reveal a complex structure in the number density distribution of Vesta family members, and a subtle but statistically significant trend in spectral colors across the family. This structure in orbit and color space is confirmed by different multivariate analysis techniques, providing strong evidence that at least two distinct cratering events have contributed to the distribution of V-type asteroids we currently identify with the Vesta family. I will present the results from these analyses, and will examine the WISE albedo database and published near-IR spectra of Vesta family members for additional evidence of compositional variation across the family.

208.06 – The size and pole of Ceres from nine years of adaptive optics observations at Keck and the VLT

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With NASA's Dawn Mission now on its way to dwarf-planet Ceres, there is considerable interest in refining that object's size and pole. At the level of a few percent, there has been a discrepancy in the polar and equatorial dimensions of the object, as measured by HST imaging vs. ground-based adaptive optics. To attempt to improve the dimensions and pole, we have analyzed a suite of adaptive optics images that we obtained at the Keck and VLT observatories from 2001 to 2010. We use a new method that we recently developed to combine data from multiple epochs and we attempt to account for limb darkening. We find that Ceres is best modeled as an oblate spheroid with equatorial and polar diameters of 966+/-10 km and 884+/-4 km, respectively. Although our equatorial diameter is within 1% of HST results (Thomas et al. 2005, Nature 437, 224-226) the polar dimension is some 3% smaller, more in line with the analysis of a subset of our AO images by Carry et al. (2008, A&A 478, 235–244). Thus, in addition to a more oblate spheroid, we predict that Dawn will find that Ceres shows strong limb darkening when it arrives in 2015. From three methods, all depending on the orientation of Ceres over the nine years of our observations, we determine its spin-vector coordinates to lie within 3 degrees of [287; +64] in equatorial EQJ2000 reference frame ([346; +82] in ECJ2000), in agreement

with previous studies, pointing to a small 3 degree obliquity between the spin and orbital poles.

208.07 – Latitudinal Spectral Variations on Asteroid 101955 Bennu

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Asteroid 101955 Bennu (1999 RQ36) is the sample return target for the OSIRIS-REx mission. From multiple observations at different aspect angles, we detect a slight but deemed reliable spectral slope difference between the polar and equatorial regions of Bennu. We explore whether these may be compositional or grain-size effects. Surface variations may be a consequence of polar-to-equatorial migration of regolith as modeled by Walsh et al. (2008; Nature 454, 188) as a consequence of spin-up induced by the YORP (Yarkovsky–O'Keefe–Radzievskii–Paddack) thermal effect. Our results are based on near-infrared spectral measurements of 101955 Bennu obtained on May 2, 2012 UT using the 6.5m Baade Telescope at the Magellan Observatory in Las Campanas, Chile. Additional Magellan 6.5m observations were obtained in July 2011. At Magellan, we utilized the FIRE (Folded-port InfraRed Echellette) spectrograph (Simcoe et al. 2010; Proc. SPIE 7735) over the wavelength range 0.8- to 2.3-microns. We compare these new Magellan data with previous results (Clark et al. 2011; Icarus 216, 462) where asteroid Bennu was measured in September 2005 using the NASA IRTF 3-m using the SpeX instrument (Rayner et al. 2003, PASP 115, 362) over a similar wavelength range.

208.08 – Physical Characterization of Binary Near-Earth Asteroid (153958) 2002 AM31

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Arecibo (2380 MHz, 12.6 cm) and Goldstone (8560 MHz, 3.5 cm) radar observations between 2012 July 12 and August 8 revealed that Apollo-class and potentially hazardous asteroid (153958) 2002 AM31 is a binary system. It is comprised of a primary component 400-500 meters in diameter and a possibly asynchronous secondary about one-fourth that size. The most striking characteristics of this system are a significant mutual-orbit eccentricity of ~0.45, one of the largest eccentricities known among near-Earth binaries, and an implied density greater than 3 g/cc (depending on the volumes of the components). The size ratio, the semimajor axis of ~1.5 km, and the mutual-orbit period of ~26.3 h are otherwise typical among near-Earth binaries. Optical lightcurves suggest rapid rotation of the primary in of order 3 h, consistent with radar echo bandwidths, and confirm the mutual-orbit period via the timing of mutual events. Near- and thermal infrared (0.8-4.1 microns) spectroscopy with SpeX on the NASA IRTF places this system in the S complex, and rotationally resolved spectra show no variation in thermal properties as the primary rotates. We will present further refined estimates of the sizes, shapes, and spin states of the components.

208.09 – Coordinated Time Resolved Spectrophotometry of Asteroid 163249 (2002 GT)

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The near-Earth asteroid 163249 (2002 GT), classified as a potentially hazardous asteroid (PHA), has been identified a potential rendezvous target for the NASA Deep Impact spacecraft on 4 Jan 2020. As part of a coordinated international effort to study this asteroid during its 2013 apparition (J. Pittichová et al. DPS 2013), we obtained simultaneous Sloan r-band photometry at the Steward Observatory Bok 2.3-m telescope (+90Prime) and optical spectroscopic observations covering a wavelength interval from ~5400 to ~8500 Angstrom at the MMT 6.5-m (+RedChannel spectrograph) on 2013 June 16 and 17 UT near close Earth approach (heliocentric distance ~1.07 AU; geocentric distance ~0.13 AU) at 180 sec intervals over the ~3.76 hr rotational period. Our objective was to obtain a temporal sequence of spectra to assess surface mineralogy (seeking to potentially detect the 0.7 micron absorption bands attributed to phylosilicate materials) and to determine whether variations in the spectral slope and/or surface mineralogy are evident as a function of rotational period. Here we present initial analysis of these datasets, describing the light-curve and the reflectance spectra as a function of rotational phase. These datasets will be incorporated into a larger compendium describing the characteristics of asteroid 163249. Acknowledgement: This research supported in part by NASA 12-PAST-12-0010 grant NNX13AJ11G , and an appointment (E.L.R.) to the NASA Postdoctoral Program at the Goddard Space Flight Center, administered by Oak Ridge Associated Universities through a contract with NASA. Observations reported here were obtained at the MMT Observatory, a joint facility of the Smithsonian Institution and the University of Arizona. P.P. was supported by the Grant Agency of the Czech Republic, Grant P209/12/0229.

208.10 – Thermal Emission Photometry of Deep Impact Flyby Target (163249) 2002 GT

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Contributing teams: The 2002 GT Observing Team

Near-Earth asteroid (163249) 2002 GT is now the target of a Deep Impact spacecraft flyby in Jan. 2020 (see Pittichova et al., this volume, for details of the flyby and observing campaign). Thermal emission photometry of 2002 GT was obtained from NIRI on Gemini-North in the L′ and M′ filters, which are centered at 3.76 and 4.68 microns respectively. J- and K-band reflectance photometry was also acquired in support of the thermal observations. The full JKL′M′ set was acquired on UT 2013-Jun-13 at a solar phase angle of 53 degrees. A further set of photometry in J, K, and L′ only was carried out on 2013-Jun-19 at a phase angle of 65 degrees. High water vapor conditions at Mauna Kea during this period unfortunately prevented acquisition of a second set of M′ measurements. In addition, N-band photometry of 2002 GT was conducted on 2013-Jun-10 from CanariCam at the 10-meter Gran Telescopio Canarias using a beta version of the moving object guiding system. Data were acquired in three filters between 8.7 and 12.5 microns, although the limitations of the guiding are complicating the analysis. (We note that N-band observing was not offered by either Gemini or IRTF during this apparition.) Data analysis is ongoing and results will be discussed. We appreciate the efforts of the Gemini and GTC staff in support of these observing programs.

208.11 – The Asteroid 1998 QE2

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This big asteroid was at 5.8 millions of kilometers from the Earth on May 31 (2013) and it has a diameter of 2.7 km. The radar images obtained by JPL showed that the period of rotation around its axis is close to five hours. Hills. K (2013) reported that the period is of 5.281 +/- 0.002 hours. On June 4 the team of Goldstone-Arecibo found a period of 4.75 +/- 0.01 hours. We also contributed with the light and phase curves to estimate the period by means of the telescope (with red filter). The radar imagery (JPL and Arecibo) revealed that 1998 QE2 has a moon, and we captured a mutual event (eclipse). From our Observatory, located in Pasto-Colombia, we captured several pictures, videos and astrometry data during several days. Our data was published by the Minor Planet Center (MPC) and also appears at the web page of NEODyS. The pictures of the asteroid were captured with the following equipment: CGE PRO 1400 CELESTRON (f/11 Schmidt-Cassegrain Telescope) and STL-1001 SBIG camera. We obtained the light curve of the body. Astrometry was carried out, and we calculated the orbital elements. We obtained the following orbital parameters: eccentricity = 0.5692181, semi-major axis = 2.41104631 A.U, orbital inclination = 12.82771 deg, longitude of the ascending node = 250.16876 deg, argument of perihelion = 345.61328 deg, mean motion = 0.26326658 deg/d, perihelion distance = 1.03863508 A.U, aphelion distance = 3.78345755 A.U. The asteroid has an orbital period of 3.74 years The parameters

were calculated based on 191 observations (2013 May: 17-24) with mean residual = 0.162 arcseconds. A video of the asteroid from our Observatory was published on the main page of the "SPACEWEATHER" web: http://www.spaceweather.com/archive.php?view=1&day=21&month=05&year=2013 Note: The autors would like to thank to: Dr. Alessondra Springmann (Arecibo Observatory), Dr. Petr Pravec (Czech Republic), Dr. Lance Benner (JPL), Dr. Carl Hergenrother (Target Asteroids Team), and Dr. Dolores Hill (Target Asteroids Team) for their special suggestions.

208.12 – AN INITIAL ANALYSIS OF GALILEO NIMS ASTEROID 951 GASPRA POINT SPECTRA

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On October 29, 1991 the Galileo spacecraft observed asteroid 951 Gaspra with the Near Infrared Mapping Spectrometer (NIMS) at wavelengths ranging from 0.7 – 5.2 micrometers [Carlson et al., 1992]. This paper reports on findings from newly processed data from this encounter, including spatially unresolved spectra acquired prior to the closest approach of Galileo to 951 Gaspra. These data include spectra that range from 17 to 408 channels across the NIMS wavelengths. They recorded spectral absorption features in the vicinity of 1.0, 2.0, 2.8, and 3.4 micrometers in wavelength. They were measured in spectra that were created by the radiometric calibration of "raw" data values that are currently archived in the NASA Planetary Data System. The Granahan [2011] analysis of the 17 channel spatially resolved data identified two groups of spectra that possessed spectral band centers measured at 0.99 and 1.05 micrometers with corresponding differences of band depth around 2.0 micrometers. They are interpreted to be caused by the presence of the minerals olivine and orthopyroxene. This trend continues in the spatially unresolved data with additional band center measurements at 0.98 and 1.05 micrometers. These families of spectra correspond to those of SII (1.05 micrometer group) and SIII (0.98 micrometer group) classes [Gaffey et al., 1993] of the S asteroids. The 2.7 micrometer absorption feature [Granahan, 2011] is also present in all of the spatially unresolved NIMS observations of 951 Gaspra. This feature is detected in the 17 channel data as an absorption in the 2.7 micrometer channel. In NIMS observations with more than 17 channels, the absorption occurs in the vicinity of 2.8 micrometers with a weaker feature present near 3.4 micrometers. These features occur in the same position as absorptions thought to be due to hydroxide bearing phyllosilicates as those detected in the carbonaceous chondrite Murchison [Hiroi et al., 1996]. Carlson, R. W., et al. (1992), Bulletin of the American Astronomical Society, 24, 932. Gaffey, M. J., et al. (1993), Icarus, 106, 573-602. Granahan, J. C. (2011), Icarus, 213, 265-272. Hiroi, T., et al. (1996), Meteoritics & Planetary Science, 31, 321-327.

208.13 – Numerical Studies of Electrostatic Dust Motion about Itokawa

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The motion of regolith grains near the surface of asteroids could significantly influence our understanding of the morphological evolution of these bodies. Dust motion about asteroids is also a concern in the design of future exploration missions. At certain launching velocities, electrostatic forces dominate the trajectories of near-surface dust grains. Prior studies of electrostatic dust motion about asteroids have relied on simplistic gravity and plasma models. We will show our current status in modeling a dust particle's trajectory about an accurate 2D shape, gravity and plasma model of the asteroid Itokawa. The shape and gravity models used are derived from measurements taken by the Hayabusa spacecraft. The plasma model is based on a Particle-In-Cell model of the solar wind flowing around an illuminated Itokawa shape model. By marrying high accuracy shape, gravity and plasma models, we will be able to more accurately predict dust motion in the near-surface environment of Itokawa.

208.14 – Contrasting Q-type Asteroid Regolith from the S-complex Through Polarimetry

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The polarization of asteroids exhibits a wavelength dependence. For the S-complex, the polarization decreases linearly with increasing wavelength. This is different from the C-complex, which has the opposite dependence of polarization on wavelength. The slope of wavelength dependence also changes with phase angle for both complexes; at higher phase angles, the wavelength dependence is steeper. The Q-type asteroids are thought to have S-complex compositions that have been resurfaced. Resurfacing removes space weathering effects that redden S-type surfaces. Alteration of the asteroid regolith should imply differences in polarization. Further comparison of S- and Q-type regolith is needed to determine whether polarization properties can be attributed to composition. Alternatively, observed differences in polarization may instead be linked to differences between weathered and resurfaced regolith. In order to explore the polarimetric differences between the Q-types and the S-complex, a series of observations were taken using the SPOL spectropolarimeter at Steward Observatory. Making a polarimetric comparison between the Q-types and S-complex will constrain the differences between these types, augmenting what is known from photometry and spectroscopy. We compare the Q-types to the S- and Sq-types using polarimetric phase curves, as well as the wavelength dependence of polarization vs. phase angle. The Q-type polarizations at higher phase angles exhibited lower values of polarization than the S- and Sq-type measurements at similar phase angles. This difference in polarization values between regoliths with different albedo has also been seen in comparing regions of the lunar surface with dissimilar albedo. Thus, we can safely assume that the Q-type regolith we observed has a higher albedo, and therefore a less weathered regolith. However, measurements of the wavelength dependence between the observed asteroid types are indistinguishable from one another. Given the current data, wavelength dependence of polarization cannot probe the surface differences between these types. The combined results imply that albedo differences do not control wavelength dependence differences between different taxonomic types in general.

208.15 – An Investigation of the 3-μm Feature in M-Type Asteroids

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The M-type asteroids had originally been interpreted as the disrupted iron cores of differentiated bodies by spectral analogy with the NiFe meteorites. More detailed studies have since indicated a range of compositions. In particular, the presence of a 3-μm feature, diagnostic of hydration, detected in more than 35% of surveyed M-type asteroids (Jones et al. 1990, Rivkin et al. 1995, 2000) has challenged the notion that these bodies are all metallic. Spectroscopy in the 0.8 – 2.5 μm region has revealed absorption features due to mafic silicates and hydroxides or phyllosilicates (Fornasier et al. 2010, Hardersen et al. 2006, 2010, Ockert-Bell et al. 2010). Radar studies have shown that most M-types are not likely to be iron cores, but they typically have a higher metal content than average (Shepard et al. 2010). Taken together, these results paint a fairly confounding picture of the M-type asteroids. While several interpretations have been suggested, more work is needed to clarify the mineralogy of these bodies. We have started a new spectroscopic study of the M asteroids in the 2 – 4 μm region. We seek to characterize the shape, band center, and band depth of the 3-μm feature where it is present, as these measures are indicative of the type and extent of hydration present on asteroids (Lebofsky et al. 1985, Rivkin et al. 2002, Takir & Emery 2012, Volguardsen et al. 2007). With this work, we hope to shed new light on the origin of hydration on M asteroids and its context within their mineralogy and thermal evolution. In July 2013, we obtained 2 – 4 μm spectra for 69 Hesperia, 136 Austria, and 261 Prymno with the SpeX at NASA's IRTF, and are in the process of reducing the data. We have also obtained 0.8 – 2.0 μm data for 261 Prymno using the NICS at the TNG in February 2013. We report the presence of an absorption feature near 0.9 μm in Prymno's spectrum, indicating a partially silicate composition. Based on spectral, physical and orbital similarities to other hydrated M-types, we predict the presence of a 3-μm feature in Prymno's 2 – 4 μm. More 2 – 4 μm observations of M-type asteroids are planned.

208.16 – 2012 DA14 and Chelyabinsk: Same Day Coincidence?

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A long anticipated near-miss by near-Earth asteroid (NEA) 2012 DA14 on 15 February 2013 was upstaged 16 hours earlier by the impact and atmospheric explosion of a ~20 m NEA over Chelyabinsk, Russia. DA14 was earlier estimated to be 45 m across and passage at a distance under geosynchronous satellites was considered to be a record close approach by an object of that size, a once-in-40-years event. Actual Earth impact by a 20 m NEA had been estimated to be a once-in-200-years event. A simplistic calculation gives a probability of these happening on the same day of 1-in-a-billion. Within hours of the Chelyabinsk impact, it was recognized and widely reported that the two asteroids were in very different orbits and could not, at least in any readily understandable way, be physically related to each other (e.g. fragments of the same precursor body). Also, some early reports suggested that the two asteroids had very different compositions, further undermining the possibility they were pieces of the same body. (It seems unlikely, though certainly conceivable, that the two NEAs could have different compositions yet have some kind of causal connection resulting in the same-day events.) Nevertheless, incredibly tiny probabilities beg for an explanation. Here, with the benefit of hindsight, I re-examine issues that affect the probabilities, such as size, albedo, probable composition, and numbers of NEAs of these sizes. I also consider difficult issues of framing the apparent coincidence, which dominate other uncertainties. Updated information about the physical nature of the two asteroids somewhat modifies the original estimates of probabilities. Moreover, more proper ways of framing elements of the coincidence considerably reduce the improbability of the same-day events, but not nearly to the level (e.g. 1-in-1000 or perhaps 1-in-10,000) where we could rationalize dismissing the events as “just a coincidence.” The events of 15 February 2013 deserve more sophisticated investigation.

208.17 – Application of a Shape-Based Thermophysical Model to Contact Binary Near-Earth Asteroids

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Radar observations of near-Earth asteroids (NEAs) show a wide variety of shapes: spherical, elongated, irregular, and two-lobed (or contact binaries). However, radar-based shape models are only available for a small fraction of near-Earth asteroids. A natural question is whether certain shapes can be recognized by other types of observations. To address this question, we examine infrared spectra of model asteroids, with a focus on asteroids whose shapes have significant concavities, such as contact binaries. Our goal is to determine whether concavities produce noticeable infrared spectral features. Over the last five years, we have obtained both radar observations and thermal infrared spectroscopy of more than 40 NEAs, including 11 contact binaries. Multiple observations at different phase angles and rotation phases cannot in general be fit with a simple thermal model that assumes a spherical shape. Detailed shape models are in progress for some of these asteroids, but all of them share the same general characteristics of two roughly equal sized lobes with a fairly deep cleft in the center. Such a concavity can prevent some thermal emission from escaping. Our shape-based thermophysical model, SHERMAN, shows that at some rotational phases, mutual heating of facets that face each other allows some areas within concavities to become hotter than the subsolar temperature. Depending on illumination and viewing geometry, the thermal flux from a contact binary may have large variations over the body (as compared to a spherical model) and can show substantial rotational variations. The size of these variations will depend on thermal inertia, albedo, and many other factors. We explore the parameter space using the thermal model for idealized cases, and apply the results to observations of contact binary NEAs.

208.18 – Asteroid Thermal Properties Derived from Meteorite Data

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The thermal inertia of an asteroid’s surface determines its response to the various Yarkovsky effects, while its internal thermal diffusivity controls its thermal evolution. Each quantity is a function of the material’s thermal conductivity, heat capacity, and density. Over the past ten years we have conducted a detailed survey measuring density in meteorites and are currently in the early stages of similar surveys for thermal conductivity and heat capacity. While various meteorite types differ in small but significant ways, for asteroid studies typical average values of these quantities can be estimated to within about 10%. (Metallic asteroids would have significantly different behavior.) The most important variable controlling density and thermal conductivity is porosity, P, while heat capacity is a strong function of temperature, T. Most stony meteorite densities are within 10% of 3500*(1-P) (SI units); basaltic and volatile rich meteorites are 10% to 30% less dense. Thermal conductivity in the temperature range of interest in the asteroid belt is nearly constant with temperature but varies strongly with porosity; assuming the trend seen for meteorite porosities up to 25% can be extrapolated to higher porosities, with zero conductivity at 100% porosity, a typical conductivity (for porosities greater than 2%) can be approximated by $k = 0.11/P - 0.11$ (SI units). Heat capacity ranges from under 250 J/kgK at 100 K to over 600 J/kgK at 250 K; over these temperatures this variation can be fitted by a quadratic in T. From these formulae we can derive representative values for thermal inertia and diffusivity and see how they vary as a function of porosity and temperature values appropriate for most asteroids. The greatest variation is with porosity. Thermal diffusivity drops by nearly two orders of magnitude from 0 to 20% porosity, more slowly at higher porosities. Thermal inertia (at 200K) varies from 3000 (SI units) near zero porosity down to 3 as porosity approaches 100%; 10% porosity has a thermal inertia near 1000 while 90% porous is about 60. Literature asteroid thermal inertias range from as high as 1000 to below 30; asteroid thermal inertias below 100 demand an extremely porous (>80%) surface.

208.19 – Constraints on Spin Axis and Thermal Properties of Asteroids in the WISE Catalog

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It has widely been accepted that dynamical state of asteroids can strongly be influenced by radiation forces (e.g., Yarkovsky and YORP). Determination of an object’s thermal properties and spin state are a critical step towards understanding the effects of these forces. In this respect, observations of thermal flux emitted from the surfaces of asteroids are a powerful tool. The emission of flux is determined by the temperature distribution which is controlled by the thermal inertia, rotation rate, and spin axis orientation. By gathering data at multiple viewing geometries, the temperature distribution can be modeled accurately enough to separate the effects attributed to (some of) these parameters. Over the length of its mission, the Wide-Field Infrared Survey Explorer (WISE) observed many asteroids in two epochs (i.e., on either side of opposition) such that data for both morning and afternoon times were gathered. We have begun a project that employs a Thermophysical Model (TPM) in order to analyze these multi-epoch thermal observations with the goal of deriving the thermal properties and spin axis of a large number of asteroids. Here, we first investigate the validity and limits of our method on objects with a previously determined spin axis. Asteroid (413) Edburga has a published spin axis of $\lambda = 202^{\circ}$, $\beta = -45^{\circ}$ (ecliptic longitude and latitude, respectively) using the lightcurve inversion method. With our technique, we estimate a solution consistent with the previous estimate. Applying our TPM to WISE multi-epoch thermal observations of (155) Scylla (no known spin axis estimate), we also place estimates for the ecliptic longitude and latitude of its spin axis. Analysis of multi-epoch thermal data enables determination of spin axis orientation without knowing the rotation period, in contrast to the lightcurve inversion method. This is due to the coupling of thermal inertia and rotation rate in determining the longitudinal distribution of temperature. Their combined effects on surface temperature can adequately be described by a dimensionless thermal parameter, which is a ratio of the time scale for radiating heat to the diurnal time scale.

208.20 – Asteroid Family Identification Using Physical Properties from WISE/NEOWISE

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Asteroid families are the signatures of massive collisions between asteroids and represent an important source of small objects in the Main Belt. Using the Hierarchical Clustering Method to identify asteroid families, and the physical properties measured by the NEOWISE survey of Main Belt asteroids to discriminate between broad albedo classes, we refine family membership lists and identify new Main Belt families. This technique allows for improved family associations, especially for more dispersed families in crowded regions. We find 76 high confidence families representing over one-third of the total Main Belt population, of which 28 were previously unknown. We present here our results, focusing on both broad physical properties and specific interesting families. This work is the critical first step in determining the ages of asteroid families through numerical simulation of orbital evolution.

208.21 – Albedo, Size and Taxonomy of the Small Body Populations Outside the Main Belt

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Using the data from the WISE/NEOWISE mission we have derived albedo and size distribution of more than ~1200 Cybeles, ~1000 Hildas, ~1700 Jovian Trojans and a dozen irregular satellites of Jupiter and Saturn. This dataset increases by an order of magnitude our knowledge of the makeup of the small body populations between the Main Belt and Saturn. We find that all these populations are dominated by low albedo objects, with only the Cybele and Hilda populations having a small (less than 10% among the Cybeles and less than 1% among the Hildas, Trojans and irregular satellites) fraction of objects with albedos higher than 15%. Using the near-infrared albedos (in the 3.4 and 4.6 micron bands) we were also able to derive the taxonomic classifications of the largest objects in each populations, showing that they are dominated by C-, P- and D-type surfaces. The dominance of these dark bodies indicate two possible formation scenarios. The small body populations may have been formed in situ beyond the snow line, potentially serving as primitive bodies that can provide significant insight into the composition of the early Solar Nebula in the region of the Giant Planets. Alternatively, they may be captured bodies that were perturbed from the region outside the Giant Planets as the planets migrated during the early stages of Solar System formation. This allows for insight into the composition of the Trans-Neptunian population by study of populations that are closer, brighter and more accessible. The low percentages of the more stony objects common in the Main Asteroid Belt indicates that few of these objects were embedded in the populations, imposing significant constraints on the migration of Jupiter inside its current orbit.

208.22 – Absolute Magnitudes of Pan-STARRS PS1 Asteroids

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Contributing teams: PS1SC collaboration

Absolute magnitude (H) of an asteroid is a fundamental parameter describing the size and the apparent brightness of the body. Because of its surface shape, properties and changing illumination, the brightness changes with the geometry and is described by the phase function governed by the slope parameter (G). Although many years have been spent on detailed observations of individual asteroids to provide H and G, vast majority of minor planets have H based on assumed G and due to the input photometry from multiple sources the errors of these values are unknown. We compute H of ~ 180 000 and G of few thousands asteroids observed with the Pan-STARRS PS1 telescope in well defined photometric systems. The mean photometric error is 0.04 mag. Because on average there are only 7 detections per asteroid in our sample, we employed a Monte Carlo (MC) technique to generate clones simulating all possible rotation periods, amplitudes and colors of detected asteroids. Known asteroid colors were taken from the SDSS database. We used debiased spin and amplitude distributions dependent on size, spectral class distributions of asteroids dependent on semi-major axis and starting values of G from previous works. H and G (G12 respectively) were derived by phase functions by Bowell et al. (1989) and Muinonen et al. (2010). We confirmed that there is a positive systematic offset between H based on PS1 asteroids and Minor Planet Center database up to -0.3 mag peaking at H~14. Similar offset was first mentioned in the analysis of SDSS asteroids and was believed to be solved by weighting and normalizing magnitudes by observatory codes. MC shows that there is only a negligible difference between Bowell's and Muinonen's solution of H. However, Muinonen's phase function provides smaller errors on H. We also derived G and G12 for thousands of asteroids. For known spectral classes, slope parameters agree with the previous work in general, however, the standard deviation of G in our sample is twice as larger, most likely due to sparse phase curve sampling. In the near future we plan to complete the H and G determination for all PS1 asteroids (500,000) and publish H and G values online. This work was supported by NASA grant No. NNX12AR65G.

208.23 – Small-body Colors From the UV to the IR: Bringing Together all Space and Ground-based Observations

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The main current asteroid taxonomical systems are defined from ground-based observations, limited to 3100-10600 Å (Tholen, Zellner et al. (1985)), and 4400-9200 Å (SMASS, Bus and Binzel (2002))), which do not include several useful regions, such as: 1) the well-known spectral features in the near-IR (20000-50000 Å) that differentiate between common asteroid and meteorite minerals and indicate the presence of volatiles; 2) the far IR, which probes the bodies' emission, thermal inertia and albedo; 3) the UV, where the degree of darkening probes the surface grain properties and space weathering. The few existing studies using multiple instruments from the UV to the IR (ground, Earth-orbit and flyby observations) have been limited to targeted observations of special-interest bodies. We aim to obtain UV to IR colors of a large sample of bodies, to study how they are distributed and how these colors differentiate among bodies with similar spectra on the standard taxonomies. The data are being gathered from archives of multiple space- and ground-based instruments: GALEX, HST, SDSS, 2MASS, Spitzer, WISE and Herschel. Such a combined use of multiple archived observations is commonly done for fixed (non-Solar System) astronomical targets, which can be easily found by their RA and Dec. To obtain such data for Solar System bodies, we are building a database of all archive observations of each known body. We are using their orbits, integrated into the past, to build an index, which will be used to determine whether an observation contains a known body. We present a preliminary cluster analysis, using a small sample of objects identified in multiple instruments, as well as the magnitude distributions on different colors, for a larger sample of objects. In the future we will expand the database to include more observations (more instruments and more bodies), and the populations we identify will be compared to spacecraft UV to IR spectra of those few bodies observed in close passes and with high resolution spectra. Ultimately, this work will prepare us for the LSST-era. Support for this work comes from the Northern Arizona University Office of the Vice President for Research.

208.24 – LINNAEUS: BOOSTING NEAR EARTH ASTEROID CHARACTERIZATION RATES

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Near Earth objects (NEOs) are being discovered at a rate of about 1000 per year, and this rate is set to double by 2015. However, the physical characterization of NEOs is only ~100 per year for each type of follow-up observation. We have proposed the LINNAEUS program to NASA to raise the characterization rate of NEOs to the rate of their discovery. This rate matching is necessary as any given NEO is only available for a relatively short time (days to weeks), and they are usually fainter on subsequent apparitions. Hence follow-up observations must be initiated rapidly, without time to cherry-pick the optimum objects. LINNAEUS concentrates on NEO composition. Optical spectra, preferably extending into the near-infrared, provide compositions that can distinguish major compositional classes of NEOs with reasonable confidence (Bus and Binzel 2002, DeMeo et al. 2009). Armed with a taxonomic type the albedo, pV, of an NEO is better constrained, leading to more accurate sizes and masses. Time-resolved spectroscopy can give indications of period, axial ratio and surface homogeneity. A reasonable program of spectroscopy could keep pace with the NEO discovery rate. A ground-based telescope can observe faint NEOs about 210 nights a year, due to time lost due to weather, bright time, and equipment downtime (e.g. Gemini), for a total of ~2000 hours/year. At 1 hour per NEO spectrum, a well-run, dedicated, telescope could obtain almost 2000 spectra per year, about the rate required. If near-IR spectra are required then a 4 m or larger telescope is necessary to reach V~20. However, if the Bus-Binzel taxomonmy suffices then only optical spectra are needed and a 2 meter class telescope is sufficient. LINNAEUS would use 50% of the KPNO 2.1 m telescope with an IFU spectrometer, the SED-machine (Ben-Ami et al. 2013), to obtain time-resolved optical spectra of 1200-2000 NEOs/year, or 4200-7000 in 3.5 years observing in an NEOO program. Robust pipeline analysis will release taxonomic types via the Minor Planet

Center within 24 hours and a full archive of spectra and products will be provided.

208.25 – Single vs. Multiple Transponders for Radio Tomography of Asteroids

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The purpose of this study was to develop numerical inverse methods for radio tomography of asteroids in which the goal is to recover the internal electric permittivity distribution of an asteroid based on radio frequency data gathered by an orbiter. The present tomography approach with a single transponder has been utilized in the CONSERT experiment which aims at reconstruction of a comet nucleus structure as a part of the ROSETTA (comet rendezvous) mission. This study aims at progress in designing the coming missions which necessitates a through investigation of implementable data gathering setups as well as forward (data) simulation and inverse computation schemes. The current signal generation approach of utilizing multiple transponders provides one potential scenario which can even be essential to achieve an appropriate reconstruction quality. Research to find the simplest and most robust (best bang for the buck) scenarios for signal generation and measurements is of utmost importance due to the high cost and long duration of planning and implementing a space mission, necessitating a highly optimized payload. Regarding the forward and inverse approaches, this study, in particular, validated the iterative alternating sequential (IAS) inversion (reconstruction) strategy with a forward simulation relying on the wave equation of the electric potential. To enable the IAS inverse approach, a linearized forward model was utilized to find the reconstructions. The inverse problem was given a Bayesian formulation. The numerical experiments included in this study compared the single and multiple transponder signal generation approaches in localization of permittivity anomalies. Three different anomaly strengths and four levels of total noise were tested to examine the tolerance of present reconstruction strategy to different error sources. Noise due to forward simulation was estimated. The results obtained were promising regarding the combination of the current forward and inverse approaches. They suggest that reconstruction quality increases along with the number of transponders and that multiple transponders can be necessary to distinguish three separate anomalies.

208.26 – Realistic Simulations Of Radar Scattering In Asteroids Using Geometric Optics

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We study the physical characteristics of asteroids that affect the circular-polarization ratio and the radar albedo at backscattering using simulations of radar scattering on asteroid surfaces. Previously, we have studied these radar parameters using aggregates of spheres and inhomogeneous spheres but without the multiple scattering effects that are relevant in realistic scattering by asteroid regolith. This time, we utilize geometric optics software for simulating electromagnetic scattering by the interacting single-scatterers (aggregated or inhomogeneous spheres) both on the surfaces of gaussian random spheres and inside them. We vary the physical parameters of the input single-scatterers as well as the refractive index and optical depth of the gaussian random spheres that simulate the asteroid in macroscopic scale. Thus, we investigate the effect of multiple scattering by various particles to the radar parameters and further develop their interpretation. The results are sensible in terms of the scale of the values of circular-polarization ratio and radar albedo as compared to the radar observations and show the well-known effect of multiple-scattering increasing the circular-polarization ratio for any particles. More importantly, the results show differences caused by the different physical parameters. For example, single-scatterers with smaller refractive indices (of, e.g., water ice) return smaller circular-polarization ratios and radar albedos compared to the particles with larger refractive indices (of, e.g., silicate materials or basalt). Also, the inhomogeneous spheres of size comparable to the wavelength can cause values of circular-polarization ratio and radar albedo a few times smaller than the spheres that are half the size but of the same material, although it is generally believed that specifically wavelength-scale roughness is the main cause of high circular-polarization ratios. This means that the effect of the scale of the surface structures, without forgetting the other physical properties, requires further investigation.

208.27 – Follow-up and Characterization of NEOs with the LCOGT Network

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Las Cumbres Observatory Global Telescope (LCOGT) network is a planned homogeneous network of over 35 telescopes at 6 locations in the northern and southern hemispheres. This network is versatile and designed to respond rapidly to target of opportunity events and also to do 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. asteroids, Kuiper Belt Objects, comets, Near-Earth Objects (NEOs)) and ultimately for the discovery of new objects. LCOGT has completed the first phase of the deployment with the installation and commissioning of nine 1-meter telescopes at McDonald Observatory (Texas), Cerro Tololo (Chile), SAAO (South Africa) and Siding Spring Observatory (Australia). The telescope network is now operating and observations are being executed remotely and robotically. I am using the LCOGT network to confirm newly detected NEO candidates produced by the major sky surveys such as Catalina Sky Survey (CSS) and PanSTARRS (PS1). An increasing amount of time is being spent to obtain follow-up astrometry and photometry for radar-targeted objects in order to improve the orbits and determine the rotation periods. This will be extended to obtain more light curves of other NEOs which could be Near-Earth Object Human Space Flight Accessible Targets Study (NHATS) or Asteroid Retrieval Mission (ARM) targets. Recent results have included the first period determination for the Apollo 2002 NV16 and our first NEO spectrum from the FLOYDS spectrographs on the LCOGT 2m telescopes obtained for 2012 DA14 during the February 2013 closepass.

208.28 – High Ecliptic Latitude Survey for Small Main-Belt Asteroids

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The collision velocity distribution is a major factor to determine the collisional evolution of the asteroid population. However, it remains unclear how the scaling law of asteroid strength against catastrophic disruption as a function of body size depends on collision velocity. Especially, we need to know the strength law in high-speed collisions around 10 km/sec (hereinafter called "hypervelocity collisions") for investigating the evolution of size distribution in the main belt during the dynamical excitation phase at the final stage of the planet formation processes (Bottke et al. 2005). To study the collisional evolution under such hypervelocity collisions, we measured the size distribution of high-inclination main-belt asteroids. We performed a wide-field survey observation at ecliptic latitude of around 25 deg using the 8.2-m Subaru Telescope. In the area of 13.6 square degrees, 221 main-belt asteroid candidates with inclinations larger than 14 deg were detected. The limiting magnitude is 24.4 mag in the SDSS r-band, corresponding to 0.6 km in diameter at a heliocentric distance of 3.3 AU. As a result of careful analysis, we found that the size distribution of our sample asteroids (i.e. high-inclination asteroids) in the diameter range of 0.6-1.0 km has an evidently shallower slope than that of low-inclination sub-km asteroids presented in the previous observation (Yoshida & Nakamura 2007). This result indicates that the asteroid population exposed to hypervelocity collisions has a steeper strength law in the gravity-scaled regime than the general main-belt asteroids.

208.29 – MP3C - the Minor Planet Physical Properties Catalogue: a New VO Service For Multi-database Query

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In the last few years we witnessed a large growth in the number of asteroids for which we have physical properties. However, these data are dispersed in a multiplicity of catalogs. Extracting data and combining them for further analysis requires custom tools, a situation further complicated by the variety of data sources, some of them standardized (Planetary Data System) others not. With these problems in mind, we created a new Virtual Observatory service named "Minor Planet Physical Properties Catalogue" (abbreviated as MP3C – http://mp3c.oca.eu/). MP3C is not a new database, but rather a portal allowing the user to access selected properties of objects by easy SQL query, even from different sources. At present, such diverse data as orbital parameters, photometric and light curve parameters, sizes and albedos derived by IRAS, AKARI and WISE, SDSS colors, SMASS taxonomy, family membership, satellite data, stellar occultation results, are included. Other data sources will be added in the near future. The physical properties output of the MP3C can be tuned by the users by query criteria based upon ranges of values of the ingested quantities. The resulting list of object can be used for interactive plots through standard VO tools such as TOPCAT. Also, their ephemerids and visibilities from given sites can be computed. We are targeting full VO compliance for providing a new standardized service to the community.

208.30 – The Mission Accessible Near-Earth Objects Survey (MANOS)

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Near-Earth objects (NEOs) are essential to understanding the origin of the Solar System. Their relatively small sizes and complex dynamical histories make them excellent laboratories for studying ongoing Solar System processes. The proximity of NEOs to Earth makes them favorable targets for space missions. In addition, knowledge of their physical properties is crucial for impact hazard assessment. However, in spite of their importance to science, exploration, and planetary defense, a representative sample of physical characteristics for sub-km NEOs does not exist. Here we present the Mission Accessible Near-Earth Objects Survey (MANOS), a multi-year survey of sub-km NEOs that will provide a large, uniform catalog of physical properties (light curves + colors + spectra + astrometry), representing a 100-fold increase over the current level of NEO knowledge within this size range. This survey will ultimately characterize more than 300 mission-accessible NEOs across the visible and near-infrared ranges using telescopes in both the northern and southern hemispheres. MANOS has been awarded 24 nights per semester for the next three years on NOAO facilities including Gemini North and South, the Kitt Peak Mayall 4m, and the SOAR 4m. Additional telescopic assets available to our team include facilities at Lowell Observatory, the University of Hawaii 2.2m, NASA's IRTF, and the Magellan 6.5m telescopes. Our focus on sub-km sizes and mission accessibility (dv < 7 km/s) is a novel approach to physical characterization studies and is possible through a regular cadence of observations designed to access newly discovered NEOs within days or weeks of first detection before they fade beyond observational limits. The resulting comprehensive catalog will inform global properties of the NEO population, advance scientific understanding of NEOs, produce essential data for robotic and spacecraft exploration, and develop a critical knowledge base to address the risk of NEO impacts. We intend to conduct this survey with complete transparency, publicly sharing our target lists and survey progress. We invite collaborative uses for these data as a way to broaden the scientific impact of this survey.

208.31 – A Search for Volatiles and Spectral Variation on the Surfaces of Trojan Asteroids

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Trojan asteroids comprise a substantial population of primitive bodies confined to Jupiter's stable Lagrange regions. Because they likely became trapped in these orbits at the end of the initial phase of planetary formation and subsequent migration, the compositions of Trojans provide unique perspectives on chemical and dynamical processes that shaped the Solar System. Ices and organics are of particular interest for understanding Trojan histories. Published near-infrared (0.7 to 4.0 μm) spectra of Trojans show no absorption bands due to H_2O or organics. However, if the Trojan asteroids formed at or beyond their present heliocentric distance of 5.2 AU and never spent significant amounts of time closer to the Sun, they should contain H_2O ice. Low densities of two Trojan multiple asteroid systems (Patroclus and Hektor) are consistent with the presence of ice. Similarly, cosmochemical and surface irradiation arguments have been used to explain the red spectral slope of Trojans as due to the presence of complex organic molecules. We present near infrared spectra of four Trojan asteroids (3451 Mentor, 3317 Paris, 627 Hektor, and 911 Agamemnon). All objects were observed at the NASA InfraRed Telescope Facility using the SpeX medium resolution spectrograph. Spectra of Mentor and Paris cover the wavelength range 0.7 to 4.0 μm. These observations were designed primarily to look for H_2O and organic absorptions in the 3 – 4 μm region. We see no evidence for any absorptions in the spectra of Mentor or Paris. Spectra of Hektor and Agamemnon cover the wavelength range 0.7 to 2.5 μm and span significant fractions of their respective rotation periods. No rotational variability is evident in the spectrum of Hektor. The spectra of Agamemnon may exhibit a very small amount of variability in spectral slope, but analysis is ongoing. We will discuss the implications of these results in terms of Trojan surface compositions.

208.32 – A Search for Colorful Characters Among the Jupiter Greeks and Trojans

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As more and more space craft rendezvous with asteroids, it has become increasingly apparent that asteroids do not always present a single heterogeneous surface to observers. Global variation in color and albedo can be caused by impact events or non-uniform composition which can, in turn, provide details about the recent collisional history and the formation mechanisms of these objects. Here we look to determine the level of surface color uniformity for a sample of Jupiter Greek and Trojan asteroids through multi-filter light curve observations. For this study high cadence, partial light curves were taken of several large (D > 60km) Trojan and Greek asteroids in simultaneous V and I broadband photometric filters using the CTIO 0.9m, the CTIO 1.0m, and the Lowell 42in telescopes. For these observations color variation of 0.03 magnitudes should be observable using relative photometry. The Greeks and Trojans themselves, as largely primordial populations and a key test parameters for the Nice Model, are very fascinating groups for studying Solar System formation. Information on the collisional history of those populations through a search for color variation in their largest members could prove vital for a better understanding of their evolution and origins.

208.33 – Search for Meter-sized Bodies in Meteoroid Streams

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We present the results of our attempts to detect large meter-sized meteoroids using ground-based optical telescopes, by targeting the radiant area of known meteoroid streams around the peak of their activity. The goals of the project are: - Determine the frequency of stream meteoroids in a size regime that is difficult to probe with other techniques; - Increase our chances of discovering a large meteoroid in an Earth-impacting trajectory. We targeted the radiant area of four established streams, selected on the basis of the peculiar properties and possible origin of the meteoroids. The radiants were imaged around the expected peak of activity using wide-field imagers on large aperture telescopes. Each set of observations consisted in multiple fields, to cover a large fraction of the radiant area; each field was exposed at least four times, and the resulting images were inspected both visually and via software to locate every detectable moving object. The typical limiting magnitude of the exposures was around V=22. Each object detected in the images was then investigated to verify if its motion could be compatible with it being a member of the targeted meteoroid stream. For the small fraction of detections that were compatible with the stream's orbit, we obtained targeted follow-up observations to clarify the actual orbital elements. None of the candidates turned out to be stream members. Interestingly, extrapolating the stream properties from the small size meteor component of the showers to the meter-size regime that we can probe with these observations resulted in a prediction that a few members of the stream should have been detected in most of the targeted radiants. Our lack of detections is therefore not a fault of the technique, but a hint that the targeted streams lack bodies in the size range of a few meters, when compared with the extrapolation from the smaller-size component that we detect as meteor activity on Earth. This information is very interesting for the interpretation of the possible formation mechanism for some of these streams, especially the ones that may not be of cometary origin.

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209.01 – A Review of Correlated Noise in Exoplanet Light Curves

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A number of the occultation light curves of exoplanets exhibit time-correlated residuals (a.k.a. correlated or red noise) in their model fits. The correlated noise might arise from inaccurate models or unaccounted astrophysical or telescope systematics. A correct assessment of the correlated noise is important to determine true signal-to-noise ratios of a planet's physical parameters. Yet, there are no in-depth statistical studies in the literature for some of the techniques currently used (RMS-vs-bin size plot, prayer beads, and wavelet-based modeling). We subjected these correlated-noise assessment techniques to basic tests on synthetic data sets to characterize their features and limitations. Initial results indicate, for example, that, sometimes the RMS-vs-bin size plots present artifacts when the bin size is similar to the observation duration. Further, the prayer beads doesn't correctly increase the uncertainties to compensate for the lack of accuracy if there is correlated noise. We have applied these techniques to several Spitzer secondary-eclipse hot-Jupiter light curves and discuss their implications. This work was supported in part by NASA planetary atmospheres grant NNX13AF38G and Astrophysics Data Analysis Program NNX12AI69G.

209.02 – Pipeline Characterization and Validation of Small HZ Planet Candidates in the Four-Year (Q1-Q16) Kepler Data Set

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Contributing teams: Kepler Science Operations Center, Kepler Science Office
The Transiting Planet Search (TPS) and Data Validation (DV) components of the Science Operations Center (SOC) Processing Pipeline were run with the SOC 8.3 codebase on the first three years (Q1-Q12) of Kepler data in October-November 2012. Threshold crossing event details and validation products were delivered in December 2012 to the Exoplanet Archive at the NASA Exoplanet Science Institute (NExScI). Kepler Objects of Interest (KOIs) identified in vetting the results of that run have subsequently been delivered to the archive. The SOC 9.1 codebase was released in July 2013. Processing of the four-year Kepler data set with SOC 9.1 was initiated shortly thereafter. Results and DV products will be exported to the Exoplanet Archive as before where they will be accessible by the science community and public at large. The primary functions of DV are to (1) characterize transiting planets identified in the Pipeline, (2) perform a powerful suite of diagnostic tests to aid in discrimination between true transiting planets and false positive detections, and (3) search for additional transiting planet signatures in light curves after transit signatures have been modeled and removed. We describe the characterization and validation of transiting planets in the Q1-Q16 data set with emphasis on small Habitable Zone (HZ) planet candidates that were not identified in earlier Pipeline runs with shorter data sets. We present planet model fit results for new candidates and examples of the diagnostics utilized to validate them. We also present examples of false positive detections most common in the region of planet radius/equilibrium temperature parameter space occupied by HZ Earths and Super-Earths. The Exoplanet Archive is located at exoplanetarchive.ipac.caltech.edu. Funding for the Kepler Mission has been provided by the NASA Science Mission Directorate.

209.03 – Follow-up of Kepler candidates transiting hot-Jupiter with ground based photometry

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We have selected a group of planetary candidates from the Kepler field with short transiting times and observed them at the West Mountain Observatory (WMO) with the objective to confirm or find their nature. The resulting light curves showed that KOI667 is a diluted eclipsing binary. Further observations at the Dominion Astrophysical Observatory (DAO) and the use of Point Spread Function (PSF) photometry resolved the eclipsing binary. We present the techniques used to obtain the light curves and the identification of the eclipsing binary.

209.04 – Photometric Observations of Transiting Planet Candidates With a Small Telescope

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We are part of a ground based team that looks for transiting planets. Our collaborators' telescopes gather photometric data on thousands of stars each night, searching for any which show the small dip in brightness that may be indicative of a planet passing in front of the star. When such a candidate has been identified, it is put into a schedule for further photometric and radial velocity observations. We take follow-up photometric data with the 16-inch David Derrick telescope at the Orson Pratt Observatory at Brigham Young University (BYU). As the predicted drops in magnitude caused by transiting planets are often quite small, we have to determine the limits of this telescope – to see if it is sensitive enough to detect such minute changes in brightness or if there is enough inherent error to hide the transit. We present follow-up data taken with our telescope on several of the team's transiting planet candidates along with observations of known transiting planets to demonstrate the telescope's capabilities. We show the errors in photometry of our target objects and also include plots of stable ensemble stars to exhibit the level of variability that we see from imperfections in images and observing conditions. This research was funded in part by the Physics and Astronomy REU program at Brigham Young University during the summer of 2013.

209.05 – Beyond Exoplanets: Taking advantage of Kepler Object of Interest fields after the presence or absence of an exoplanet has been documented.

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Contributing teams: Dr. Denise Stepehns, Dr. Michael Joner
Since the Kepler Mission made public its data on planet-candidates we have observed a few Objects of Interest -KOI- with our 0.9 m telescope at West Mountain Observatory to confirm or reject their nature as planets. Most of our chosen targets were found not to be planets. However, the data acquired need not be discarded since other bodies in the fields may present interesting light curves deserving of further investigation and study. This is the case for one of our KOI candidates, which turned out to be an eclipsing binary system. While performing differential photometry with stars in the field, I found a contact eclipsing binary that was not in the Kepler data base. In this poster I will present data on the new contact binary and discuss other interesting variable objects I have found in the Kepler field of view. This research was performed while participating in the Physics and Astronomy REU program at Brigham Young University during the summers of 2012 and 2013.

209.06 – TRANSIT MODEL FITTING IN THE KEPLER SCIENCE OPERATIONS CENTER PIPELINE: NEW FEATURES AND PERFORMANCE

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We describe new transit model fitting features and performance of the latest release (9.1, July 2013) of the Kepler Science Operations Center (SOC) Pipeline. The targets for which a Threshold Crossing Event (TCE) is generated in the Transiting Planet Search (TPS) component of the pipeline are subsequently processed in the Data Validation (DV) component. Transit model parameters are fitted in DV to transit-like signatures in the light curves of the targets with TCEs. The transit model fitting results are used in diagnostic tests in DV, which help to validate planet candidates and identify false positive detections. The standard transit model includes five fit parameters: transit epoch time (i.e. central time of first transit), orbital period, impact parameter, ratio of planet radius to star radius and ratio of semi-major axis to star radius. Light curves for many targets do not contain enough information to uniquely determine the impact parameter, which results in poor convergence performance of the fitter. In the latest release of the Kepler SOC pipeline, a reduced parameter fit is included in DV: the impact parameter is set to a fixed value and the

four remaining parameters are fitted. The standard transit model fit is implemented after a series of reduced parameter fits in which the impact parameter is varied between 0 and 1. Initial values for the standard transit model fit parameters are determined by the reduced parameter fit with the minimum chi-square metric. With reduced parameter fits, the robustness of the transit model fit is improved significantly. Diagnostic plots of the chi-square metrics and reduced parameter fit results illustrate how the fitted parameters vary as a function of impact parameter. Essentially, a family of transiting planet characteristics is determined in DV for each Pipeline TCE. Transit model fitting performance of release 9.1 of the Kepler SOC pipeline is demonstrated with the results of the processing of 16 quarters of flight data. New model fit diagnostic figures that appear in DV export products are also presented. Funding for the Kepler Mission has been provided by the NASA Science Mission Directorate.

209.07 – Computational Challenges in Processing the Q1-Q16 Kepler Data Set

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Contributing teams: Kepler Science Operations Center

Since launch on March 6th, 2009, NASA's Kepler Space Telescope has collected 48 months of data on over 195,000 targets. The raw data are rife with instrumental and astrophysical noise that must be removed in order to detect and model the transit-like signals present in the data. Calibrating the raw pixels, generating and correcting the flux light curves, and detecting and characterizing the signals require significant computational power. In addition, the algorithms that make up the Kepler Science Pipeline and their parameters are still undergoing changes (most of which increase the computational cost), creating the need to reprocess the entire data set on a regular basis. We discuss how we have ported all of the core elements of the pipeline to the Pleiades cluster at the NASA Advanced Supercomputing (NAS) Division, the needs driving the port, and the technical challenges we faced. In 2011 we ported the Transiting Planet Search (TPS) and Data Validation (DV) modules to Pleiades. These pipeline modules operate on the full data set and the computational complexity increases roughly by the square of the number of data points. At the time of the port it had become infeasible to run these modules on our local hardware, necessitating the move to Pleiades. In 2012 and 2013 we turned our attention to the front end of the pipeline; Pixel-level Calibration (CAL), Photometric Analysis (PA), and Pre-Search Data Conditioning (PDC). Porting these modules to Pleiades will allow us to reprocess the complete data set on a more frequent basis. The last time we reprocessed all data for the front end we only had 24 months of data. We estimate that the full 48-month data set would take over 200 days to complete on local hardware. When the port is complete we expect to reprocess this data set on Pleiades in about a month. The NASA Science Mission Directorate provided funding for the Kepler Mission.

209.08 – Effect of Clouds on Exoplanet Visible-Wavelength Phase Curve Observations

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We investigate the effect of clouds in hot Jupiter atmospheres on the observations of transiting exoplanets. We consider how non-uniformity in cloud coverage on hot Jupiters may affect the reflectance spectra and resulting phase curve. Hot Jupiters are Jovian-sized exoplanets orbiting close to their parent star. The predicted temperatures at these close separations generally would not support cloud formation. However, tidal locking will create a permanent day-side and night-side with large temperature, pressure, and species-state contrasts that might favor cloud formation on the night-side. A rapid eastward equatorial flow of hot-Jupiter atmospheres has been well studied and observed. This jet causes the hottest and coldest parts of the atmosphere to be misaligned from the substellar and anti-stellar points. This misalignment can be seen as an offset in the infrared phase curve maximum from the secondary eclipse. The addition of clouds into this complex thermal and advective system will change the albedo spectra of the planet and the phase curve of reflected intensity. The current state of exoplanet atmospheric modeling couples radiative transfer with the dynamics of the atmosphere. Our albedo model inputs temperature and pressure profiles from radiative-convective simulations to produce albedo spectra in the visible wavelengths based on parameters that include planet-star separation, gravity, metallicity, and source-observer geometry. Optical phase curves are produced from these albedo spectra in a variety of filters. We first test this method on a Jupiter-like model with a 90° misalignment, resulting in a dayside that is half cloudy. This misalignment manifests as a large shift of the phase curve maximum because of the increased reflectivity of the cloud-covered area. The model is then extended to a 30° misalignment similar to what is expected for optical observations of an HD189733b-like planet.

209.09 – A radiative-convective equilibrium model for young giant exoplanets: Application to beta Pictoris b

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We developed a radiative-convective equilibrium model for young giant exoplanets. Input parameters are the planet's surface gravity, effective temperature and elemental composition. Under the additional assumption of thermochemical equilibrium, the model predicts the equilibrium temperature profile and mixing ratio profiles of the most important gases. Opacity sources include the H2-He collision-induced absorption and molecular lines from H2O, CO, CH4, NH3, VO, TiO, Na and K. Line opacity is modeled using k-correlated coefficients pre-calculated over a fixed pressure-temperature grid. Cloud absorption can be added above the expected condensation level (e.g. iron or silicates) with given scale height and optical depth at some reference wavelength. Scattering is not included at the present stage. Model predictions will be compared with the existing photometric measurements of planet Beta Pictoris b in the J,H,K,L and M bands (Lagrange et al. 2009; Quanz et al. 2010; Bonnefoy et al. 2011, 2013). This model will be used to interpret future photometric and spectroscopic observations of exoplanets with SPHERE, mounted at the VLT with first light expected in mid-2014.

209.10 – Formation of Atmospheric Jets and Vortices: From Gas Giants to Brown Dwarfs

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The recent discovery of ~1000 brown dwarfs has provided a unique opportunity to study a new paradigm of atmospheric dynamics. These substeller bodies resemble high-mass versions of gas-giant planets in our solar system but with hot atmospheres, which implies large convective heat fluxes in their interiors and strong radiative damping in their atmospheres. They also differ from both Jupiter and extrasolar hot Jupiters since most brown dwarfs experience no external stellar forcing. Observations show that both Jupiter and hot Jupiters exhibit east-west jet streams and equatorial superrotation in their atmospheres. Under the conditions of fast rotation, short radiative time constant and no external stellar flux, do the atmospheres of the brown dwarfs also exhibit similar circulation patterns? Or they are dominated by small-scale turbulence and vortices instead? The answers to these basic questions will provide a foundation for understanding the observed infrared time variability of many brown dwarfs in the L/T transition region. From the point of view of atmospheric dynamics, gas giants and brown dwarfs can be considered as two end members of a single population. We use a global shallow-water model to investigate the dominant atmospheric dynamics during the continuous transition from gas giants to brown dwarfs. The shallow-water layer represents the flow in the outer atmospheric layer (pressure less than several bars), which is driven by the internal convective processes from below. Two kinds of forcing are investigated in the shallow water framework: a mass forcing that represents the effect of condensation and latent heating; and a topographic forcing that represents perturbations caused by convection at the radiative-convective boundary. We investigate the extent to which the atmospheric turbulence self-organizes into vortices or zonal jets, the role of inverse energy cascades and inhomogeneous mixing associated with Rossby wave breaking (if any), and the dominant length and time scales of the flow as a function of the radiative time constant, rotation rate, details of the forcing, and other parameters. Our results will be compared to observations, both for solar-system giant planets and brown dwarfs.

209.11 – "Exploring atmospheres of Mini-Neptunes orbiting different stars: the effect of stellar flares"

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Ground and space based surveys resulted in the discovery of a growing number of hot mini-Neptunes. Since no such planets exist in our Solar System, their atmospheric composition and structure remains poorly understood. These planets are also interesting targets for future observations, therefore, addressing their atmospheric structure and composition is a major issue and the aim of our work. We address the differences in Mini-Neptunes atmospheres according to the observables semimajor axis and stellar type. Our models explore the detectable atmospheric features for a wide range of stellar types. Many main sequence M stars present strong chromospheric activity that produces high-energy radiation. We particularly study the effect of this radiation in hot mini-Neptunes atmospheres, simulating the effects of a flare and exploring the change in the photochemistry.

209.12 – Exoplanet Equilibrium Chemistry Calculations

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Recently, Agundez et al. (2012, A&A 548, A73) used a chemical kinetics code to study a model HD 209458b (equilibrium temperature of 1450 K, assuming full redistribution and 0 albedo). They found that thermochemistry dominates most of the dayside, but that significant compositional gradients may exist across the dayside. We calculate equilibrium-chemistry molecular abundances for several model exoplanets, using NASA's open-source Chemical Equilibrium Abundances code (McBride and Gordon 1996). We vary the degree of radiation redistribution to the dark side, ranging from total redistribution to instantaneous reradiation. Atomically, both the solar abundance multiple and the carbon fraction vary. Planet substellar temperatures range from just above 1200 K, where photochemistry should no longer be important, to those of hot planets (3000 K). We present synthetic abundance images for the key spectroscopic molecules CO, CH4, and H2O for several hot-Jupiter model planets. This work was supported by the NASA Planetary Atmospheres grant NNX12AI69G.

209.13 – Spectral Fingerprints of Mini and Super Earths

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Kepler is detecting a range of potentially rocky planets in the habitable zone, some smaller and some bigger than Earth. The mass and resulting gravity will change the observable spectrum for such planets - was well as our ability to detect those signature, including biosignatures, with future missions. We explore the spectral changes of Mini-Earths and Super-Earths for various stellar types in the Habitable Zone, and the detectability of biosignatures.

209.14 – The Effects of Refraction on Transit Transmission Spectroscopy

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We present a new model for transit transmission spectroscopy that includes refraction, and examine the effects of refraction on transit transmission spectra. We also perform detectability studies to show the potential effects of refraction on hypothetical observations of Earth analogs with the James Webb Space Telescope (JWST) Near-Infrared Spectrograph (NIRSPEC). Due to refraction there will be a maximum tangent pressure that can be probed in transit for each planet-star system, with the maximum pressure depending on the planet's composition, the size of the star and the planet-star distance. We show that for an Earth-analog orbiting a Sun-like star, this maximum tangent pressure is ~0.2 bars. The 0.2 bar cutoff leads to a decrease in signal-to-noise ratio (SNR) of 80% when compared to the non-refracted spectrum for many key spectral features in the visible and near-infrared. We also show that for an Earth-analog orbiting an M5V star, the maximum tangent pressure is ~0.9 bars, which leads to a decrease in SNR of 15%. Furthermore, we have found that refraction can cause temporal variations in a transit transmission spectrum, with more flux transmitted from progressively lower altitudes as a planet nears center of transit. These variations may provide a way to obtain altitude-dependent spectra of exoplanet atmospheres, and could potentially be used to retrieve vertical mixing ratio profiles of gases. While obtaining such observations at sufficiently high SNR is unlikely for Earth analogs in the near future, it may be possible to do this with JWST for Jupiter and Neptune-sized planets.

209.15 – Two HAT-P-16b Spitzer Eclipse Observations

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We report two Spitzer secondary eclipses of exoplanet HAT-P-16b. Discovered by Buchhave et al. (2010), this hot Jupiter is four times more massive than Jupiter and has a blackbody equilibrium temperature of 1626 K. We find a 3.6-micron eclipse depth of 0.129% ± 0.013% and a 4.5-micron eclipse depth of 0.210% ± 0.015%. These correspond to brightness temperatures of 1804 ± 71 K and 1946 ± 69 K respectively. We use the eclipse depths to constrain atmospheric models both with and without a thermal inversion, and find that those with a thermal inversion more closely match the data. We also refine the orbit of the planet, and confirm a small yet significant eccentricity of 0.0435 ± 0.0013. These observations are part of the Spitzer Exoplanet Target of Opportunity program. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA, which provided support for this work.

209.16 – Secondary Eclipse Observations of the Low-Mass Hot-Jupiter WASP-11b/HAT-P-10b

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Contributing teams: UCF Exoplanets Group

WASP-11b/HAT-P-10b is a hot-Jupiter planet that orbits a K3 dwarf every 3.722 days at a distance of 0.0439 AU. Using the Spitzer Space Telescope in 2009 (Harrington, P.I.) and 2010 (Knutson, P.I), we observed five secondary eclipses of WASP-11b/HAT-P-10b: two in the 3.6-micron channel, two in the 4.5-micron channel, and one in the 8-micron channel. We present eclipse-depth measurements, estimates of infrared brightness temperatures, and the first constraints on the atmospheric pressure and temperature profile and chemical compositions. We also refine its orbit using our own secondary-eclipse measurements in combination with external radial-velocity and transit observations from both professional and amateur observers. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. This work was supported in part by NASA Planetary Atmospheres grant NNX13AF38G.

210 – Rings Posters

210.01 – Features in Saturn's F Ring

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We report on the results of 150 stellar occultations by the F ring of Saturn performed between 19 May 2005 and 2 July 2013 by the High Speed Photometer of the Cassini Ultraviolet Imaging Spectograph. A total of 56 statistically-significant features have been detected by an algorithm and visually confirmed. These features include unusually-shaped F ring cores and regions of increased density interpreted as clumps ('kittens'). We have measured approximate radial widths for features interpreted as clumps, which range from 0.17 to 1.17 kilometers. When fit to a cumulative size distribution, the power-law index of -1.80 is similar to the value of -1.49 determined by Meinke, et al. (2012).

210.02 – Some results on the production and orbital evolution of small particles in the G ring arc

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The G ring, located at about 168000km from Saturn, is a faint ring of 6000km wide. Images sent by the Cassini spacecraft have revealed a denser region (arc) located at 167500km. Immerse in this arc a small satellite, named Aegaeon, was also discovered in a sequence of several Cassini images. Aegaeon, with size smaller than 1km, is trapped in a 7:6 corotation resonance with Mimas. This satellite can generate small particles as a result of collisions of interplanetary debris onto its surface. From the analytical model summarized in Sfair & Giuliatti Winter (2012), and assuming the typical mass flux at Saturn to be 1.8×10^{-16} km/s^2 and the nominal parameters of Saturn and Aegaeon we could determine the ejecta yield (Y) and the mass production rate (M^+) to be 21153.86 and 5.9×10^{-6} kg/s, respectively. In 100yrs the satellite Aegaeon can produce a mass of 10^4 kg of dust particles. We also study the orbital evolution of a sample of small particles (sizes ranging from 1 to 10μm) under the gravitational effects of Mimas and the solar radiation pressure. These particles were initially located in the arc about ±20km from the semimajor axis resonance of Aegaeon with ±30° in longitude. Our results show that, despite the particles are initially in a corotation resonance with Mimas, the effects of the solar radiation pressure remove the particles from the arc in a timespan of 50yrs. We will discuss our results and compare with the other arcs and small satellites located in the saturnian system.

210.03 – Predator-Prey Model for Haloes in Saturn's Rings

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Particles in Saturn's rings have a tripartite nature: (1) a broad distribution of fragments from the disruption of a previous moon that accrete into (2) transient aggregates, resembling piles of rubble, covered by a (3) regolith of smaller grains that result from collisions and meteoritic grinding. Evidence for this triple architecture of ring particles comes from a multitude of Cassini observations. In a number of ring locations (including Saturn's F ring, the shepherded outer edges of rings A and B and at the locations of the strongest density waves) aggregation and dis-aggregation are operating now. ISS, VIMS, UVIS spectroscopy and occultations show haloes around the strongest density waves. Based on a predator-prey model for ring dynamics, we offer the following explanation: 1. Cyclic velocity changes cause the perturbed regions to reach higher collision speeds at some orbital phases, which preferentially removes small regolith particles; 2. This forms a bright halo around the ILR, if the forcing is strong enough; 3. Surrounding particles diffuse back too slowly to erase the effect; they diffuse away to form the halo. The most rapid time scale is for forcing/aggregate growth/disaggregation; then irreversible regolith erosion; diffusion and/or ballistic transport; and slowest, meteoritic pollution/darkening. We observe both smaller and larger particles at perturbed regions. Straw, UVIS power spectral analysis, kittens and equinox objects show the prey (mass aggregates); while the haloes' VIMS spectral signature, correlation length and excess variance are created by the predators (velocity dispersion) in regions stirred in the rings. Moon forcing triggers aggregation to create longer-lived aggregates that protect their interiors from meteoritic darkening and recycle the ring material to maintain the current purity of the rings. It also provides a mechanism for creation of new moons at resonance locations in the Roche zone, as proposed by Charnoz etal and Canup.

210.04 – Looking Forward to Cassini's Proximal Orbits: the Innermost Radiation Belt of Saturn

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Contributing teams: Cassini Proximal Hazard Working Group

The Cassini mission to Saturn will conclude with over twenty flybys of the equatorial gap region between Saturn's upper atmosphere and the inner D ring. This region at 62,000 - 65,000 kilometers from the center of Saturn is of comparable width to the inner Van Allen radiation belt of Earth and could contain Saturn's innermost belt of presently uncertain intensity and impact on the Cassini spacecraft. As first proposed by Cooper [BAAS 40(3), 460, 2008] this innermost belt could be populated to potentially very high intensities by protons and electrons from cosmic ray albedo neutron decay. The primary neutron source at high energies above 10 MeV would be from galactic cosmic ray interactions with the main rings of Saturn, but more recent work suggests a secondary source at lower energies from similar interactions with Saturn's upper atmosphere. At keV energies a third source from magnetospheric energetic neutral atom interactions with the exospheric gas extending through the gap region could be effective as observed earlier by Cassini. A fourth source includes eV - keV ions from low-energy neutral atom ejection out of the ring atmosphere. Ions from the ring ionosphere were also observed by Cassini. Since trapping lifetimes of keV - GeV protons due to radial diffusion in the gap region are projected to be extremely long, correspondingly high intensities could arise unless there was sufficient exospheric gas and ring material to reduce lifetimes far below the diffusion limit. Limits from new modeling are presented for the potential range of trapped particle intensities at MeV - GeV energies. Apart from the potential radiation and other hazards, this first exploration of the gap region will provide a fascinating conclusion to the Cassini mission.

210.05 – Temperatures of wakes in Saturn's A ring

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Contributing teams: Cassini CIRS ring team

The physical temperatures of the Saturn's A ring measured by the Cassini Composite Infrared Spectrometer (CIRS) show quadraople azimuthal modulations besides temperature drops in Saturn's shadow. These azimuthal modulations are likely to be caused by self-gravity wakes. In this paper, we develop a new thermal model in which wakes are modeled as elliptical cylinders ignoring inter-wake particles. All the heat fluxes are calculated explicitly taking into account inter-wake shadowing and heating. We apply our model to azimuthal scans of the A ring obtained by the CIRS. The thermal inertia estimated from the eclipse data (data only inside and near Saturn's shadow) of the low phase scans is found to be about 10 in MKS units. With this value of the thermal inertia, the amplitude of the azimuthal temperature modulation is overestimated in our model as compared with those observed. This is likely to be because our model ignores inter-wake particles. The bolometric reflectance of wakes is estimated to be 0.35-0.4 although lower values are required to reproduce temperatures at low solar phase angles. This apparent phase dependence of the reflectance indicates that roughness on the wake surfaces is necessary.

210.06 – Small Particle Population in Saturn's A Ring from Self-Gravity Wake Observations

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Particles in Saturn's A and B rings form ephemeral elongated gravitationally bound clumps known as self-gravity wakes. These clumps are torn apart by shear across the clump leading them to have a characteristic cant angle of about 25 degrees to the direction of orbital motion. This preferred orientation of the clumps leads to a strong dependence of the observed optical depth of the rings with viewing geometry. Previous studies have taken advantage of this preferred orientation and the multitude of stellar occultation observations of the rings to determine the characteristics of self-gravity wakes in the A and B rings (Colwell, J. E., et al. 2006. Geophys. Res. Lett. 33, L07201, doi:10.1029/2005GL025163, Colwell, J. E., et al. 2007. Icarus, 190, 127-144, Hedman et al. 2007 Astron. J. 133, 2624-2629, Nicholson and Hedman 2010 Icarus 206, 410-423.). Here we combine data from the Cassini UVIS and VIMS stellar occultations to model the self-gravity wakes. We present results of modeling self-gravity wakes combining both UVIS and VIMS data where the population of sub-cm particles in the gaps between the wakes and the size of the smallest particle are free parameters. Light diffracted by particles smaller than ~1 cm in diameter is not replaced by diffraction from neighboring particles in the small VIMS field of view, while all lost diffracted light in UVIS observations is replaced by light diffracted from particles in its much larger field of view. Consequently VIMS measures a higher optical depth than UVIS if there is a population of

sub-cm particles. We find that there is a significant population of sub-cm particles in the outer A ring with an increasing fraction as the ring edge is approached. In addition, the size of the smallest particle decreases in the outer A ring. This is consistent with earlier findings based on differential optical depth measurements at radio wavelengths (Zebker et al. 1985, Icarus 64, 531-548). These results suggest that there may be more vigorous interparticle collisions in the outer A ring, where satellite perturbations are strong, leading to greater erosion of weakly bound clumps.

210.07 – Higher Order Moments in the Statistics of Stellar Occultations of Saturn's Rings

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The Ultraviolet Imaging Spectrometer aboard the Cassini spacecraft has observed more than 100 stellar occultations by Saturn's rings. Analysis of the statistics of the photon counts collected during these occultations is a potentially useful tool for probing ring particle sizes and unresolved structure. We have previously discussed the presence of variance in photon counts in excess of that due to counting statistics, and have related this excess to an autocorrelation length associated with the finite size of particles and clumps in the rings (Colwell et al. 2012, DPS meeting #44, #501.05). Here we consider the higher order moments of skewness and kurtosis of the photon count time series. The skewness measures the asymmetry of the distribution of photon counts. In regions of low optical depth the mean count rate is high and the distribution approaches a normal distribution with skewness of zero. In high optical depth regions the mean count rate is low and the distribution becomes asymmetric due to the truncation of the distribution at zero counts. This corresponds to a positive skewness. We find that the C ring plateaus deviate from the distribution of skewness with optical depth of the rest of the rings, exhibiting a higher skewness than other ring regions with similar optical depth. The higher skewness in the plateaus indicates more measurements of high count rates, consistent with occasional holes or so-called "ghosts" in the plateaus (Baillié et al. 2013, Astron J. 145, 171, doi:10.1088/0004-6256/145/6/171). Another interesting region is the inner 700km of the B ring which has a lower skewness than the remainder of the "B1" region of the B ring. We will present results of skewness and kurtosis across the main ring system.

210.08 – Hydrodynamic Simulations of Planetary Rings

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Simulations of rings have traditionally been done using N-body methods, granting insight into the interactions of individual ring particles on varying scales. However, due to the scale of a typical ring system and the sheer number of particles involved, a global N-body simulation is too computationally expensive, unless particle collisions are replaced by stochastic forces (Bromley & Kenyon, 2013). Rings are extraordinarily flat systems and therefore are well-suited to existing geophysical shallow-water hydrodynamics models with well-established non-linear advection methods. By adopting a general relationship between pressure and surface density such as a polytropic equation of state, we can modify the shallow-water formula to treat a thin, compressible, self-gravitating, shearing fluid. Previous hydrodynamic simulations of planetary rings have been restricted to axisymmetric flows and therefore have not treated the response to nonaxisymmetric perturbations by moons (Schmidt & Tscharnuter 1999, Latter & Ogilvie 2010). We seek to expand on existing hydrodynamic methods and, by comparing our work with complementary N-body simulations and Cassini observations, confirm the veracity of our results at small scales before eventually moving to a global domain size. We will use non-Newtonian, dynamically variable viscosity to model the viscous transport caused by unresolved self-gravity wakes. Self-gravity will be added to model the dynamics of large-scale structures, such as density waves and edge waves. Support from NASA Outer Planets and Planetary Geology and Geophysics programs is gratefully acknowledged.

210.09 – Compositional and Mixing Model Analysis of Cassini UVIS Spectra of Saturn's Rings

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The composition of non-icy material and micro-scale morphological properties of icy mixtures in the Saturn system are investigated by comparing photometric models to far ultraviolet reflectance spectra of the rings. In particular different compositions and mixing models are used as a means to constrain the abundance of non-icy material in Saturn's rings and the manner in which the non-icy material is dispersed. Mixing models investigated consist of either having non water ice constituents embedded in water ice grains so that the optical constants are a linear combination of individual optical constants or that the regolith consists of discrete grains of water ice and non-ice constituents. In either case the ring particle albedo for the A, B, C rings and Cassini division is determined at discrete wavelengths across the water ice absorption edge at 165 nm and then compared to spectral models that use available optical constants in the FUV for water ice and contaminant material. We find that a mixture with discrete grains of water ice and contaminant fit the data best, which may suggest that at very short wavelengths the regolith constituents are distinguishable.
With this type of mixture we find water ice abundance greater than 95%, water ice grain sizes of a few microns, and contaminant diameters much less than a micron. There may also be a small positive correlation between larger grain sizes and contaminated regions of the rings.

210.10 – Modeling Saturnshine in Cassini Images of the Rings

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In some viewing geometries, such as large solar phase angles or small solar elevation angles, the light reflected by or transmitted through Saturn's rings can be dominated by Saturnshine, i.e., illumination of the rings by the planet. Saturnshine results in longitudinal variations in the reflectivity of the rings. In addition, Saturn's A Ring and, to a lesser extent, B Ring, show intrinsic longitudinal variations ('azimuthal asymmetry') due to self-gravity wakes. Any attempt to infer physical properties of ring particles and their spatial distribution using ring photometry must consider both Saturnshine and self-gravity wakes. 'Ringshine,' in turn, complicates photometry of Saturn itself [1]. We have improved the Saturnshine model in [2], which applies a ray-tracing code to N-body simulations of a patch of Saturn's rings, by incorporating measurements of the planet's reflectivity in Cassini images taken in a range of viewing geometries through a number of broadband filters. We will compare the results of our photometric model with measurements of the I/F of the main rings, and will attempt to constrain the intrinsic properties of ring particles, such as their coefficients of restitution in collisions and internal densities. We thank the Cassini project for support. [1] Skinner, R.W., and Weiss, J.W. (2011). http://serc.carleton.edu/cismi/undergrad_research/posters/52679.html [2] Porco, C.C., et al. (2008). Astron J. 136, 2172-2200

210.11 – Mapping the Thermal Inertia of Saturn's Rings with Cassini CIRS

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We use data from Cassini's Composite Infrared Spectrometer to map out the thermal response of Saturn's ring particles passing through Saturn's shadow and to determine variations in ring thermal inertia. CIRS records far infrared radiation in three separate detectors, each of which covers a distinct wavelength range. In this work, we analyze rings spectra recorded at focal plane 1 (FP1), as its wavelength response (16.7-1000 microns) is well suited to detecting direct thermal emission from Saturn's rings. The thermal budget of the rings is typically dominated by solar radiation. When ring particles enter Saturn's shadow this source of energy is abruptly cut off with a consequential drop in ring temperature. Likewise, temperatures rebound when particles exit the shadow.
To characterize these heating and cooling events, FP1 was repeatedly scanned across the main rings. Each scan was offset from either the ingress or egress shadow boundary by an amount corresponding to a fraction of a Keplerian orbit. By resampling these scans onto a common radial grid, we can map out the rings' response to the abrupt changes in insolation at shadow ingress and egress. Periods near equinox represent a unique situation. During this time the Sun's disk crosses the ring plane and its rays strike the rings at zero incidence. Solar heating is virtually absent, and thermal radiation from Saturn and sunlight reflected by Saturn dominate the thermal environment. While ring temperature variations at equinox are much more subtle, they represent temperature contrasts that vary at the unique timescale corresponding to variations in Saturn contributions to the rings' thermal

budget. By analyzing CIRS data at a variety of locations and epochs, we will map out thermal inertia across the rings and attempt to tease out structural information about the particles which comprise Saturn's rings. This presentation will report upon our progress towards these ends. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Copyright 2013 California Institute of Technology. Government sponsorship acknowledged.

210.12 – Analysis of Bending Waves in Saturn's Rings with Cassini UVIS Stellar Occultations

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Spiral bending waves in Saturn's rings are caused by vertical resonances with Saturn's moons, in particular Titan and Mimas. These waves are revealed in stellar occultation data from the Ultraviolet Imaging Spectrograph aboard the Cassini Spacecraft. The detectability of these waves in the occultation data depends on the viewing geometry: individual wave peaks and troughs are only seen at stellar elevation angles B<45 degrees from the ring plane. Bending waves, like the more abundant density waves, act as local tracers of the ring mass. The local surface mass density can be determined from the wavelength dispersion. We present analyses of the bending waves associated with the relatively strong 5:3, 7:4 and 8:5 inner vertical resonances with Mimas located at 127,765 km, 131,900 km, and 135,640 km from Saturn's center, respectively. All three of these waves are located in the A ring. We have not yet performed an analysis of the Mimas 4:2 bending wave due to the complex structure of the B ring region in which it propagates. The Mimas 5:2 resonance also lies within the B ring and will be analyzed later. While individual wavelengths cannot be detected in occultation profiles with B greater than 45 degrees, there is an overall rise in optical depth at the location of the Mimas 5:3 bending wave that corresponds with the radial extent of the wave (130 km). Interference with nearby density waves complicates the analysis of the Mimas 7:4 and 8:5 bending waves. Wavelet analysis reveals the radial extent of the 7:4 and 8:5 waves to be 70 km and 40 km, respectively. We provide a comparison of the surface mass densities at these locations with the surface mass densities previously determined from analysis of density waves.

210.13 – Saturn's Maxwell Ringlet from Cassini UVIS Observations

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The Maxwell ringlet is one of the most prominent ringlets in Saturn's rings. In contrast to the Titan and Huygens ringlet no ring-moon resonance has been associated with its location at about 87500km. First measured from Voyager images and occultations the Maxwell ringlet exhibits a clear m=1 pattern and a linear radius-width-relation consistent with a freely, uniformly precessing ringlet. Stellar occultations by Cassini UVIS confirm this basic understanding of the ringlet's kinematics. However, despite its location in the rather faint C ring it has significant optical depth ranging between 1 and 5 depending on corotating longitude. Moreover, the data show regions of higher and lower optical depth within the ringlet. The peaks and troughs in each occultation cut appear very regular, giving an impression of a wave whose wavelength decreases towards Saturn. This wavy signature exhibits a clear but changing dispersion relation which can be expressed as a function of corotating longitude. We will present our current understanding of the Maxwell ringlet from nearly a hundred of Cassini UVIS occultations and compare it to the Titan and Huygens ringlets.

210.14 – Analytical and numerical study of capture scenarios of a satellite in coupled mean motion resonances

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Many bodies in the Solar System are involved in mean motion resonances. The simplest case of all is that of two satellites, one of them with negligible mass (test particle), orbiting in the same plane and close to a mean motion first order resonance of the type m+1 :m. In this situation, two critical resonant angles appear, respectively called the Corotation Eccentric Resonance (CER) and the Lindblad Eccentric Resonant (LER) arguments. Each of them has very different physical effects on the test particle, but surprisingly, no general treatment of the coupling between these two resonances has been presented so far in the literature. Here we present a generic dynamical study of this coupling, that we call the CoraLin model. It uses non-dimensional quantities, and describes all possible configurations between the satellites near horizontal first order mean motion resonances. We apply this model to several recently discovered small Saturnian satellites dynamically linked to Mimas through first mean motion resonances : Anthe, Methone and Aegaeon, all associated with ring arc material. The presence of these three structures are consistent with their confinement by CER with Mimas : Aegaeon is trapped in an inner 7 :6 CER with Mimas, while Anthe and Methone are respectively near the outer 14 :15 and a 10 :11 CER resonances. All satellites are also perturbed by the associated LER's, in a way described by the CoraLin model. Poincare surfaces of section reveal the dynamical structure of each orbit, and for some of them, their proximity to chaotic regions. Those sections may reveal the dynamical origin of those bodies. In particular, we discuss the probability of capturing a satellite into one of the CER's with Mimas. Two possible processes of capture for Anthe, Methone and Aegaeon are investigated, the first is a direct capture in CER, it occurs in eccentric Mimas's orbit. The second scenario involves a capture first in LER, which occurs for a circular Mimas's orbit, before the excitation of the eccentricity of Mimas orbit by the Mimas-Thetys resonance. We will discuss the potential implications of this work, in particular the constraints it may provide on Mimas' orbital evolution.

210.15 – The effects of Micrometeoroid Bombardment and Ballistic Transport on the C ring's Structure.

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The rings huge surface area-to-mass ratio make them particularly susceptible to modification due to extrinsic meteoroid bombardment. Meteoroid impacts on the rings can produce a large amount of particulate ejecta with the vast majority of the dust and debris produced from these collisions being ejected at speeds much less than the velocity needed to escape the rings. As a result, a copious exchange of ejecta between different ring regions can occur through ballistic transport, which over time can lead to the structural and compositional evolution of the rings on a global scale. We have employed a recently developed code for simultaneously modeling the structural and compositional evolution of rings to that of Saturn's C ring and inner B ring where most of the current structure remains poorly understood. We focus here particularly on the C ring plateaus and explore what role ballistic transport may play in their observed structure. We have modeled the effect of various important parameters such as the magnitude of the collisional viscosity, the mass contained in the C ring plateaus (through the opacity), and the steepness and lower velocity threshold of the ejecta velocity distribution, assuming a prograde-biased ejecta distribution. We find that the outer edges of plateaus can be maintained at their current observed sharpness even as they 'migrate' over long periods. However, a retrograde component to the ejecta distribution (that might arise from disruptive impacts rather than cratering) is likely needed in order to prevent them from smearing out due to advection. With this component in place, we predict that C ring plateaus could be maintained at their observed sharpness over long periods of time due to ballistic transport provided the micrometeoroid flux at Saturn is not too different from its current accepted value. Finally, we also confirm the claim by Durisen et al. (1992, Icarus) that an inner edge with a large optical depth contrast can be maintained for very long periods.

210.16 – Ground-based optical and polarized opposition effect of the Saturn's B ring: observations and numerical modeling

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After studying the morphology of the Saturn's main rings opposition effect (Deau et al., 2013, Part 1, Icarus, vol. 226, 591) and applying analytical radiative models to derive physical properties of the ring particles and their regolith (Deau, 2013, Part 2, Icarus, Accepted), we continue our investigation of the Saturn's rings opposition effect by studying the polarimetry of rings near zero phase. For this study, we have used only Earth-based observations of the B ring in unpolarized and polarized lights (Franklin and Cook, 1965, AJ, 70, pp 704-720; Lyot, 1929, Annales Obs. Paris, vol.8, 1). We used the most high end modeling available so far, which consists of single and multiple scattering in a packed media, and includes the coherent backscattering and shadow hiding (Muinonen and Videen, 2012, JQSRT, vol. 113, 2385 ; Muinonen, K., et al., 2010, Light Scatter. Rev., vol. 5, 477). We ran various batches of simulations between 100'000 and 500'000 rays, by fitting both optical and polarized opposition phase curves to adjust the model parameters. This work is still in a preliminary phase, however two results have been noticed so far. Our first result shows that the single scattering albedo of the individual scatterers has to be very close to unity to reproduce the optical surge. Our second result is that the optical and polarized surges are not that easy to fit together, which is unexpected. The optical surge is indeed very easy to fit, but the polarized surge seems shifted in a few ‰ to the theoretical behavior. This can be partially explained when considering the uncertainty on the polarimetric data (Lyot, 1929), which, besides being very old, have points with a large scattering. More investigations, and especially more simulations, are needed to conclude.

210.17 – Cassini UVIS highest resolution occultations of Saturn's rings

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Since the beginning of the Cassini mission in 2004 the UVIS instrument has recorded >100 stellar occultations of Saturn's rings. Despite achieved radial resolutions of <1m true resolution is limited by the orbital motion of particles. These can move by almost 20m during a 1ms integration period, effectively smearing the ring profile. In order to achieve superior true resolution we designed a special type of observations, dubbed tracking occultations, where the spacecraft velocity projected onto the rings cancels the orbital motion of ring particles. The ring particles are thus nearly motionless in the field of view of UVIS instrument and essentially tracked. So far Cassini UVIS has recorded two 'tracking' occultations of mid-A ring, one of the inner A ring, and one of the so called A ring ramp (a transition region between Cassini division and A ring). The occultations have at least 2m true resolution limited only by diffraction. The two mid-A ring occultations for the first time directly resolve the self-gravity (SG) Toomre like wakes. The SG wakes show as a train of opaque regions (tau>1.5) and nearly transparent gaps (tau<0.05). The observed opaque wakes can be as large as 200m, while transparent gaps are somewhat shorter (L<100m). The opaque and transparent regions are interspersed with material in an intermittent state (0.05

211 – Missions and Facilities: Present and Future Posters

211.01 – Planetary investigations in the X-ray band: Prospects for an X-ray imaging spectrometer

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Every object in the Solar system emits X-rays, although the nature and magnitude of this emission varies. In every case sensitive X-ray imaging and spectroscopic measurements would provide direct information about a wide range of atmospheric, magnetospheric, and geologic processes that cannot be gleaned from observations in other energy bands. We are developing a CMOS-based sensor that when combined with existing X-ray telescope technologies would provide a significant advance in capability to the planetary community. Advantages of this sensor technology over other Si-based imagers such as CCDs include near Fano-limited performance to 100 eV, extreme radiation hardness, high speed windowing, high frame rates to handle high fluxes in single counting mode, and low power (~mW). Our instrument could detect all the CHNOPS elements, and most importantly carbon, via X-ray fluorescence from rocky bodies in the Solar system. Additionally, our sensor could be used for plasma investigations in the magnetospheres of the gas giants in particle environments that would rapidly destroy other Si imaging technologies. In this poster we describe the unique planetary investigations that could be made with this instrument, and present the current status of our instrumentation development.

211.02 – The Earth-orbiting EUV spectroscope (EXCEED) on board the SPRINT-A mission

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Contributing teams: EXCEED team

Extreme ultraviolet spectroscope (EXCEED) on board the Earth-orbiting satellite SPRINT-A was launched in last August by Japanese newly developed rocket which is named as "Epsilon". The orbital altitude of the spacecraft is 950km to 1150km and its inclination is 31 degrees. The orbit is decided according to the contamination evaluation both from the Geocoronal emission and high energy electrons which come from the radiation belt. The instrument will be calibrated on-orbit during next several months. After the successful calibration, EXCEED will start to observe the emissions from Venus and Jupiter in EUV (52 – 148nm) with its spectral resolution of 0.3-0.9 nm FWHM. The mission is dedicated and optimized for observing the solar system planets such as Venus, Mars, and Jupiter. Because of its large effective area and the simplicity of the scientific targets, better temporal resolution and more complete coverage for Io plasma torus observation is expected. In this presentation, the optical design and performance of the EXCEED according to the on-orbit calibration is introduced.

211.03 – Deriving Atmospheric Properties and Escape Rates from MAVEN's Imaging UV Spectrograph (IUVS)

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Contributing teams: IUVS Science Team

MAVEN (Mars Volatile and Atmosphere EvolutioN) is a Mars Scout mission being readied for launch in November 2013. The key hardware and management partners are University of Colorado, Goddard Space Flight Center, University of California at Berkeley, Lockheed Martin, and the Jet Propulsion Laboratory. MAVEN carries a powerful suite of fields and particles instruments and a sophisticated remote sensing instrument, the Imaging UltraViolet Spectrograph (IUVS). This presentation begins by describing IUVS' science goals, instrument design, operational approach and data analysis strategy. IUVS supports the top-level MAVEN science goals: measure the present state of the atmosphere, observe its response to varying solar stimuli, and use the information to estimate loss from Mars' atmosphere over time. The instrument operates at low spectral resolution spanning the FUV and MUV ranges in separate channels, and at high resolution around the hydrogen Lyman alpha line to measure the D/H ratio in the upper atmosphere. MAVEN carries the instrument on an Articulated Payload Platform which orients the instrument for optimal observations during four segments of its 4.5 hr elliptical orbit. During periapse passage, IUVS uses a scan mirror to obtain vertical profiles of emissions from the atmosphere and ionosphere. Around apoapse, the instrument builds up low-resolution images of the atmosphere at multiple wavelengths. In between, the instrument measures emissions from oxygen, hydrogen and deuterium in the corona. IUVS also undertakes day-long stellar occultation campaigns at 2 month intervals, to measure the state of the atmosphere at altitudes below the airglow layer and in situ sampling. All data will be pipeline-processed from line brightnesses to column abundances, local densities and global 3-D maps. The focus of the presentation is development of these automatic processing algorithms and the data products they will provide to the Mars community through the PDS Atmospheres Node. The combined results from all instruments on ion and neutral escape will bear on the central question of the history of Mars' atmosphere and climate history. This work has been supported by NASA's MAVEN mission.

211.04 – The Ultraviolet Spectrograph (UVS) on ESA's JUICE Mission

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The Jupiter Icy Moons Explorer (JUICE) was selected in May 2012 as the first L-class mission of ESA's Cosmic Vision Program. JUICE will launch in 2022 on a 7.6-year journey to the Jovian system, including a Venus and multiple Earth gravity assists, before entering Jupiter orbit in January 2030. JUICE will study the entire Jovian system for 3.5 years, concentrating on Europa, Ganymede, and Callisto, with the last 10 months spent in Ganymede orbit. The Ultraviolet Spectrograph (UVS) on JUICE was jointly selected by NASA and ESA as part of its ~130 kg payload of 11 scientific instruments. UVS is the fifth in a series of successful ultraviolet imaging spectrographs (Rosetta-Alice, New Horizons Pluto-Alice, LRO-LAMP) and is largely based on the most recent of these, Juno-UVS. It observes photons in the 55-210 nm wavelength range, at moderate spectral and spatial resolution along a 7.5-degree slit. A main entrance “airglow port” (AP) is used for most observations (e.g., airglow, aurora, surface mapping, and stellar occultations), while a separate “solar port” (SP) allows for solar occultations. Another aperture door, with a small hole through the centre, is used as a “high-spatial-resolution port” (HP) for detailed observations of bright targets. Time-tagging (pixel list mode) and programmable spectral imaging (histogram mode) allow for observational flexibility and optimal data management. As on Juno-UVS, the effects of penetrating electron radiation on electronic parts and data quality are substantially mitigated through contiguous shielding, filtering of pulse height amplitudes, management of high voltage settings, and careful use of radiation-hard, flight-tested parts. The science goals of UVS are to: 1) explore the atmospheres, plasma interactions, and surfaces of the Galilean satellites; 2) determine the dynamics, chemistry, and vertical structure of Jupiter’s upper atmosphere from equator to pole; and 3) investigate the Jupiter-Io connection by quantifying energy and mass flow in the Io atmosphere, neutral clouds, and torus. Here we present the salient features of the UVS instrument and describe the science we plan to address.

211.05 – Developing and Calibrating a Tunable Spatial Heterodyne Spectroscopy (SHS) for Visible and UV Interferometry of Extended Targets

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We present the progress toward the stable coupling and preliminary calibration observations of an interferometric sensor that has being characterized at the Coudé Auxiliary Telescope (CAT) on Mt. Hamilton. The instrument, Khayyam, is a broadly tunable all-reflective spatial heterodyne spectrometer (SHS). SHS instruments are two-beam, common path interferometers that produce 2-D spatial patterns of linear fringes that discrete Fourier transform back to input spectrum. The utility of SHS comes from its high resolving power (of order 10^4-10^5) and wide (up to ~1°) input acceptance angle. Its opto-mechanical advantages come from internal self-compensation of the optical path difference, compact format, and relaxed tolerances on optical surface quality and positioning. Addition of a tuning feature enables coverage of a useful band 100-200 nm wide. For many targets, SHS is best matched to meter-class telescopes, which are infrequently used for high resolving power spectroscopy. Their caveat is that most, like the CAT, are on-axis designs that project a spider pattern into the interferogram. In this presentation we will provide the results of initial multispectral observations with Khayyam including on-sky emission and absorption line targets. The effect of tuning on fringe formation and photometric stability will be discussed, along with an analysis of the spider pattern’s impact on the transformed power spectrum. We will also report developing of a data processing and transform pipeline that compensates for these effects.

211.06 – Occultations with the LCOGT network.

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Contributing teams: the LCOGT team

With nearly complete sky coverage and the availability of high speed instrumentation from every network node the Las Cumbres Global Telescope Network (LCOGT) is developing a facility uniquely suitable to observe occultations by outer solar system objects. The LCOGT Network is developing a global telescope network of 2.0m, 1.0m, and 40cm class telescopes, to achieve continuous coverage of the night sky from multiple locations in both hemispheres. EMCCDs cameras for high speed photometry will be available at every network node on the node’s largest telescope class (2.0m or 1.0m). As of July 2013 we have 2 fully operational 2.0m aperture telescopes in Haleakala, HW, and Siding Spring, Australia, and we deployed 1.0m telescopes to 4 sites: Cerro Tololo Inter-American Observatory (Chile), South African Astronomical Observatory (South Africa), McDonald Observatory (Texas, USA), and Siding Spring Observatory (Australia). Several occultations have already been observed with our 2.0m systems. Even while awaiting the installation of the EMCCD cameras at each site, occultations have been observed with the guider cameras, and the availability of multiple 1.0m telescopes at each site allows us to obtain complete lightcurves sampled as fast as 2 second cadence.

211.07 – Solar System Science with HST and JWST: Connecting the Past, Present, and Future

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NASA’s Great Observatories have long provided solar system scientists with unique imaging and spectroscopic capabilities which have resulted in many important discoveries. As a successor to the Hubble Space Telescope (HST), the James Webb Space Telescope (JWST) will also make valuable contributions to solar system research. This poster summarizes some of HST’s key past contributions to solar system science such as SL9, Pluto and its moons, and KBOs. Highlights of current HST solar system observing (e.g. Comet ISON) are presented; and finally, examples of future JWST observations are presented with an emphasis on how JWST will extend and improve on what HST has done.

211.08 – Solar System Science with the James Webb Space Telescope

Heidi B. Hammel[1, 2], J. Norwood[3], N. Chanover[3], D. C. Hines[4], J. Stansberry[4], J. I. Lunine[5], M. S. Tiscareno[5], S. N. Milam[6], G. Sonneborn[6], M. Brown[7]
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The James Webb Space Telescope (JWST) will succeed the Hubble Space Telescope as NASA’s premier space-based platform for observational astronomy. This 6.5-meter telescope, which is optimized for observations in the near and mid infrared, will be equipped with four state-of-the-art imaging, spectroscopic, and coronagraphic instruments. These instruments, along with the telescope’s moving target capabilities, will enable the infrared study of solar system objects with unprecedented detail (see companion presentation by Sonneborn et al.). This poster features highlights for planetary science applications, extracted from a white paper in preparation. We present a number of hypothetical solar system observations as a means of demonstrating potential planetary science observing scenarios; the list of applications discussed here is far from comprehensive. The goal of this poster and the subsequent white paper is to stimulate discussion and encourage participation in JWST planning among members of the planetary science community, and to encourage feedback to the JWST Project on any desired observing capabilities, data products, and analysis procedures that would enhance the use of JWST for solar system studies. The upcoming white paper updates and supersedes the solar system white paper published by the JWST Project in 2010 (Lunine et al., 2010), and is based in part on JWST events held at the 2012 DPS, the 2013 LPSC meeting, and this DPS (JWST Town Hall, Thursday, 10 October 2013, 12-1 pm).

211.09 – Solar System Observing Capabilities With The James Webb Space Telescope

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The James Webb Space Telescope (JWST) will provide breakthrough capabilities to study our Solar System. JWST is a large aperture, cryogenic, infrared-optimized space observatory under construction by NASA, ESA, and CSA for launch in 2018 into a L2 orbit. Imaging, spectroscopy, and coronography covers 0.6-29 microns. JWST is designed to observe Solar System objects having apparent rates of motion up to 0.030 arcseconds/second. This capability includes the planets, satellites, asteroids, Trans-Neptunian Objects, and comets beyond Earth’s orbit. JWST can observe solar elongation of 85 to 135 degrees, and a roll range of +/-5 degrees about the telescope’s optical axis. During the observation of a moving target, the science target is held fixed in the desired science aperture by controlling the guide star to follow the inverse of the target’s trajectory. The pointing control software uses polynomial ephemerides for the target generated using JPL’s HORIZON system. The JWST guider field of view (2.2x2.2 arcmin) is located in the telescope focal plane several arcmin from the science apertures. The instrument apertures are fixed with respect to the telescope focal plane. For targets near the ecliptic, those apertures also have a nearly-fixed orientation relative to the ecliptic. This resultsfrom the fact that the Observatory’s sun-shade and solar panels must always be between the telescope and the Sun. On-board scripts autonomously control the execution of the JWST science timeline. The event-driven scripts respond to actual slew and on-board command execution, making operations more efficient. Visits are scheduled with overlapping windows to provide execution flexibility and to avoid lost time. An observing plan covering about ten days will be uplinked weekly. Updates could be more frequent if necessary (for example, to accommodate a Target of Opportunity - TOO). The event-driven operations system supports time-critical observations and TOOs. The minimum response time for TOOs is 48 hours (observation approval to execution).

211.10 – SOFIA: Review of Initial Science Operations, 2010 - 2013

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The long-awaited debut of the Stratospheric Observatory for Infrared Astronomy (SOFIA) occurred with first light on May 26, 2010. Subsequent initial science flight operations in 2010 and 2011 are reviewed to obtain a preliminary estimates of some general characteristics of operations to date, as a preview of what might be expected for flight operations in the near future. This includes the geographic envelope of science flights, altitude profiles, telescope elevation range, and observing leg durations. A brief summary is given of the distribution on the sky of observations during Basic Science, and the same for observations now being pursued in the current 2013 Observing Cycle 1. Solar system objects observed include Jupiter, Neptune, Pluto, asteroids, and Comet Hartley 2. These aspects of airborne astronomy and SOFIA operations to date are factors in evaluating airborne observing efficiency, science productivity, and operations cost effectiveness.

211.11 – The NASA Infrared Telescope Facility: Instrument Upgrades and Plans

Alan T. Tokunaga[1], Schelte J. Bus[1], Michael S. Connelley[1], John T. Rayner[1]
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The NASA Infrared Telescope Facility (IRTF) is a dedicated planetary 3-m telescope located at the summit of Mauna Kea. We discuss detector upgrades for our facility instruments, new instrument capabilities, and image quality upgrades. Detector upgrades are planned for SpeX during semester 2014A. We are also designing and constructing a new echelle spectrograph for 1-5 μm, to be commissioned starting in 2015. In terms of future capabilities, we would like input for planetary science cases needing diffraction-limited imaging at 1-5 μm and fast follow up of discoveries from sky surveys. Current instruments include: (1) SpeX, a 1-5 μm moderate-resolution spectrograph and camera, (2) MORIS, a high-speed CCD imager attached to SpeX for simultaneous visible and near-IR observations, (3) CSHELL, a 1-5 μm high-resolution spectrograph, and (4) NSFCAM, a 1-5 micron camera. MIRSI, an 8-25 μm camera, will be available after an upgrade to the array control electronics. Information on these instruments and also visitor instruments are given at: http://irtfweb.ifa.hawaii.edu/Facility/. The IRTF supports remote observing from any site. This eliminates the need for travel to the observatory, and therefore short observing time slots can be supported. We also welcome on-site visiting astronomers. For further information see: http://irtfweb.ifa.hawaii.edu/. We gratefully acknowledge the support of Cooperative Agreement no. NNX13AG88A with the NASA Science Mission Directorate, Planetary Astronomy Program.

211.12 – A Multi-Color Simultaneous Imager Instrument Concept for the IRTF

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We present a concept for a multi-channel imaging camera optimized for the rapid characterization of small planetary bodies. This instrument will be a seeing limited imager with a 2′ field of view that will simultaneously observe in 8 color channels from Sloan g′ through K band. This very broad simultaneous wavelength coverage enables several key science goals, with a strong emphasis on time critical and variable observations. First among these is the taxonomic classification of solar system minor bodies, such as main belt and near-Earth asteroids, as well as trans-Neptunian objects. Asteroid taxonomy is key to understanding the history of the asteroid belt, characterizing the NEA population, and connecting the NEA population to its origins in the Main Belt. Giant planet monitoring will be made significantly more efficient with this instrument by doing simultaneously what observers now do in series. This instrument will be a powerful tool for the characterization of the atmospheres of transiting exo-planets by providing relative photometry in several optical and near-IR bands simultaneously. The multicolor imaging of this instrument will also have broad astrophysical applications. These include disentangling newly discovered brown dwarf candidates from quasars, monitoring color variability of young stars, and the rapid follow-up of gamma ray bursts. Although this instrument has the potential to be very powerful, it will also be very simple. Similar instruments use a separate detector for each channel requiring a 'dichroic tree'. Although we will observe in 8 color channels simultaneously, this concept will only use two detectors. We will project four color channels onto each detector; 4 visible light images onto a CCD and 4 near-IR images onto an IR-array. Narrowband imaging is possible by placing a filter array in the color channels. Optically mapping multiple color channels onto a single detector reduces instrument size, cost and risk.

211.13 – An Approach to Spectropolarimetry for Solar System Exploration

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An approach to spectropolarimetry is described which offers the prospect of high sensitivity over a very wide wavelength range (FUV, NUV, optical, NIR, MIR). Using static, robust components the polarization information is encoded onto one dimension of a two-dimensional data array, while the other dimension records the spectrum. No moving parts are required and all polarimetric information is available on a single data frame, hence the technique is immune to time dependencies, free of fragile modulating components, has the potential for high sensitivity while offering a wide wavelength range with full Stokes spectropolarimetry. In the Solar System, space-based spectropolarimetry offers diagnostics for dust (cometary, zodiacal, rings), surfaces (rocky, regolith, icy), aerosols (clouds, dust storms) and high energy plasma emission processes. Beyond the Solar System, space-based telescopic spectropolarimetry has important contributions to make in the detection of extrasolar planets and their characterization. There are astrobiological applications for full Stokes polarimetry stemming from the interaction of light with chiral living organisms, which offers the potential for a remote sensing detection capability for microbial life. The proposed instrumentation concept is exceptionally well-suited to future exploration missions given its light weight, small size and robustness, coupled to a versatile and powerful generic diagnostic method, spectropolarimetry.

211.14 – Mission Concepts Enabled by Solar Electric Propulsion and Advanced Modular Power Systems

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Introduction: Over the last several years we have introduced a number of planetary mission concepts enabled by Solar Electric Propulsion and Advanced Modular Power systems. The Boeing 702 SP: Using a common spacecraft for multiple missions reduces costs. Solar electric propulsion (SEP) provides the flexibility required for multiple mission objectives. Hosted payloads allow launch and operations costs to be shared. Advanced Modular Power System (AMPS): The 702 SP for deep space is designed to be able to use the Advanced Modular Power System (AMPS) solar array, producing multi Kw power levels with significantly lower system mass than current solar power system technologies. Mission Concepts: Outer Planets. 1) Europa Explorer - Our studies demonstrate that New Frontiers-class science missions to the Jupiter and Saturn systems are possible with commercial solar powered spacecraft. 2) Trojan Tour -The mission objective is 1143 Odysseus, consistent with the Decadal Survey REP (Radioisotope Electric Propulsion) mission objective. Small Body. 1) NEO Precursor Mission - NEO missions benefit greatly by using high ISP (Specific Impulse) Solar Electric Propulsion (SEP) coupled with high power generation systems. This concept further sets the stage for human exploration by doing the type of science exploration needed and flight demonstrating technology advances (high power generation, SEP).
2) Multiple NEO Rendezvous, Reconnaissance and In Situ Exploration - We propose a two spacecraft mission (Mother Ship and Small Body Lander) rendezvous with multiple Near Earth Objects (NEO). Mars. Our concept involved using the Boeing 702SP with a highly capable SAR imager that also conducts autonomous rendezvous and docking experiments accomplished from Mars orbit. Conclusion: Using advanced in-space power and propulsion technologies like High Power Solar Electric Propulsion provides enormous mission flexibility to execute baseline science missions and conduct Technology Demonstrations in deep space on the same missions.

211.15 – Venus Atmospheric Maneuverable Platform (VAMP)

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We have explored a possible new approach to Venus upper atmosphere exploration by applying Northrop Grumman (non-NASA) development programs to the challenges associated with Venus upper atmosphere science missions. Our concept is a low ballistic coefficient (<50 Pa), semi-buoyant aircraft that deploys prior to entering the Venus atmosphere, enters the atmosphere without an aeroshell, and provides a long-lived (months to years), maneuverable vehicle capable of carrying science payloads to explore the Venus upper atmosphere. In this presentation we report results from our ongoing study and plans for future analyses and prototyping. We discuss the overall mission architecture and concept of operations from launch through Venus arrival, orbit, entry, and atmospheric science operations. We present a strawman concept of VAMP, including ballistic coefficient, planform area, percent buoyancy, inflation gas, wing span, vehicle mass, power supply, propulsion, materials considerations, structural elements, subsystems, and packaging. The interaction between the VAMP vehicle and the supporting orbiter will also be discussed. In this context, we specifically focus upon four key factors impacting the design and performance of VAMP: 1. Feasibility of and options for the deployment of the vehicle in space 2. Entry into the Venus atmosphere, including descent profile, heat rate, total heat load, stagnation temperature, control, and entry into level flight 3. Characteristics of flight operations and performance in the Venus atmosphere: altitude range, latitude and longitude access, day/night performance, aircraft performance (aerodynamics, power required vs. power available, propulsion, speed, percent buoyancy), performance sensitivity to payload weight 4. Science payload accommodation, constraints, and opportunities We discuss interdependencies of the above factors and the manner in which the VAMP strawman's characteristics affect the CONOPs and the science objectives. We show how these factors provide constraints as well as enable opportunities for novel long duration scientific studies of the Venus upper atmosphere that support VEXAG goals 2 and 3.

211.16 – Mars Mission Concepts: SAR and Solar Electric Propulsion

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Introduction: The time has come to leverage technology advances to reduce the cost and increase the flight rate of planetary missions, while actively developing a scientific and engineering workforce to achieve national space objectives. Mission Science at Mars: A SAR imaging radar offers an ability to conduct high resolution investigations of the shallow subsurface of Mars, enabling identification of fine-scale layering within the Martian polar layered deposits (PLD), as well as the identification of pingos, investigations of polygonal terrain, and measurements of the thickness of mantling layers at non-polar latitudes. It would allow systematic near-surface prospecting, which is tremendously useful for human exploration purposes. Limited color capabilities in a notional high-resolution stereo imaging system would enable the generation of false color images, resulting in useful science results, and the stereo data could be reduced into high-resolution Digital Elevation Models uniquely useful for exploration planning and science purposes. Mission Concept: Using a common spacecraft for multiple missions reduces costs. Solar electric propulsion (SEP) provides the flexibility required for multiple mission objectives. Our concept involves using a Boeing 702SP with a highly capable SAR imager that also conducts autonomous rendezvous and docking experiments accomplished from Mars orbit. Summary/Conclusions: A robust and compelling Mars mission can be designed to meet the 2018 Mars launch window opportunity. Using advanced in-space power and propulsion technologies like High Power Solar Electric Propulsion provides enormous mission flexibility to execute the baseline science mission and conduct necessary Mars Sample Return Technology Demonstrations in Mars orbit on the same mission. An observation spacecraft platform like the high power (~5Kw) 702SP at Mars also enables the use of a SAR instrument to reveal new insights and understanding of the Mars regolith for both science and future manned exploration and utilization.

211.17 – Mars 2020 Science Rover: Science Goals and Mission Concept

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The Mars 2020 Science Definition Team (SDT), chartered in January 2013 by NASA, formulated a spacecraft mission concept for a science-focused, highly mobile rover to explore and investigate in detail a site on Mars that likely was once habitable. The mission, based on the Mars Science Laboratory landing and rover systems, would address, within a cost- and time-constrained framework, four objectives: (A) Explore an astrobiologically relevant ancient environment on Mars to decipher its geological processes and history, including the assessment of past habitability; (B) Assess the biosignature preservation potential within the selected geological environment and search for potential biosignatures; (C) Demonstrate significant technical progress towards the future return of scientifically selected, well-documented samples to Earth; and (D) provide an opportunity for contributed instruments from Human Exploration or Space Technology Programs. The SDT addressed the four mission objectives and six additional charter-specified tasks independently while specifically looking for synergy among them. Objectives A and B are each ends unto themselves, while Objective A is also the means by which samples are selected for objective B, and together they motivate and inform Objective C. The SDT also found that Objective D goals are well aligned with A through C. Critically, Objectives A, B, and C as an ensemble brought the SDT to the conclusion that exploration oriented toward both astrobiology and the preparation of a returnable cache of scientifically selected, well documented surface samples is the only acceptable mission concept. Importantly the SDT concluded that the measurements needed to attain these objectives were essentially identical, consisting of six types of field measurements: 1) context imaging 2) context mineralogy, 3) fine-scale imaging, 4) fine-scale mineralogy, 5) fine-scale elemental chemistry, and 6) organic matter detection. The mission concept fully addresses the requirements specified by NASA in the SDT charter while also ensuring alignment with the recommendations of the National Academy of Sciences Decadal Survey for Planetary Exploration (Visions and Voyages, 2011).

211.18 – Planetary Surface Exploration Using Raman Spectroscopy on Rovers and Landers

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Planetary surface exploration using laser induced breakdown spectroscopy (LIBS) to probe the composition of rocks has recently become a reality with the operation of the mast-mounted ChemCam instrument onboard the Curiosity rover. Following this success, Raman spectroscopy has steadily gained support as a means for using laser spectroscopy to identify not just composition but mineral phases, without the need for sample preparation. The RLS Raman Spectrometer is included on the payload for the ExoMars mission, and a Raman spectrometer has been included in an example strawman payload for NASA's Mars 2020 mission. Raman spectroscopy has been identified by the community as a feasible means for pre-selection of samples on Mars for subsequent return to Earth. We present a next-generation instrument that builds on the widely used green-Raman technique to provide a means for performing Raman spectroscopy without the background noise that is often generated by fluorescence of minerals and organics. Microscopic Raman spectroscopy with a laser spot size smaller than the grains of interest can provide surface mapping of mineralogy while preserving morphology. A very small laser spot size (~ 1 μm) is often necessary to identify minor phases that are often of greater interest than the matrix phases. In addition to the difficulties that can be posed by fine-grained material, fluorescence interference from the very same material is often problematic. This is particularly true for many of the minerals of interest that form in environments of aqueous alteration and can be highly fluorescent. We use time-resolved laser spectroscopy to eliminate fluorescence interference that can often make it difficult or impossible to obtain Raman spectra. We will discuss significant advances leading to the feasibility of a compact time-resolved spectrometer, including the development of a new solid-state detector capable of sub-ns time resolution. We will present results on planetary analog minerals to demonstrate the instrument performance including fluorescence rejection.

211.19 – Advanced Mass Spectrometry for In Situ Analysis of Comet and Primitive Asteroid Composition

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The study of the composition of comets and icy, carbonaceous asteroids has benefitted greatly by sustained efforts in recent years to observe and conduct spectroscopy on these objects from terrestrial and orbital observatories. Our ability to classify these small bodies and conduct comparisons between individual objects has broadened our understanding of the commonalities and diversity that they exhibit. To contribute to and complement our understanding of the formation, distribution, and evolution of small bodies throughout the solar system, it will be critical to form connections between broad surveys of coma composition and in situ measurements of evolved compounds at various distances from the nuclei of representative objects. Future missions that can inform our understanding of coma-nucleus interactions could take the form of a close flyby, an orbiter, or a lander, or some combination. We present recent efforts by our group to develop compact but capable analytical instrumentation that spans the scope of mission opportunities, offering advanced mass spectrometric analysis of the composition of near-surface volatiles and the parent species at the surface. It is now feasible, with mature instrumentation and recent advances in mass spectrometry and sampling, to address the connection between surface materials and the evolution of gases and small organic species, thereby establishing the relationship between in situ measurements of parent compounds and remote observations of product species in the coma. Three instrument development efforts will be presented, spanning the opportunities for sampling the in situ composition of a comet or active asteroid: (1) highly sensitive and mature mass analyzers to sample volatile production near the surface of the body, (2) a gas and dust collector that is optimized for the analysis of trace volatiles, such as astrochemically important small organics, and dust that may be lofted by surface activity, and (3) laser desorption/ionization mass spectrometry that is well suited to landed analyses of non-volatile inorganic and organic composition of nucleus surface materials.

211.20 – Scientific Packages on Small Bodies, a Deployment Strategy for New Missions

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The exploration of asteroids is currently a topic of high priority for the space agencies. JAXA will launch its second asteroid explorer, aimed at 1999 JU3, in the second half of 2014. NASA has selected OSIRIS-REx to go to asteroid Bennu, and it will launch in 2016. ESA is currently performing the assessment study of the MarcoPolo-R space mission, in the framework of the M3 (medium) competition of its Cosmic Vision Program, whose objective is now 2008 EV5. In the continuity of these missions, landing for an extended period of time on the ground to perform measurements seems a logical next step to asteroid exploration. Yet, the surface behavior of an asteroid is not well known and landing the whole spacecraft on it could be hazardous, and pose other mission operations problems such as ensuring communication with Earth. Hence, we propose a new approach to asteroid surface exploration. Using a mothership spacecraft, we will present how multiple landers could be deployed to the surface of an asteroid using ballistic trajectories. Combining a detailed simulation of the bouncing and contact dynamics on the surface with numerical and mathematical analysis of the flight dynamics near an asteroid, we show how landing pods could be distributed at the surface of a body. The strategy has the advantages that the mothership always maintains a safe distance from the surface and the landers do not need any GNC (guidance, navigation and control system) or landing apparatus. Thus, it allows for simple operations and for the design of lightweight landers with minimum platform overhead and maximum payload. These pods could then be used as a single measurement apparatus (e.g. seismometers) or as independent and different instruments, using their widespread distribution to gain both global and local knowledge on the asteroid.

211.21 – Castalia: A European Mission to a Main Belt Comet

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Contributing teams: Castalia mission science team

Main Belt Comets (MBCs) are a newly identified population, with stable asteroid-like orbits in the outer main belt and a comet-like appearance. It is believed that they survived the age of the solar system in a dormant state and that their activity occurred only recently. Water ice is the only volatile expected to survive, and only when buried under an insulating surface. Excavation by impact could bring the water ice (closer) to the surface and trigger the start of MBC activity. The specific science goals of the Castalia mission are: 1. Characterize a new Solar System family, the MBCs, by in-situ investigation 2. Understand the physics of activity on MBCs 3. Directly detect water in the asteroid belt 4. Test if MBCs are a viable source for Earth's water 5. Use MBCs as tracers of planetary system formation and evolution These goals can be achieved by a spacecraft designed to rendezvous with and orbit an MBC for some months, arriving before the active period begins for mapping before directly sampling the gas and dust released during the active phase. Given the low level of activity of MBCs, and the expectation that their activity comes from only a localized patch on the surface, the orbiting spacecraft will have to be able to maintain a very close orbit over extended periods – the Castalia plan envisages an orbiter capable of 'hovering' autonomously at distances of only a few km from the surface of the MBC. The straw-man instrument payload is made up of: - Visible and near-infrared spectral imager - Thermal infrared imager - Radio science - Dust impact detector - Dust composition analyzer - Neutral/ion mass spectrometer - Magnetometer - Plasma package In addition to this, the option of a surface science package is being considered. At the moment MBC 133P/Elst-Pizarro is the best-known target for such a mission. A design study for the Castalia mission has been carried out in partnership between the science team, DLR and OHB Systems. This study looked at possible missions to 133P with launch dates around 2025, and found that this (and other MBC targets as backups) are reachable with an ESA M-class type mission.

211.22 – Trojan Tour Enabled by Solar Electric Based Mission Architecture

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Introduction: A Trojan Tour and Rendezvous mission was one of the missions recommended by the most recent Planetary Science Decadal Survey. To the greatest extent possible, we will utilize this concept as a basis for re-examining the feasibility of a Solar Electric Propulsion (SEP) mission using a Boeing bus and Advanced Modular Power System (AMPS) solar power generation. The concept study for the Decadal survey concluded that s SEP mission is not viable because of low solar intensity levels. Mission Overview: With the advent of the new high power solar array technology, SEP missions to the outer planets become viable. The mission objective is 1143 Odysseus, a Trojan within the Trojan cloud, consistent with the Decadal Survey. Our mission analysis using SEP yielded a 6 year travel time. The Decadal mission concept uses REP (Radioisotope Electric Propulsion) mission objective. For comparison, the REP mission concept flight time was 8 years. For the purposes of our study, the science payload instruments, data rates, mass and power requirements are identical to the Trojan Decadal study. Our investments focus on innovative lightweight structures, advanced solar array deployment systems, high voltage power systems, and high efficiency solar cells. Summary/ Conclusion: By using advanced, high power generation solar arrays, SEP becomes a viable alternative for Jupiter system missions. We show that a SEP mission reduces the flight time to the Trojans by 2.5 years. We also show that a proven commercial bus can provide the necessary pointing accuracy and stability required for the Decadal mission concept and its science instrument suite.

211.23 – Characterizing the Populations of Small Bodies from the Kuiper Belt to the Oort Cloud: Technology Development and Science Case for the Whipple Mission Concept

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More than 99.9999% of the volume of our Solar system lies beyond the orbit of Neptune and Pluto, and this region is almost totally unexplored. We are developing a mission concept, called Whipple, to study the small bodies of the outer Solar System using a blind stellar occultation survey. This space-based mission would consist of a nominal 0.77 m diameter optical telescope with a focal plan comprising 32 Teledyne H1RG hybrid CMOS sensors. We would simultaneously monitor the brightnesses of tens of thousands of stars at a cadence of up to 40 Hz to search for occultations by Kuiper Belt, inner Oort cloud, and outer Oort Cloud objects. We will detect tens of thousands of these objects over the course of the mission, which will allow us to characterize the spatial and size distribution of these outer Solar System bodies. These data will be used to constrain models of the early history and evolution of the Solar System. In this poster, we summarize the scientific goals for this mission and present the current status of instrumentation development.

211.24 – A Discovery Mission to Determine the Interior Structure of Gas- and Ice-Giants

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The Ice Giants (Uranus and Neptune) are fundamentally different than the better-known Gas Giants (Jupiter and Saturn). Ice Giants are roughly 65% water by mass, compared to Gas Giants which are ~95% hydrogen and helium. Knowing the interior structure of both types of planets is a key measurement needed to advance our understanding of the formation and evolution of planetary systems, particularly in light of recent findings that Ice Giants are far more abundant in our galaxy than Gas Giants (Borucki et al., ApJ 2011). In the past, gravity measurements from spacecraft in low orbits have been the primary way to tease out information on interior structure. A new approach, Doppler imaging, can provide detailed information on interior structure from great distances (Gaulme et al., A&A 2011). A planetary Doppler Imager (DI) builds on the well-established fields of helio- and stellar-seismology, which have revolutionized our understanding of the interior of stars. The great advantage of a DI is that its observations do not require the spacecraft to enter orbit. We have designed a Discovery mission around such an instrument to determine the interior structures of Jupiter and Uranus during flybys of each planet. The data collected at Jupiter (after a 1.5 year flight) will compliment observations to be made by the Juno spacecraft in 2016, creating a much more accurate picture of the interior than is possible from the gravity technique alone. Roughly 6.5 years after the Jupiter flyby, DI measurements of Uranus will open that planet's interior for the first time. At both planets, measurements of the interior structure are made over a 4-month period centered on closest approach (CA), but with a ~1 week gap at CA when the planet is too close for whole-disk imaging. This allows other measurements to be made at that time, such as of small-scale weather features or satellites. We note that the DI technique, while enabling a Discovery-class mission, can also benefit larger missions. Not only does it achieve key science, but because it does not impose any orbital requirements, it makes it easier to accommodate other experiments such as a probe.

211.25 – The Exoplanet Characterisation Observatory (EChO) : an ESA mission to characterize exoplanets

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Contributing teams: EChO ESA Science Team, EChO ESA Study Team

The EChO mission is proposed in the frame of the European Space Agency/M3 Cosmic Vision program. Its main goal is to provide a spectroscopic characterization for a significant sample of exoplanets by transit spectroscopy. The results of the existing ground-based and space surveys on exoplanets count for more than 900 objects, with radius/semi-major axis/temperature spanning a large amplitude in a parameter space. Even if biased by the detection techniques, the current sample shows clearly that Solar System planets are not representative of the exoplanets diversity, and the next step in exoplanets study will be to characterize this diversity. EChO is a mission dedicated to give a chemical survey over a diverse sample of exoplanets, with repeated observations on a more restricted sample. During the 5 years mission posted at the L2, a predetermined sample of ~120 exoplanets will be repeatedly observed, from a reference sample of over 200. The observational technique of EChO is to use temporal variations to separate planetary light from parent star in primary transits, secondary eclipses and planet phase variations. By recording simultaneously a spectrum from 0.55 to 11 micron (0.4-16 micron goal), at a spectral resolution between 30 and 300, molecular detection and abundance retrieval from the main constituents of exoplanetary atmospheres (CH_4, H_2O, CO, CO_2, etc.) will be obtained. Planetary categories will include in size Jupiters, Neptunes and Superearths, and in temperature from hot (> 1000 K) to temperate (~300 K). On a limited sample of exoplanets, spatial and temporal variability will be accessible, addressing questions on thermal and chemical transport or weather questions. The question of the formation of exoplanets will be addressed from measurements of bulk and atmospheric chemical composition.

211.26 – NASA's Planetary Data System—An Accumulating Archive developed by Scientists for Scientists

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NASA's Planetary Data System (PDS) was formed in 1986 to ensure that digital data from our planetary missions are efficiently and effectively archived, and to provide the planetary science community access to that data. The archive now includes almost 60 years of data from NASA's missions. The PDS is a distributed system with individual nodes with expertise tailored to meet the needs of specific discipline areas (from planetary geology to space physics). The PDS has multiple roles. First we work with NASA Flight Programs and missions from the initial Announcement of Opportunity through the end of mission to organize the data, including documentation to ensure that the data sets obtained will be useful for both current and future generations. This process includes peer-review by members of the science community to ensure that the data sets are scientifically useful, effectively organized, and well documented (and searchable). Another role of the PDS is to make the data in our accumulating archives easily searchable so that members of the science community can both query the archive to find data relevant to specific scientific investigations and easily retrieve the data for analysis. A third role of the PDS (and a sister organization, the NSSDC) is to ensure long term preservation. As new capabilities in Information Technology (IT) become available (and as existing technologies become obsolete), it is necessary for the PDS to adapt to the current IT environment. A major new effort by the PDS, known as PDS4, was released in September, 2013. The first two NASA missions to archive under this new PDS4 system are LADEE and MAVEN.

211.27 – BRRISON Mission Design and Development

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In September 2012, the comet C/2012 S1 "ISON" was discovered by Russian amateur astronomers. A team consisting of personnel from Glenn Research Center (GRC) Space Science Project Office, the Johns Hopkins University Applied Physics Lab (APL), and the Southwest Research Institute (SWRI) was established to identify the science return on a high altitude balloon mission to observe ISON, and develop a plan based on re-using most of the hardware from the Stratospheric Terahertz Observatory (STO). The team determined that measuring the comet's H_2O/CO_2 ratio with an infra-red Camera would be a high-value and unique scientific contribution of a balloon borne payload. The BRRISON scientific payload consists of a heritage 80-cm telescope, a near-ultraviolet visible optical bench and instruments, and an infrared optical bench and instruments. The telescope, which has flown on prior balloon missions, consists of a light-weighted f/1.5 hyperboloid 80 cm diameter primary and a secondary mirror to provide an f/17 beam. The near ultra-violet and visible cameras and associated instruments are being integrated to an optics bench by SwRI. These instruments consist of a fine steering mirror (FSM) and a CMOS high rate camera to provide sub-arcsec pointing, and a CCD camera for low noise science operation, and a dichroic for splitting the f/17 beam between the two cameras. The infrared optics bench and instruments consist of an optics bench, re-imaging optics and cold stop, filter wheel and filters, and an infrared camera that is sensitive over the required wavelengths of 2.5 – 5 microns. The IR optics bench and instruments will be enclosed in an aluminum housing, which will be cooled to reduce the thermal background contribution to the IR signal. The BRRISON gondola is composed of a metal frame that carries and protects the science payload and subsystems and is the structural interface with the balloon flight train. They are composed of a Command & Control system, a Pointing Control System, a Power System, and a Balloon Control and Telecommunications System. The balloon launches from the Ft. Sumner, NM launch site sometime from mid-September until mid-October 2013 for a 10 – 22 hour flight.

211.28 – An update on the NASA Planetary Science Division R&A Program: Historical trends, ROSES 2012 statistics, and lessons learned

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This presentation will provide historical trends of the Research Opportunities in Space and Earth Sciences (ROSES) awards for the Planetary Science Division's R&A program, including a detailed analysis of the 2012 call selections (and lessons learned). An overview of the submission process via NSPIRES will be provided, as well as an overview of the review process and information on how to volunteer for review panels (via the SARA site). Additional details will be provided on the Cassini Data Analysis Program (CDAPS) and Origins of Solar System Program (SSO, Planetary Science Division), for which Dr. Richey is the Program Officer.

211.29 – TRIDENT: Taking Remote and In-situ Data to Explore Neptune and Triton

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The 2013-2022 Planetary Science Decadal Survey identified a detailed investigation of Solar System evolution as a priority for future NASA missions. Measuring the atmospheric composition and physical and chemical characteristics of the Neptune-Triton (N-T) system would provide answers about their history and evolution, thus yielding information about the makeup and dynamics of the early Solar System, as well as the later evolution of the Solar System. In addition, as Neptune-sized exoplanets are the most common type discovered, studying Neptune would provide insight into the structure and dynamics of extrasolar planetary systems. We present a conceptual design for a $1.4bn flyby mission to the N-T system (TRIDENT), consistent with these goals as the result of the 2013 NASA-JPL Planetary Science Summer School Session II. In this report, we present our initial orbiter designs and our final change to a flyby mission due to propulsion mass limitations. The results of this study show a second flyby of N-T provides significant new information about the system relative to the Voyager 2 flyby and to later Earth-based observations. TRIDENT consists of a 13 year cruise to the N-T system with an Earth-Earth-Jupiter-Neptune trajectory, a Triton flyby with a closest approach of less than 1000 km, a Neptune flyby of 30,000 km, and the release of a NASA-donated Neptune atmospheric probe. The probe is one of our key science drivers, which will measure in-situ isotope ratios and noble gas abundances of Neptune's atmosphere that are critical constraints on Solar System formation. Our spacecraft also carries a versatile remote sensing package consisting of a narrow angle camera, magnetometer, plasma spectrometer, UV spectrometer, NIR spectrometer, and a doppler imager, which will provide unprecedented high-resolution, regional-to-global datasets for the target bodies. TRIDENT's remote sensing suite would provide information on the dynamics, structure, and composition of Neptune's atmosphere and magnetosphere, and on Triton's surface age, interior structure, composition, and atmosphere.

300 – Exoplanets 5: System Architectures

300.01 – Hot Jupiter Spin-Orbit Misalignments As Consequences of Disk-Driven Migration

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The existence of gaseous giant planets whose orbits lie in close proximity to their host stars ("hot Jupiters') can naturally be accounted for by protoplanety disk-driven (type-II) migration, associated with viscous evolution of the nebulae. Recently, observations of the Rossiter-McLaughlin effect during planetary transits have revealed that a considerable fraction of detected hot Jupiters reside on orbits that are misaligned with respect to the spin-axes of their host stars. This observational fact has cast significant doubts on the importance of disk-driven migration as a mechanism for production of hot Jupiters, thereby reestablishing the origins of close-in planetary orbits as an open question. Here we show that spin-orbit misalignment is a natural consequence of disk-driven migration. The abundance of binary stellar companions, whose orbital plane is uncorrelated with the spin axes of the individual stars, is enhanced in star formation environments. Accordingly, gravitational torques arising from massive distant bodies generally act to adiabatically perturb protoplanetary disks (and the embedded planets) away from their primordial planes, giving rise to orbital obliquity. Spin-orbit misalignment can be additionally amplified by non-trivial spin-axis dynamics of disk-bearing stars. Specifically, as stellar interiors evolve along pre-main-sequence tracks and protoplanetary disks loose mass, a secular resonance between the disk-torqueing frequency and the nodal recession rate of the stellar spin pole may be encountered, yielding further excitation of inclination. Collectively our results signal a consistency between disk-driven migration and the current observational aggregate (see also Crida & Batygin 2013, DPS meeting) while predicting that non-zero spin-orbit misalignments should be observed in systems of low-mass multi-transiting planets.

300.02 – Distribution of Spin-Orbit misalignments: disk-torquing is compatible with observations

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Over the last few years, it has become possible to infer the spin-orbit misalignment angles of a few exoplanets (mainly hot Jupiters). More precisely, the projected spin-orbit angle can be measured using the Rossiter-MacLaughlin effect. Accordingly, the discovery of (projected) misalignments has re-opened the question of how the hot Jupiters transport in to close in orbits. Planetary migration is often considered as the most likely explanation for the small orbital radii of the hot Jupiters, but spin-orbit misalignment seems to advocate for scattering processes : assuming that the proto-planetary disk was in the equatorial plane of the star, the spin - orbit angle should be zero. Whatever the dominant process, its imprint can likely be found in the relic distribution of observed angles, rendering the reproduction of such a distribution a necessary property of any proposed mechanism. By linking the real spin-orbit angle to the projected angle, we enable the comparison between a theoretical distribution and the observations. We evaluate the spin-orbit misalignment distribution inherent to the recently-proposed adiabatic disk-torquing mechanism (Batygin 2012 ; see also Batygin & Adams 2013, DPS) and perform a statistical comparison of the synthetic data set with available observations. We find the agreement to be good, especially in light of various simplifications employed in generating the synthetic dataset and imperfect knowledge of the input parameters. Consequently, our results indicate that planetary migration inside a tilted disk could indeed be the dominant process responsible for the observed non-zero spin-orbit misalignments.

300.03 – The high multiplicity systems Gliese 667C and KOI 3158

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High multiplicity extra-solar systems display a wealth of planetary interactions which can constrain the orbital properties of the system as well as the physical nature of the planets (e.g, rocky vs. volatile rich). These systems may also serve as analogues for our own high-multiplicity solar system. One example is KOI 3158, a metal-poor, high-proper-motion star for which has been identified in the Kepler data set evidence for five small planets. Given the probable stellar type, K0V (Wilson 1962), we infer that the planets range in size from 0.3 to 0.5 Earth radii. The star's high proper motion and radial velocity are compatible with membership in the Milky Way's thick disk. The orbital architecture of this system includes proximity to several mean motion resonances, which allow us to constrain the mass and eccentricities of the planets. Gliese 667C, another metal poor star, hosts a system of 6 or 7 planets, 3 of which are potentially in the habitable zone. Classical secular theory of non-resonant interactions, coupled with standard tidal evolution theory, can constrain the tidal dissipation parameters Q for each of the planets. The eccentricities and pericenter longitudes from Anglada-Escude et al.'s (2013) currently-most-stable 6-planet solution (S_6, their Table 6) imply that the one of the two large-amplitude secular eigenmodes is controlled by the innermost planet. Therefore, if the innermost planet's Q is $< 10^4$, going backwards in time the amplitude of this already high-amplitude mode increases, so < 2 Gyr ago (the minimum age of the

star) the planets would have been too close for stability. Tides on the other planets only affect eigenmodes that are currently of low amplitude. As a result, the Qs of these planets could be very low and still be consistent with the past stability of the system. Thus, the orbital solution that is currently the most stable indicates that the inner planet cannot be rocky, while the other planets can be. In particular, the dynamics permit the planets in the habitable zone to be rocky, and thus does not exclude any of those planets from having a solid surface and being habitable.

300.04 – Putting the Chaos and Instability of the Terrestrial Planets in Context

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Past work has shown that the dynamical evolution of the solar system's terrestrial planets is chaotic. Further, the inner planets seem to be near the edge of stability, as Mercury has a ~1% chance of colliding with the Sun or Venus in the next 5 Gyrs. Meanwhile, models of terrestrial planet formation have been tuned to reproduce numerous features of the inner solar system. We compare the long-term dynamical evolution of terrestrial planet systems formed in simulations with that of our own solar system, both in terms of stability and chaos. In addition, we attempt to use the diffusion of planetary eccentricities to predict the timescale in which systems of chaotic orbits will eventually become unstable.

300.05 – In-situ Planet Formation: Implications for Planets near Resonances

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We investigate a very simple model of planet formation in which planets grow in-situ, without migration or any dissipative process. Quite remarkably, this model exhibits an asymmetric distribution of orbital periods around mean motion resonances, with a gap around the nominal resonance location and a pile-up wide of the resonance, qualitatively similar to that observed in the Kepler sample of multiple planet systems. This suggests that dissipation and migration may not be necessary to account for the resonant features seen in Kepler data.

300.06 – Anomalies in the architectures of Kepler systems

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Contributing teams: Kepler

The large number of Kepler multiplanet system provides a unique opportunity to understand the formation and dynamical evolution of the inner parts of planetary systems. Of particular interest are subsets of the Kepler systems that have orbital architectures that are unique, such as planet pairs near mean-motion resonance (MMR). I show that the MMR near which a planet pair resides depends somewhat on the number of planets in the system. Specifically, systems with many planets have excess systems near the 3:2 MMR while systems with only a few planets have a sharp peak near the 2:1 MMR. In addition, systems with the shortest orbital periods show a significant lack of close-proximity planet pairs.

300.07 – Measuring the Masses and Radii of Sub-Neptunes with Transit Timing Variations.

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The bounty of sub-Neptunes discovered by Kepler enables us to study a regime in planetary size and mass that is absent from the Solar System. This regime includes a transition from rocky planets to those with substantial amounts of volatiles– in either ice mantles or deep atmospheres. Characterizing these worlds by their bulk densities can probe this transition, and this requires mass and radius determinations. Outside our solar system, there is a small sample of planets with known masses and radii, mostly hot jupiters whose radii are known from transit depths, and whose masses are determined from radial velocity spectroscopy (RV). In the absence of mass determinations via RV observations, transit timing variations (TTVs) offer a chance to probe perturbations between planets that pass close to one another or are near resonance, and hence dynamical fits to observed transit times can measure planetary masses and orbital parameters. Such modelling can probe planetary masses at longer orbital periods than RV targets, although not without some challenges. For example, in modeling pairwise planetary perturbations, a degeneracy between eccentricity and mass exists that limits the accuracy of mass determinations. Nevertheless, in several compact multiplanet systems, fitting complex TTV signals can break the degeneracy, permitting useful mass determinations. The precision in measuring the radius of a transiting planet rests on the uncertainty in the stellar radius, which is typically ~10% for targets with spectral follow-up. With dynamical fits, however, solutions for the orbital parameters including the eccentricity vectors can, alongside the transit lightcurves, tightly constrain the stellar density and radius. Revisiting the six-planet system of Kepler-11, our dynamical fits to TTVs, alongside spectroscopic data on the host star, reduced the stellar and hence planetary radius uncertainties to just 2%, permitting useful planetary density determinations. In the case of Kepler-11, planetary densities are lower than typical RV determinations in the same mass range. Other similar compact multi-planet systems follow the trend set by Kepler-11.

300.08 – SMACK: A New Algorithm for Modeling Collisions and Dynamics of Planetesimals in Debris Disks

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We present the Superparticle Model/Algorithm for Collisions in Kuiper belts (SMACK), a new method for simultaneously modeling, in 3-D, the collisional and dynamical evolution of planetesimals in the Solar System or in an extrasolar debris disk. SMACK can simulate azimuthal asymmetries and how these asymmetries evolve in time. We show that SMACK is stable to numerical viscosity and numerical heating over 10 Myr, and that it can reproduce analytic models of disk evolution. We demonstrate the use of SMACK to model the evolution of a debris ring with an embedded planet on an eccentric orbit, and illustrate how partial collisional damping affects the disk morphology.

300.09 – Circumplanetary Debris Disks and Consequences of an Eccentric Fomalhaut b

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Each of the Solar System's giant planets hosts many small and distant irregular satellites. These moons' radially overlapping orbits and their unusually shallow size distributions imply a violent collisional history (Bottke et al. 2010). Thus, at early epochs, the giant planets likely displayed prominent circumplanetary debris clouds. For my PhD I numerically studied how such debris in the Saturnian system would evolve inward through radiation forces to coat the striking two-faced moon Iapetus (Tamayo et al. 2011). I also investigated the analogous process at Uranus, where the planet's extreme obliquity renders infalling dust orbits chaotic. We find that this could explain the color dichotomies observed on the largest four Uranian satellites (Tamayo et al. 2013a, 2013b). Even today, Saturn has such a vast dust disk, sourced by the irregular satellite Phoebe (Verbiscer et al. 2009). This 'Phoebe Ring', can be used to observationally study the gravitational effects of moons on the dust; I have successfully probed this ring with Cassini, but was unsuccessful with Herschel observations. By these combined observational and dynamical studies, I hope to inform the field of extrasolar debris disks, where one tries to use dust signatures to infer the existence of planets that are too faint to see. I am now focusing on a related problem involving the exoplanet candidate Fomalhaut b (Kalas et al. 2008). While its optical flux is too large to come directly from a planet, perhaps we are observing a disk supplied by irregular moons (Kennedy & Wyatt 2011). Additional observation epochs imply that Fomalhaut-b's orbit is very eccentric (Kalas et al. 2013). Yet despite crossing the system's observed circumstellar debris disk in projection, Fomalhaut b does not appear to have significantly disturbed it. We argue from simulations that if Fomalhaut b is a giant planet, it must have scattered into its present orbit in the past ~10 Myr. If so, the young Fomalhaut system (~400 Myr) may provide an analogue to the Solar System's reshuffling of the giant planets, thought to have occurred under the Nice Model (Tsiganis et al. 2005).

301 – Asteroids 5: Geophysics

301.01 – Using a Radar Shape Model to Interpret Spectral Observations of near-Earth Asteroid 4179 Toutatis

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We have observed a number of near-Earth asteroids (NEAs) using radar to determine shape and spin characteristics, along with NASA IRTF near- and thermal infrared spectroscopy to determine composition and thermal properties. The radar shape model allows us to determine the orientation of the asteroid at the time of observation, and thus link spectra to specific parts of the asteroid, usually after the fact. Takahashi et al. (2013) have used extensive radar observations over several apparitions to determine the complex rotation state of NEA 4179 Toutatis. Busch et al. (2013) have refined the shape model derived by Hudson et al. (2003). The images of Chang'e 2 confirm the elongated shape of this asteroid, and show a more detailed view of the large end that was poorly resolved in the radar observations prior to 2012. Near-infrared spectra of Toutatis have been obtained by many observers at a variety of observing geometries. We can now connect these spectra to specific areas of the asteroid, and investigate spectral variations, and determine the extent to which phase reddening and regolith sorting may affect the measurements. Several observations consistently suggest that the larger end of this elongated body is spectrally different than the rest of the surface. This difference is contrary to the findings of Davies et al., (2007), who did not see any spectral changes over a large range of phase angles. We will explore the possible causes of these differences, and compare to other NEAs that also show spectral differences across the surface. Even objects with very similar compositions do not always show the same spectral trends, which makes generalizations hard to support.

301.02 – Rotation Induced Disruption of Cohesive Asteroids

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We use a Soft-Sphere Discrete Element Method (SSDEM) code to study the evolution of self-gravitating cohesive granular aggregates that are spun to disruption as a proxy to 'rubble-pile' asteroids. Calculations have shown that the fine regolith in asteroids and molecular Van der Waals forces together may act as a cohesive matrix that provides enough structural strength to hold small NEAs together even at the observed high spin rates. With this in mind we have implemented cohesive forces between the large (~10 m) particles that form our aggregates; its strength being controlled by the mean particle size of the matrix. The addition of rolling friction also has allowed us to obtain cohesionless aggregates with friction angles of at least 35° as measured by the Drucker-Prager yield criterion. A series of experiments were run with the code, keeping the size, density and number of grains constant while increasing the cohesive strength of the matrix holding the grains in place. It can be shown, through a scaling analysis, that when the cohesive strength between rubble pile components is increased by a factor of f, that the effective size of the asteroid being modeled will decrease by a factor of $1/\sqrt{f}$. To evaluate this we ran a series of 12 cases with increasing cohesive strength, effectively modeling rubble piles of size from 0.1 km up to 100 km with a constant cohesive strength of 25 Pa. Some of our main results are as follows: 1. results from simulations are compatible with a simple model of asteroid strength that predicts, in the cohesion dominated case, that the spin rate for fission is inversely proportional to the size of the asteroid; 2. aggregates may disrupt by shedding or fission, depending on the cohesive strength and the size of the aggregate (shape and heterogeneity factors have not yet been considered); 3. disruption by fission is more likely for small aggregates than for larger aggregates with the same cohesive strength. Further results with spherical and a asymmetrical shapes will be presented at the conference.

301.03 – The Effect of Rotation on Mass Loss in Simulations of Rubble-Pile Collisions

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Much of the evolution of small solar system bodies (SSSBs) is dominated by collisions, whether from the initial build-up of planetesimals or the subsequent impacts between remnant bodies that exist today. In the quasi-steady-state collisional system of a protoplanetary disk, impact speeds are of order the escape speed of the largest body. Until the largest body becomes protoplanet sized, impacts typically will be at speeds less than the sound speed of the assumed rocky material (here we focus on asteroids). Since the dominant source of confining pressure for planetesimal-sized SSSBs is self-gravity, rather than material strength, they can be treated as gravitational aggregates. A rotating body has lower effective surface gravity than a non-rotating one (with the difference increasing with decreasing latitude) and therefore might suffer more mass loss as the result of a collision. What is less obvious, however, is whether rotation systematically increases mass loss on average regardless of the impact trajectory. This has important implications for the efficiency of planet formation via planetesimal growth, and also more generally for the determination of the impact energy threshold for catastrophic disruption (leading to the largest remnant having 50% of the original mass), as this has generally only been evaluated for non-spinning bodies. Here we carry out a systematic exploration of the effect of pre-impact rotation on the outcomes of rubble-pile collisions. We use pkdgrav, a cosmology code adapted to collisional problems and recently enhanced with a new soft-sphere collision algorithm that includes more realistic contact forces and permits simulations with many more particles than the older hard-sphere algorithm. We find that for most collision scenarios, rotation lowers the threshold energy for catastrophic dispersal. Furthermore, we discuss our results in the context of scaling laws that may be used to predict collision outcomes for planetary formation studies.

301.04 – Hill Slope Failure as a Mechanism to Resurface Asteroids During Planetary Flybys

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Laboratory measurements of meteorite reflectance spectra rarely match telescopic observations of asteroid reflectance spectra. This difference is likely due to the process(es) of space weathering, which rapidly redden asteroid surfaces on million year timescales (e.g. Chapman 2004, Annu. Rev. Earth Planet. Sci. 32, 539). While nearly all Main Belt asteroids are "weathered," many asteroids on terrestrial planet crossing orbits appear "unweathered" (Marchi et al., 2006, MNRAS 368, L39). Numerical integration of the orbits of these unweathered asteroids suggest that close approaches within 5~16 Earth radii may reset the surfaces of asteroids, and erase the signatures of space weathering (Binzel et al. 2010, Nature 463, 331; Nesvorny et al. 2010, Icarus 209, 510). Despite the evidence that close approaches may play a role in resurfacing asteroids, the specific resurfacing mechanism is unknown.
I hypothesize that tidal perturbations during planetary close approaches trigger debris flows, which resurface portions of the asteroid. I have developed an original numerical model for evaluating the stability of hill slopes on rigid asteroids of arbitrary shape, density, and spin during planetary flybys. I present preliminary results for a limited range of asteroid and flyby parameters, which suggest that significant fractions of the asteroid surface (a few percent) can become unstable to hill slope failure during flybys with close approach distances out to ~10 Earth radii. In future work, I will explore a range of asteroid and flyby parameters, in order to better constrain the critical distance required for resetting asteroid surfaces. By characterizing this critical distance, it may be possible to better constrain the space weathering rate on asteroids.

301.05 – Global Landslides on Rapidly Spinning Spheroids

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The angle of repose and conditions for global landslides on the surfaces of small, rapidly spinning, spheroidal asteroids are studied. Applying techniques of soil mechanics, we develop a theory for, and examples of, how regolith will fail and flow in this microgravity environment. Our motivation is to develop an understanding of the 'top-shaped' class of asteroids based on analytical soil mechanics. Our analysis transforms the entire asteroid surface into a local frame where we can model it as a conventional granular pile with a surface slope, acceleration and height variations as a function of the body's spin rate, shape and density.
A general finding is that the lowest point on a rapidly spinning spheroid is at the equator with the effective height of surface material monotonically increasing towards the polar regions, where the height can be larger than the physical radius of the body. We study the failure conditions of both cohesionless and cohesive regolith, and develop specific predictions of the surface profile

as a function of the regolith angle of friction and the maximum spin rate experienced by the body. The theory also provides simple guidelines on what the shape may look like, although we do not analyze gravitationally self-consistent evolution of the body shape. The theory is tested with soft-sphere discrete element method granular mechanics simulations to better understand the dynamical aspects of global asteroid landslides. We find significant differences between failure conditions for cohesive and cohesionless regolith. In the case of cohesive regolith, we show that extremely small values of strength (much less than that found in lunar regolith) can stabilize a surface even at very rapid spin rates. Cohesionless surfaces, as expected, fail whenever their surface slopes exceed the angle of friction. Based on our analysis we propose that global landslides and the flow of material towards the equator on spheroidal bodies are precipitated by exogenous effects such as impact induced seismic shaking or torques during planetary flybys.

301.06 – Lutetia's lineaments

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During the fly-by of the Rosetta spacecraft in July 2010, asteroid (21) Lutetia has been partially observed with its remote sensing instrument and its visible camera OSIRIS. The geology and morphology of the asteroid is widely influenced by the large "recent" impact crater located close to the North Pole (also named North Polar Crater Cluster (NPCC) due to the superposition of numerous circular depressions), with its ejecta blankets that have resurfaced a portion of the local terrains around the impact. Impact craters, landslides, boulders and lineaments have been observed in various location and concentration, with the origin of the last three possibly related to the NPCC. The identification of the lineaments and their possible origin has been already investigated [1], with more than 400 lineaments mapped. The location and orientation of the lineaments present a correlation with the NPCC, thus the impact could be the source of the lineaments [2]. In this work, we define more restrictive criteria for the identification of lineaments in order to define orientations and poles of sub-group of lineaments. We follow the same approach taken in studies of 433 Eros and Vesta [3, 4]. We find that the lineaments have two pole directions that point to two locations on the surface. We also investigate the relationship between crosscutting lineaments and the interaction with craters to investigate the timeline of the formation of the lineaments, and indirectly the origin of the formation. Understanding the relationship between orientations and relative ages of the lineaments could provide valuable information on the origin of the lineaments, and interior structure of Lutetia. References [1] N. Thomas, et al., The geomorphology of (21) Lutetia: Results from the OSIRIS imaging system onboard ESA's Rosetta spacecraft, Planetary and Space Science 66, 96-124, 2012 [2] M. Jutzi, et al., The influence of recent major crater impacts on the surrounding surfaces of (21) Lutetia, Icarus 226, 89-100, 2013 [3] D. Buzkowski et al., 433 Eros lineaments: Global mapping and analysis. Icarus, 193, p.39-52, 2008. [4] R. Jaumann et al.,. Vesta's Shape and Morphology. Science, 336(6), pp.687–690, 2012.

301.07 – Small asteroids – rubble piles or boulders?

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The asteroid rotation spin barrier at ~2.2 h period among asteroids 10 km > D > 200 m doesn't prove all such asteroids are rubble piles, and the faster rotations among smaller asteroids doesn't require monolithic strength, either. Only a very modest strength, perhaps no more than van der Waals force, might suffice to hold regolith together on a small super-fast rotator (Sanchez & Scheeres, 2013, arXif:1306.1622v1). The problem is that for a constant or only slowly varying strength with respect to diameter, the spin barrier becomes proportional to 1/D below the size where material strength is dominant, or perhaps a bit steeper if strength increases with decreasing D. What we observe in the distribution of asteroid spins versus diameter is that below D ~ 200 m, the spin barrier goes up at least $\sim D^{3.5}$, if not abruptly. Models with constant or slowly varying strength fail to fit this observation, and the abrupt transition cannot be an observational selection effect: the void in the phase space of rotations would be among the easiest rotations to observe, e.g. the one conspicuous exception, 2001 OE84 (D ~ 0.7 km, P = 0.5 h) was easily and unambiguously measured (Pravec, et al. 2002, Proc. ACM 2002, ESA SP-500, 743-745). This abrupt transition is most easily explained as a real transition in material properties of asteroids in the size range ~200 m diameter, from "rubble pile" to "boulder", although neither term may be fully descriptive of the actual structure. Two other lines of evidence suggest that this transition in properties is real: the dip in the size-frequency distribution of NEAs is maximum at ~150 m, suggesting that a transition to stronger material structure occurs about there, and we observe, e.g., Tunguska and the recent Chelyabinsk bolide, that bodies in the tens of meters size range entering the atmosphere behave more like solid rocks than rock piles (Boslough & Crawford 2008, Int. J. Imp. Eng. 35, 1441-1448). I encourage those doing computer modeling of asteroid rotations and size-frequency distributions to consider a strength model with a fairly abrupt transition from rubble pile to boulder rather than slowly varying or constant strength.

301.08 – Effects of YORP-induced rotational fission on the small size end of the Main Belt asteroid size distribution.

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From the results of a comprehensive asteroid population evolution model, we conclude that the YORP-induced rotational fission hypothesis has strong repercussions for the small size end of the Main Belt asteroid size frequency distribution. These results are consistent with observed asteroid population statistics. The foundation of this model is the asteroid rotation model of Marzari et al. (2011), which incorporates both the YORP effect and collisional evolution. This work adds to that model the rotational fission hypothesis (i.e. when the rotation rate exceeds a critical value, erosion and binary formation occur). The YORP effect timescale for large asteroids with diameters D > ~6 km is longer than the collision timescale in the Main Belt, thus the frequency of large asteroids is determined by a collisional equilibrium (e.g. Bottke 2005), but for small asteroids with diameters D < ~6 km, the asteroid population evolution model confirms that YORP-induced rotational fission destroys small asteroids more frequently than collisions. Therefore, the frequency of these small asteroids is determined by an equilibrium between the creation of new asteroids out of the impact debris of larger asteroids and the destruction of these asteroids by YORP-induced rotational fission. By introducing a new source of destruction that varies strongly with size, YORP-induced rotational fission alters the slope of the size frequency distribution. Using the outputs of the asteroid population evolution model and a 1-D collision evolution model, we can generate this new size frequency distribution and it matches the change in slope observed by the SKADS survey (Gladman 2009). This agreement is achieved with both an accretional power-law or a truncated "Asteroids were Born Big" size frequency distribution (Weidenschilling 2010, Morbidelli 2009).

301.09 – Asteroid failure modes due to YORP spin-up: A survey

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We study the first failure mode of real asteroids driven to high spin-rates by the YORP effect. We focus on two failure modes: structural failure and surface shedding. The analysis only considers self-gravity and centrifugal forces. Also, we assume that the body spins in a principal axis mode, has a homogeneous density distribution, is cohesionless, and can be characterized by a friction angle between 30 and 45 degrees. We analyze surface shedding by tracking the dynamical equilibrium points. This mode causes a body to lose material from its extremities due to centrifugal accelerations overcoming gravitational accelerations. Shedding first occurs when one of the equilibrium points reaches the surface. We assume that the original shape is fixed, and thus the analysis provides a conservative condition. This condition does not consider temporary small-scale mass movement like saltation by landslides. We determine structural failure using the upper bound theorem of limit analysis. This failure mode causes a body to catastrophically deform or break into smaller components. The theorem by Holsapple (2008, INT J NONLINEAR MECH) guarantees that for any static surface traction and body force, the yield due to a smooth and convex yield envelope associated with the volume average is identical to the upper bound. We use this theorem with two volume averaging techniques: total volume (Holsapple, 2008, Icarus) and partial volume (Hirabayashi et al., 2013, Apj, submitted). This method is conservative as well. We investigate the failure modes for 21 shape models, including 1999KW4, Betulia, Geographos, Nereus, Itokawa, and 1996HW1. We can

classify three shape morphologies in terms of their internal properties and failure modes: spheroidal, ellipsoidal, and bifurcated. Spheroidal bodies such as 1999KW4 and Betulia undergo structural failure first, not surface shedding. Ellipsoidal bodies such as Geographos and Nereus can experience either surface shedding or structural failure first, depending on their shape morphology. Bifurcated bodies such as Itokawa and 1996HW1 undergo structural failure at their neck region. For 1996HW1 our analysis also constrains its bulk density to lie between 0.7 to 1.1 g/cm3.

302 – Titan 2: Ground Down

302.01 – A Late Major Merger at Saturn: Consequences for Titan and Iapetus

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Titan is arguably the Solar System's most unusual satellite. It is twenty times more massive than Saturn's other moons and is the only satellite with a substantial atmosphere. Titan shares a unique resonance with nearby Hyperion, but otherwise sits in a particularly large gap between Rhea and Iapetus. Titan has the largest eccentricity of all Saturn's regular satellites and has a reasonably large orbital tilt; its distant neighbor Iapetus has an even more impressive eight degree free inclination. None of these peculiarities are even partially understood. A late major merger in the saturnian system has great promise to explain most of these puzzling properties. A massive collision between two proto-Titans would naturally excite Titan's eccentricity while simultaneously accounting for the very large regions of empty space both inside and outside Titan's current orbit. Such a collision is sufficiently energetic to release gases into Titan's atmosphere. Hyperion would be the last of the remaining clump of ejecta from the hypothetical collision, preserved from reaccretion by its 4:3 orbital resonance with Titan. Such eject should be produced in quantity according to the simulations of Asphaug (2012). Finally, we will present a compelling tidal migration scenario that - during the instant of collision - produces the orbital tilts of both Titan and Iapetus.

302.02 – Interior Models for Saturn's Moon Titan Consistent with Cassini Observations

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We demonstrate that a model of Titan's interior with a core dominated by hydrated silicates can explain three major geophysical constraints available for this body: the mean moment of inertia (revised values currently in the literature or being published), tidal Love number k2, both of which were inferred from Cassini radio science observations, as well as indirect estimate of the dissipation factor inferred from Titan's orbital properties. Other models in which ice has remained partially mixed with silicates as a consequence of limited early heating fail to explain the dissipation factor. A core hydrated in silicate is difficult to maintain over the long term and may be in the process of dehydrating, which may involve significant transfer of water enriched in salts from the core to the ocean and destabilize the high-pressure ice layer. We will present possible observations that could help test this model with future observations to be obtained by the Cassini Orbiter. Acknowledgements: This work has been carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. Government sponsorship acknowledged.

302.03 – Infrared Study of Liquid / Solid Hydrocarbons and their Mixtures under Titan Conditions

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This study presents the first experimental investigation of the infrared properties of hydrocarbons under Titan simulated conditions. Infrared spectra of liquid and solid CH_4, C_2H_6 and their mixtures are taken to characterize infrared properties of Titan's liquid and solids. We also monitor continuous change in mass of the compounds to emphasize the presence or absence of these compounds during evaporation/sublimation processes which are also quantified using IR spectra. Using our experimental evaporation/ sublimation rates in the liquid-liquid and solid-liquid hydrocarbon mixtures we can determine the amount of CH_4 that accumulates in the arid equatorial regions to produce liquid flows. Dark patches in the surface reflectance at 2 and 5 μm have been observed by Cassini spacecraft as seasonal formation of hydrocarbons lakes through a CH_4 cycle. Identification of solid versus liquid phase states of CH_4 and C_2H_6 on Titan requires laboratory measurements at relevant temperatures. The results for both CH_4 and C_2H_6, reflectivity change as their phase changes from liquid to solid. In CH_4 the band-depth of absorption bands decrease over time due to sublimation. Whereas in ethane, the band-depth is increasing over time due to its non-volatile nature. We have also investigated C_2H_2, as it was detected on the surface of Titan by the infrared spectrum in two of VIMS atmospheric windows at 1.54 μm and in the 2 μm region. The absorption features seen in the laboratory spectra are large enough to be potentially detected in VIMS. Currently, the solubility experiments of C_2H_2, CH_3CN, and C_4H_{10} in liquid CH_4 and C_2H_6 are undergoing in our lab at 94 K and 1.5 bar. Since the amount of C_2H_2 present in Titan lakes can be several times the atmospheric amount, and is thought to be major soluble component in Titan lakes. We can correlate the laboratory experiments to the evaporites detected on the shoreline of Ontario Lacus by Cassini VIMS. Analyzing the Infrared spectra of the liquid-liquid and solid-liquid mixtures will provide the solubility percentages of each compound. This will help explain the discrepancy between the amount of C_2H_2 and other compounds present on the shoreline of Ontario Lacus.

302.04 – Evidence of Titan's Climate History from Evaporite Distribution

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5-μm bright material on the surface of Titan has been positively correlated with the shores of RADAR-dark (liquid-filled) and the bottoms of RADAR-bright (empty) lakebeds in the region just south of Ligea Mare by Barnes et al. (2011). This water ice-poor spectral unit was thus proposed to be evaporite, the formerly-dissolved solute deposits left behind when the solvent (here presumably a methane/ethane mixture) evaporates. Because evaporite forms under specific conditions—solute and solvent at or near saturation, no outlets or other means of affecting the solution balance, etc.—the presence of evaporite can shed light on Titan's climate history. Adding to the previously identified cases, we use the breadth of available Cassini VIMS data to comprehensively map new instances of evaporite. In particular, we found new instances of evaporite in the north polar region and the midlatitudes. Our map of the global distribution of Titan's 5-μm-bright deposits can be used to constrain the historical evolution of Titan's surface volatile inventory and may bear on the question of the time variation of the methane concentration in Titan's atmosphere. Furthermore, we explore the implications of the idea that the 5-S\mu$m-bright areas are indeed mostly evaporitic in nature with respect to the relationship between the regional and global volatile cycles.

302.05 – Titan's dry lakebeds chemical composition and lakes formation time-scale

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Already, during the first RADAR detection of Titan's lakes, the presence of features that ressemble to dry lakebeds have been noticed. A strong correlation between RADAR dry lakebeds and surface patches bright at 5 micrometers has been found (Barnes et al, 2011). This brightness associated to high reflectivity in the 2.8 micrometers window relative to the 2.7 micrometers window, seems to be characteristic of very low water ice abundance relative to the rest of Titan (Barnes e tal, 2009, Barnes et al, 2011). In summary, all of this suggests the formation of an evaporitic layer of organic matter, but the real chemical nature of these deposits remains mysterious. The solubility theory, based on solid-liquid equilibrium, allows estimation of the quantities of dissolved solids in the hydrocarbon solutions of Titan's polar lakes. In this work, thanks to the solubility theory coupled to an evaporation prescription, we have computed abundancies of species that could form these organic layers. We found that acetylene and butane seem to be good candidate for building the evaporite top layer. Beside this, under assumption of a formation driven by dissolution, we were able to evaluate the minimum age of Titan's lakes.

302.06 – Titan's "blandlands": nature, distribution, and possible origin of Titan's plains

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Contributing teams: Cassini RADAR Team

Titan's diverse and Earth-like geologic features have been mapped and interpreted based on their morphological characteristics (e.g. Lopes et al., 2010, Icarus 205; Aharonson et al., 2012, Titan: Surface, Atmosphere, Magnetosphere, Cambridge University Press). While the interpretation for the origin of some units, such as dunes and well-preserved impact craters, has been relatively straightforward, others have been more challenging. In particular, the undifferentiated plains first mapped by Lopes et al. (2010) remain mysterious. These vast expanses, often referred to as "blandlands" (also "undifferentiated plains unit", Lopes et al., 2010) are mostly found at mid-latitudes and appear relatively featureless at radar wavelengths, with no significant topography. Their gradational boundaries and paucity of features in SAR data make geologic interpretation particularly challenging. We examine and evaluate different formation mechanisms. Plains may be sedimentary in origin, resulting from fluvial or lacustrine deposition or accumulation of photolysis products created in the upper atmosphere. Alternatively, the plains may be cryovolcanic, consisting of overlapping flows of low relief, obscured by accumulation of sediments. In this paper, we use SAR, radiometry, scatterometry, and SARTopo data to examine the characteristics of the plains and compare them with other geologic units. We also compare their global distribution with that of other units and examine the implications.

302.07 – Elevation distribution of Titan's craters suggests extensive wetlands

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Using a new global topographic map of Titan, we find that craters on Titan preferentially lie at higher than average elevations. We explore several explanations for this observed behavior, and judge the most reasonable explanation to be the presence of widespread wetlands of liquid hydrocarbons at low elevations over much of geologic time. Impacts into a shallow marine environment or a saturated layer of sediments more than several hundred meters thick would produce crater morphologies similar to terrestrial submarine impacts. These are known to lack significant topographic expression, and would thus be difficult to observe with the Cassini spacecraft. Since Titan's near-surface methane inventory likely fluctuated over geologic time, with episodic delivery and continuous depletion, a few craters at low elevations can nonetheless be expected.

302.08 – Volcanic Destabilisation of Methane Clathrate Hydrate on Titan: the Mechanism for Resupplying Atmospheric CH_4?

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Titan may have an upper crust rich in methane clathrates which would have formed early in Titan's history [1-3]. The abundance of atmospheric methane, which has a limited lifetime, and the presence of ^{40}Ar require replenishment over time. Volcanic processes may release these gases from Titan's interior, although, so far, no conclusive evidence of an ongoing volcanic event has been observed: no "smoking gun" has been seen. Still, some process has recently supplied a considerable amount of methane to Titan's atmosphere. We have investigated the emplacement of "cryolavas" of varying composition to quantify thermal exchange and lava solidification processes to model thermal wave penetration into a methane-rich substrate (see [4]), and to determine event detectability. Clathrate destabilisation releases methane and other trapped gases, such as argon. A 10-m-thick cryolava covering 100 km^2 raises 3 x 10^8 m^3 of substrate methane clathrates to destabilization temperature in ~10^8 s. With a density of 920 kg/m^3, and ≈13% of the mass being methane, 4 x 10^{10} kg of methane is released. This is an impressive amount, but it would take 5 million similar events to yield the current mass of atmospheric methane. However, meeting Titan's current global methane replenishment rate is feasible through the thermal interaction between cryolavas and methane clathrate deposits, but only (1) after the flow has solidified; (2) if cracks form, connecting surface to substrate; and (3) the cracks form while the temperature of the clathrates is greater than the destabilisation temperature. The relatively small scale of this activity may be hard to detect. This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.© 2013 Caltech. We thank NASA's OPR Program for support. References: [1] Choukroun, M. and Sotin, C. (2012) GRL, 39, L04201. [2] Tobie, G. et al. (2006) Nature, 440, 61–64. [3] Lunine, J. et al. (2009) Origin and Evolution of Titan, in Titan From Cassini-Huygens, ed. R. Brown et al., 35-59, Springer. [4] Davies, A. G. et al. (2013) LPSC 44 abstract 1681.

302.09 – Temporal Variations of Titan's Surface Regions with Cassini/VIMS

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We investigate three potentially "active" areas on Titan [e.g. 1;2;7]., i.e. locations subject to change over time (in brightness and/or in color etc.), namely Tui Regio, Hotei Regio and Sotra Patera. We apply two methods on Cassini/VIMS data in order to retrieve their surface properties and monitor temporal variations. First, we apply the Principal Component Analysis (PCA) statistical method [3;4], isolating regions of distinct and diverse chemical composition (Region of interest –RoI). Then, we focus on retrieving the spectral differences (with respect to the Huygens landing site albedo) among the RoIs by applying a radiative transfer code (RT) [5;3]. We are thus able to evaluate the dynamical range and the differences in surface albedo among the RoIs of the three areas. In addition, using this double procedure, we study the temporal surface variations of the same areas. Hotei Regio has been previously suggested to present brightness variations over a two-year period (2004-2005) [3]. However, we find that to-date available observations of that area have issues (e.g. geometry conditions), which prevent an accurate application of our plane-parallel RT code. The surface information we infer for Hotei Regio does not show variations from 2004-2009 but the uncertainties here are high [8]. On the other hand, our findings indicate a significant darkening for Tui Regio from 2005-2009 (at all wavelengths). For Sotra Patera a brightening is observed from 2005-2006 [8], while test cases from two distinct dunes fields for the same period of time show that their surface albedo does not change with time. We will discuss the relation of these surface variations with the presence of volcanic-like features [7] within these areas and interior processes (tidal forces) [6] and the implications for the satellite's astrobiological potential. [1] Soderblom, L.A. et al.: Icarus 204, 610-618, 2009. [2] Nelson, R. et al.: Icarus 199, 429-441, 2009. [3] Solomonidou, A., et al.: submitted. [4] Stephan, K. et al.: PSS 56, 406–419, 2008. [5] Hirtzig, M. et al.: Icarus 226, 470-486, 2013. [6] Sohl, F. et al.: submitted. [7] Lopes, R.M.C., et al.: JGR 118, 1-20, 2013. [8] Solomonidou, A., et al.: in prep.

303 – Pluto 1

303.01 – Heterogeneous and Evolving Distributions of Pluto's Volatile Surface Ices

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We report observations of Pluto's 0.8 to 2.4 μm reflectance spectrum with IRTF/SpeX on 70 nights over the 13 years from 2001 to 2013. The spectra show numerous vibrational absorption features of simple molecules CH4, CO, and N2 condensed as ices on Pluto's surface. These absorptions are modulated by the planet's 6.39 day rotation period, enabling us to constrain the longitudinal distributions of the three ices. Absorptions of CO and N2 are concentrated on Pluto's anti-Charon hemisphere, unlike absorptions of less volatile CH4 ice that are offset by roughly 90° from the longitude of maximum CO and N2 absorption. In addition to the diurnal/longitudinal variations, the spectra show longer term trends. On decadal timescales, Pluto's stronger CH4 absorption bands have deepened, while the amplitude of their diurnal variation has diminished, consistent with additional CH4 absorption by high northern latitude regions rotating into view as the sub-Earth latitude moves north (as defined by the system's angular momentum vector). Unlike the CH4 absorptions, Pluto's CO and N2 absorptions are declining over time, suggesting more equatorial or southerly distributions of those species. The authors gratefully thank the staff of IRTF for their tremendous assistance over the dozen+ years of this project. The work was funded in part by NSF grants AST-0407214 and AST-0085614 and NASA grants NAG5-4210 and NAG5-12516.

303.02 – Interpreting the Shifted CH_4 Spectra of Pluto and Triton

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It is known that the concentration of methane in Pluto's atmosphere and surface ice is significantly greater than for Triton. The spectra of both bodies show methane lines shifted in wavelength relative to the laboratory spectrum by an amount that is characteristic of a solid solution of methane dissolved in nitrogen. In addition, Pluto shows an unshifted methane spectrum that is not seen for Triton. Moreover, the relative amounts of CH_4, N_2, and CO have been reported to vary with longitude for Pluto. The lack of a wavelength shift and the continent-sized variations have sometimes been interpreted to mean that the pure species exist and can relocate separately. This view simplifies the interpretation of the vapor pressure of each ice component because the vapor pressure is then assumed to be simply a function of the temperature. However, because the interaction between the atmosphere and volatile ice tends to move towards a dynamic equilibrium, it is likely that each pair of these species exits in both phases of a binary solid solution. At low temperature, the phase diagram of a solid solution of CH_4 and N_2 shows that saturation occurs at relatively dilute concentrations, about 3.5% and 5%, respectively, at 38 K. Therefore, N_2 dissolved in CH_4 should coexist with CH_4 dissolved in N_2 while exhibiting an essentially unshifted CH_4 spectrum owing to the dominance of CH_4 in this phase. Thus, the presence of both shifted and unshifted CH_4 lines in Pluto's spectrum suggests that there is more than enough CH_4 to saturate N_2 ice so that the leftover CH_4 forms a saturated CH_4-rich phase. In thermal equilibrium, both phases are saturated and no other phase exists. In Triton's case, the ice CH_4 inventory is not high enough to result in detectable unshifted CH_4 lines in Triton's spectrum. Raoult's law does not apply near saturation, where activity matters. Laboratory experiments are needed for the vapor pressures in saturated solid solution mixtures to understand the role that ice plays in supporting the atmospheres of Pluto and Triton.

303.03 – Absorption Coefficients of the Methane-Nitrogen Binary Ice System: Implications for Pluto

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Near infrared spectroscopic measurements of Pluto display methane (CH_4) ice absorption bands shifted toward shorter wavelengths compared to the central wavelengths of pure CH_4 obtained in the laboratory. This shift, described by Schmitt and Quirico (1992), occurs when CH_4 is dissolved at low concentrations in a matrix of solid N_2, and the magnitude of the shift varies from one CH_4 band to another. This is the main argument behind the modeling analysis of Pluto's spectra available in literature, employing pure CH_4 and CH_4 diluted at low concentrations in N_2. However, the nitrogen–methane binary phase diagram generated from X-ray diffraction studies by Prokhvatilov & Yantsevich (1983) indicates that at temperatures relevant to the surfaces of icy dwarf planets, like Pluto, two phases contribute to the absorptions: methane ice saturated with nitrogen and nitrogen ice saturated with methane. No optical constants are available so far for the latter component, limiting this way the knowledge of the methane-nitrogen mixing ratio across and into the surface of Pluto and other dwarf planets. New infrared absorption coefficient spectra of CH_4-I diluted in β-N_2 and β-N_2 diluted in CH_4-I were measured at temperatures between 40 and 90 K, in the wavelength range 0.8-2.5 μm at different mixing ratios. The spectra were derived from transmission measurements of crystals grown from the liquid phase in closed cells. In particular, a systematic study of the changes in CH_4:N_2 mixtures spectral behavior with mixing ratio is presented for the first time, in order to understand whether the peak frequencies of the CH_4-ice bands correlate with the amount of N_2-ice. We report a linear trend of the blueshifts of the CH_4-ice bands vs CH_4 abundance. This trend varies from band to band, while it is fairly constant with temperature. These data are applied to interpret unpublished high dispersion H and K bands spectra of Pluto acquired with the NACO instrument at the ESO VLT on 27 June 2008. Acknowledgments: This work was supported in part by grant number NNX11AM53G from NASA's Outer Planets Research Program.

303.04 – FUV Studies of Pluto and Its Satellites: From HST to New Horizons

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The Alice extreme- and far-ultraviolet (EUV/FUV) imaging spectrograph onboard the New Horizons spacecraft was designed to observe airglow emissions from species in Pluto's atmosphere, study the atmosphere around Pluto (and possibly Charon) by solar and stellar occultations, and to quantify the FUV surface reflectivity of these (and other) bodies in the system. We predict the FUV airglow emission originating from Pluto's atmosphere using the Atmospheric Ultraviolet Radiance Integrated Code program (AURIC) for various atmospheric model assumptions. Observation circumstances (e.g., ranges, phase angles, etc.) are selected from planned Alice activities in the nominal New Horizons encounter. We also examine the expected surface reflectivity of Pluto in the EUV/FUV by modeling the emergent spectrum through gases in Pluto's atmosphere. These calculations estimate the surface vs. atmospheric contributions from previous HST observations at MUV wavelengths and extrapolate the surface albedo to the FUV. In addition we perform surface reflectance calculations for the nominal encounter observations of Charon, Hydra, and Nix, assuming no atmosphere and previous measurements of Charon's surface albedo at MUV wavelengths. Our surface models consider a range of surface ice compositions including H2O, NH3, and CO2 based on laboratory FUV reflectance data. Nix and Hydra will be barely detectable in the Alice bandpass, however Charon spectra should exceed SNR of 5 at wavelengths longer than 1200 Angstroms.

303.05 – Satellite formation around Pluto-Charon

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Pluto and its companion Charon are host to a growing number of satellites–currently P5, Nix, P4, and Hydra. We consider how this rich system may in a disk of solid particles, as in the debris from the giant impact that likely produced the Pluto-Charon binary. We apply a hybrid N-body–coagulation code to track the evolution of the particle disk. Our simulations, which include viscous diffusion, coagulation, and migration show that collisional evolution within a ring or disk of debris leads to a few small satellites orbiting Pluto-Charon as observed. We also predict a population of smaller bodies, ranging from centimeters to kilometers in size. The details depend on the physics of the disk, including its initial state. New Horizons will help tune the models and so provide insight that we can apply to planet formation elsewhere in the universe.

303.06 – Cometary Impacts Produce Transient Atmospheres on Charon

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Introduction: Although Charon's H2O-ice surface has long suggested a lack of a permanent atmosphere (e.g., Stern et al. 1988), impacts from KBO comets must import N2, CO, CH4, and other cometary super-volatiles that create temporary atmospheres around Charon from time to time. Impacts may also excavate volatiles below Charon's surface, also sourcing transient atmospheres. Synopsis: In this report we estimate the frequency of cometary impacts on Charon and the imported mass of super-volatiles from each such impact, finding a mean time between impacts of d=1 km comets to be of order 1x106 years. We then examine certain characteristics of such atmospheric transients, including their expected column densities, scale heights, loss timescales, and dynamical regimes. We then evaluate the detectability of such transient atmospheres by the Alice UV spectrograph aboard New Horizons. References: Stern, S.A., Trafton, L.M., and Gladstone, G.R., 1988. Icarus, 75, 485-498.

303.07 – Ejecta Transfer within the Pluto System

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The small satellites of Pluto have sufficiently low surface gravity that micrometeorite impacts can easily produce ejecta that escapes from their surfaces. This ejecta can either escape from the Pluto system or be swept up by Pluto or its satellites. We show through n-body integrations that Charon primarily sweeps up lower velocity ejecta, while Pluto is impacted by dust that is ejected at higher velocities. The dust also impacts Pluto in different locations depending on its ejection velocity. We show that the albedo features of Pluto and Charon correspond well to the expected distribution of impacts from higher velocity small satellite ejecta.

303.08 – Ground and space-based separate PSF photometry of Pluto and Charon from New Horizons and Magellan.

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While Pluto and Charon are easily resolvable in some space-based telescopes, ground-based imaging of Pluto and Charon can yield separate PSF photometry in excellent seeing. We present B and Sloan g', r', i', and z' separate photometry of Pluto and Charon taken at the Magellan Clay telescope using LDSS-3. In 2011, observations were made on 7, 8, 9, 19, and 20 March, at 9:00 UT, covering sub-Earth longitudes 130°, 74°, 17°, 175° and 118°. The solar phase angle ranged from 1.66-1.68° to 1.76-1.77°. In 2012, observations were made on February 28, 29 and March 1 at 9:00 UT covering longitudes 342°, 110° and 53° and on May 30 and 31 at 9:30 UT and 7:00 UT, covering longitudes 358° and 272°. Solar phase angles were 1.53-1.56° and 0.89°-0.90° degrees. All longitudes use the convention of zero at the sub-Charon longitude and decrease in time. Seeing ranged from 0.46 to 1.26 arcsecond. We find that the mean rotationally-averaged Charon-to-Pluto light ratio is 0.142±0.003 for Sloan r',i' and z'. Charon is brighter in B and g', with a light ratio of 0.182±0.003 and 0.178±0.002 respectively. Additionally, we present separate PSF photometry of Pluto and Charon from New Horizons images taken by the LORRI instrument on 1 and 3 July 2013 at 17:00 UT and 23:00 UT, sub-Earth longitude 251° and 125°. We find that the rotation-dependent variations in the light ratio are consistent with earlier estimates such as those from Buie et al. 2010, AJ 139, 1117-1127. However, at a solar phase angle of 10.9°, Charon appears 0.25 magnitudes fainter relative to Pluto at the same rotational phase than measurements from the ground with the largest possible solar phase angle. Thus we provide the first estimate of a Pluto phase curve beyond 2°. These results represent some of the first Pluto science from New Horizons. This work has been funded in part by NASA Planetary Astronomy Grant NNX10AB27G and NSF Award 0707609 to MIT and by NASA's New Horizons mission to Pluto.

304 – Asteroids 6: Spin, Size, Shape

304.01 – Thermal Lightcurves of 1999 JU3, Target of Hayabusa 2, Using Warm Spitzer

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The JAXA mission Hayabusa 2, scheduled for launch in 2014 or 2015, will rendez-vous with 1999 JU3 and will return samples of surface regolith to Earth. Mission planning benefits greatly from accurate pre-encounter determinations of physical properties such as size, albedo, and thermal inertia (indicating the presence or absence of fine surface regolith). We observed the thermal emission (3.6 and 4.5 micron) of 1999 JU3 using 'Warm Spitzer' in Jan-May 2013, at high SNR and spanning a range in solar phase angle of 55-88 degrees. We obtained two thermal lightcurves at different observing geometries, plus 12 shorter 'point-and-shoot' observations for phase-angle coverage. If the spin-axis solution proposed by Müller et al. (2011) is correct, we obtained the first thermal observations of the afternoon side, important for thermal-inertia determinations, and our lightcurves were taken with sub-Spitzer latitudes on both the Northern and Southern hemisphere. A first analysis of our Spitzer data confirms previous estimates of diameter (~ 0.9 km) and geometric albedo (~ 0.07). The two lightcurves, taken three months apart, differ significantly in shape, further constraining existing models of shape and spin axis. Our observations will lead to a much improved determination of the thermal inertia of 1999 JU3, to be presented at the meeting. We will also address the question of a possible thermal-inertia variegation over the surface of this primitive NEO, which would have profound implications on the sample-taking mechanism.

304.02 – The Size Distribution of Very Small Near Earth Objects As Measured by Warm Spitzer

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We have carried out a pilot search for Near Earth Objects (NEOs) with 84 hours of Warm Spitzer time in April, 2013. Results are obtained through a multi-step process: implanting synthetic objects in the Spitzer data stream; processing the Spitzer data; linking non-sidereal sources to form plausible orbits; validating candidates; determining orbits; and determining diameters through thermal modeling. Each of these steps is well-tested on both synthetic populations and real data. Through these steps, we expect to be able to constrain the NEO size distribution down to ~10 meters (at present, through ExploreNEOs and NEOWISE, the size distribution is well-known only to 100 meters). We will present results from this preliminary data and prospects for a large or very large survey that could be carried out in future cycles.

304.03 – Ultra-Slow Rotating Outer Main Belt and Trojan Asteroids: Search for Binaries

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Binaries are already known to exist in the Outer Main Belt, Hilda, and Trojan (OMB+) populations and appear to fall into two main categories. The first are objects like 624 Hektor, 121 Hermione, 107 Camilla, and 87 Sylvia which contain elongated/bilobed primaries with small satellites, a rapidly rotating primary, and densities greater than 1000 kg/m3. On the other hand, 617 Patroclus, 17365, and 29314 have have similar-sized components, are synchronously locked (or in contact), and have densities below 1000 kg/m3. These two classes of binaries may reflect different formation mechanisms (collision vs. primordial), differences in the origin of the planetesimals and/or their subsequent dynamical and collisional evolution. As a test, we have conducted a search for other possible binary systems in the OMB+. We targeted eight objects with periods of 56-540 hours that, if tidally locked binaries like Patroclus, would be resolvable using HST. Observations completed in June 2013 with none of the objects showing clear evidence of being binary. PSF-fitting is required to rule out partially resolved systems. A negative result for eight slow rotators places only weak constraints on the binary fraction of this population subset. When combined with other published searches of Trojans, regardless of rotation period, it appears that the binary fraction in the OMB+ population is lower than among similar sized objects in the Kuiper Belt.

304.04 – Direct Detection of YORP Spin-up on Asteroid (25143) Itokawa and Implications for its Internal Structure

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Near-Earth asteroid (25143) Itokawa was visited by the Hayabusa spacecraft in 2005, resulting in a highly detailed surface shape and topography model. This model has led to several predictions for the expected radiative torques on this asteroid, suggesting that its spin rate should be decelerating. Through an observational survey spanning 2001 to 2013 we have successfully measured an acceleration in its spin rate of dω/dt = 3.54 (± 0.38) × 10^(-8) rad day^(-2), equivalent to a decrease of its rotation period of ~ 45 ms year^(-1). Using the shape model determined from the Hayabusa spacecraft, we applied a detailed thermophysical analysis, to reconcile the predicted YORP strength with that observed. We find that the center-of-mass for Itokawa must be shifted by ~20 m along the long-axis of the asteroid to reconcile observations with theory. This can be explained if Itokawa is composed of two separate bodies with very different bulk densities of 1740 ± 110 kg m^(-3) and 2730 ± 440 kg m^(-3), and was formed from the merger of two separate bodies, consistent with the collapse of a binary system or the re-accumulation of material from a catastrophic collisional disruption. We demonstrate that an observational measurement of radiative torques, when combined with a detailed shape model, can provide insight into the interior structure of an asteroid.

304.05 – New Asteroid Shape Models Derived from the Lowell Photometric Database

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Asteroid shapes and spin states can be derived from their disk-integrated sparse-in-time photometry by the lightcurve inversion method. A huge amount of sparse photometry is provided by current all-sky surveys. However, the data from surveys suffer from large random and systematic errors. Oszkiewicz et al. (2011, JQSRT 112, 1919) partly removed the systematic trends in the photometry reported to the MPC and created the so-called 'Lowell photometric database'. The database consists of re-calibrated photometry for about 500,000 asteroids, with typically hundreds of brightness measurements per object. Bowell et al. (M&PS, submitted) used this database to analyze brightness variations with ecliptic longitude and estimated spin-axis longitudes for about 350,000 asteroids. In our work, we processed data for the first 10,000 numbered asteroids with the lightcurve inversion method (Kaasalainen et al., 2001, Icarus 153,37) using an enormous computational power of Asteroids@home (http://asteroidsathome.net) - a distributed computing project built on the BOINC platform. More than 10,000 users have joined the project and their computers were used for the time-consuming search for the sidereal rotation period in the sparse data. Although the photometric accuracy of the Lowell data is low (~0.2 mag), we were able to find unique models for several hundred asteroids. We will present the first results based on the statistical analysis of the sample (distribution of spin vectors, for example) and we will also discuss the relevance of our approach to Gaia, LSST, ATLAS, and other future sources of asteroid photometry with sparse sampling.

304.06 – In Search of Fresh Material on Asteroid Pairs

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Asteroid Pairs are those found to share almost identical orbital elements. Studies have shown that each pair had a single progenitor that split in the last ~1 Myrs due to rotational-fission of a 'rubble-pile' structured body. This process may have exposed non-weathered sub-surface material, thus examining pairs' reflectance spectra could inform us about the physics of the rotational-fission mechanism. We report near-IR spectroscopic observations of a sample of 25 asteroid pairs, performed with the IRTF and Magellan telescopes. Since the rough division of the spectral taxonomy has arbitrary borders, and in order to quantify the extent of weathering, we analyzed the features of the spectra: the slope and the center and width of the 1-micron absorption band. We compared these values to those of asteroids of the background population that were measured in the same manner and were chosen to match the range of absolute magnitude and an orbit within the main belt. While the preliminary results show that the pairs' band parameters are distributed most similarly to those of fresh objects (Q-type) than of weathered asteroids (S-type), a careful examination reveals that asteroid pairs of the Ordinary Chondrite type may be observationally biased towards Olivine-rich asteroids (the meteoritic LL-type) that share some of the band parameters of Q-type asteroids. Since Olivine-rich asteroids are more common in the inner main belt (the Flora family) they are just easier to observe, therefore more pairs are identified within this group, even though other types of asteroids can split by rotational-fission as well. The spectral slope distributions of asteroid pairs and of the background population resemble one another with no significant distinction. This suggests that on average, there may be no readily evident for excess in fresh material that is excavated and exposed on the surfaces of asteroid pairs. This leads to a model of a gentle breakup of the fast rotating progenitor with no large amount of transported dust and boulders. This level of detail is not yet treated in pair formation models, but should be considered in future work.

304.07 – Asteroid Models from Sparse Photometry and Spin Vectors in Asteroid Families

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The lightcurve inversion method is a powerful tool that allows us to derive basic physical parameters of asteroids (such as convex shapes and rotational states) from their disk-integrated photometry. We investigate the photometric accuracy of the sparse-in-time data from astrometric surveys available on AstDyS (Asteroids, Dynamic Site) and use the most accurate data in combination with relative lightcurves in the lightcurve inversion method. With this method, we derive ~300 asteroid physical models. To validate the newly determined asteroid models, we introduce several reliability tests. We investigate rotational properties of our MBAs sample (~450 asteroid models derived here or previously by the lightcurve inversion method), especially the spin vector distribution. We have found that smaller asteroids (D <= 30 km) have strongly anisotropic spin vector distribution even when we remove the bias of the lightcurve inversion, the poles are clustered towards ecliptic poles. We explain this anisotropy as a result of non-gravitational torques (the YORP effect) acting on these objects. Without accounting for these torques, we would not be able to explain such anisotropic distribution. We also focus on the spin vector distribution among several individual collisional families - Flora, Koronis, Eos, Eunomia, Phocaea, Themis, Maria and Alauda. Using a combined orbital- and spin-evolution model we can reproduce fairly well the observed spin-vector properties of these collisional families. Finally, we estimate sizes for 48 and 10 asteroids by scaling their convex models to fit the adaptive optics profiles and occultation observations, respectively. The work of JH and JD has been supported by grants GACR P209/10/0537 and P209/12/0229 of the Czech Science Foundation, the work of JD and MB by the Research Program MSM0021620860 of the Czech Ministry of Education, and the work of MB by grant GACR 13-013085 of the Czech Science Foundation.

304.08 – Rotational properties of Maria asteroid family

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The Maria family is a typical old population (~3±1 Gyr) of asteroids that have undergone significant collisional and dynamical evolution in the history of the inner Solar System; it is also believed to be one of the candidate source regions for a couple of giant S-type NEAs. The study of rotational properties, i.e. rotational period, the pole orientation, and overall shape of lightcurves in asteroid families offers a unique opportunity to gain an insight on the collisional breakup process and dynamical evolution of asteroids in the Main-belt. However, to date, rotational properties of members of this family have been known only for 56 of larger asteroids among 3,230 cataloged objects, accounting for less than 2 percent of the family. Observations of Maria asteroid family members were performed during 134 nights spanning from July 2008 to May 2013, with 0.5 m- to 2 m- class telescopes at 7 observatories in the northern hemisphere. From our observations, we obtained 218 individual lightcurves for a total of 74 Maria family members and derived synodic rotational periods for 52 objects including newly obtained periods of 36 asteroids for the first time. In this study, we found that there is a surprisingly big excess of fast rotators with periods shorter than 6 hours. From the Kolmogorov-Smirnov test, the compatibility between observed distribution and the Maxwellian is completely inconsistent at a 99% confidence level. We also investigate if there are any correlations between spin status, size and overall shapes of asteroids. The Yarkovsky footprints on Maria asteroid family will be discussed based on our analysis on pole orientations.

305 – Titan 3: Air Out

305.01 – In Situ Measurements of the Size and Density of Titan Aerosol Analogs

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The organic haze produced from complex CH4/N2 chemistry in the atmosphere of Titan plays an important role in processes that occur in the atmosphere and on its surface. The haze particles act as condensation nuclei and are therefore involved in Titan's methane hydrological cycle. They also may behave like sediment on Titan's surface and participate in both fluvial and aeolian processes. Models that seek to understand these processes require information about the physical properties of the particles including their size and density. Although measurements obtained by Cassini–Huygens have placed constraints on the size of the haze particles, their densities remain unknown.We have conducted a series of Titan atmosphere simulation experiments and measured the size, number density, and particle density of Titan aerosol analogs, or tholins, for CH4 concentrations from 0.01% to 10% using two different energy sources, spark discharge and UV. We find that the densities currently in use by many Titan models are higher than the measured densities of our tholins.

305.02 – Revised tholin profile in the atmosphere of Titan

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We present a recent effort for analyzing the stellar occultation data from Cassini/UVIS instrument. The mean optical depth as a function of line of sight impact parameter is derived for the spectral range between 1700 and 1900 A from four stellar occultations. Vertical profiles of tholin particles above ~300 km are then retrieved. The profiles show two depletion regions: 750-800 km and 400-500 km ranges. A photochemistry-transport is developed and used to interpret the production, loss, and transport in the atmosphere. Processes that affect the profile are (1) aerosol production via ion-neutral and neutral-neutral chemical reactions, (2) aggregation to form fractal aggregates, (3) aerosol coagulation, and (4) diffusion and dynamical transport via gravitational settling. Sensitivity of the resulting tholin profile to the above processes is examined and discussed.

305.03 – Post-Equinox Evolution of Titan's Detached Haze and South Polar Vortex Cloud

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Instruments on the Cassini spacecraft discovered new phenomena related to the (presumably) seasonal behavior of photochemical haze and formation of the winter polar vortex. West et al. 2011 (Geophys. Res. Lett. , 380 , L06204. doi: 10.1029/2011GL046843) described a 'detached' haze layer that dropped in altitude from about 500 km in 2005 to about 360 km by late 2010. New images from the Cassini ISS camera show that the appearance of a detached layer is produced by a gap in the haze vertical profile and it is the gap rather than a haze layer that drops in altitude. Intensity profiles from different epochs form an envelope when plotted on top of each other, and the downward movement of the gap can be most easily seen when plotted that way. The movement of a gap rather than movement of a layer of enhanced haze density was suspected in the earlier publication but now it is more apparent. In recent months the gap became very shallow and the limb intensity profiles at a pixel scale ~10 km/pixel evolved from one local maximum/minimum into two local minima/maxima of smaller amplitude and appear to be trending toward the disappearance of relative maxima and minima, leaving a smooth envelope. These observations will require new developments in coupled dynamical and haze microphysical models as none of the current models account for this behavior. Titan's south polar vortex cloud was detected concurrently by the ISS, VIMS, and CIRS instruments on Cassini in May of 2012. It has an unusual color (more yellow than Titan's main haze in ISS images), morphology and texture (suggestive of a condensate cloud experiencing open cell convection) and displays a spectral feature at 220 cm-1 (Jennings et al., 2012, Astrophys. J. Lett. 761, L15 DOI: 10.1088/2041-8205/761/1/L15). These attributes point to a condensate of unknown composition. The haze patch is seen in images up to the present (July, 2013), but the latest images suggest a 'softening' or more diffuse edge than the earlier images. The feature is being engulfed by shadow as the season progresses, eventually preventing future observations in reflected sunlight. Acknowledgement: Part of this work was performed by the Jet Propulsion Lab, Calif. Inst. Of Technology.

305.04 – The Vertical Composition of Titan's Atmosphere observed by VIMS/Cassini Solar Occultations

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The VIMS instrument has acquired 10 solar occultations since the beginning of the Cassini-Huygens mission. This dataset covers different seasons and latitudes and allows to study a large part of the atmosphere (between 50 and 700 km) by the acquisition of spectra in the infrared range (1-5 μm) with a vertical resolution of ~ 10 km on average. We present here the vertical profiles of gases and other atmospheric components, together with their spatial and temporal evolution, for a selection of VIMS occultations. Two main components of Titan's atmosphere, CH4 and CO, are observed in particular. Methane presents strong bands at 1.2, 1.4, 1.7, 2.3 and 3.2 μm. Its vertical profile, computed by the inversion of the 2.3 μm band, shows an almost constant abundance of ~ 1.2-1.3% above 250 km, less than the reference value of 1.41% from the GSMS instrument (Niemann et al. 2010). CO is detectable below ~ 160 km through its band at 4.7 μm. The resulting profiles are in good agreement with CIRS results that indicate a constant mixing ratio of 50 ppm (De Kok et al. 2007). Other spectral signatures have been detected by VIMS solar occultations. The strongest of these signatures is blended with the 3.2 μm CH4 band. It is centered at 3.4 μm and was discovered by a previous analysis of one solar occultation (Bellucci et al. 2009). It has been attributed to the C-H stretch by alkanes and aromatics present in Titan's aerosols. An additional absorption observed at 2.4 μm, within the 2 μm methane band, can tentatively be attributed to overtone signatures of this C-H stretch. We are discussing this interpretation and its implications on the composition of aerosols and their temporal and spatial variability. Other bands at 2.7 and 4.2 μm have been detected for the first time by the present study and are still unidentified. Their characteristics and possible attribution are analyzed.

305.05 – Titan's Seasonal North-South Asymmetry Separated into two Components

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We investigated the north-south asymmetry of Titan's haze with respect to five variables: wavelength, methane absorption, center-to-limb position, latitude on Titan, and season on Titan. We used 54 exposures taken with the Space Telescope Imaging Spectrograph. Each exposure recorded up to 18 spectra along the slit with wavelengths 530-1020 nm in 1000 pixels. Multiple exposure offsets perpendicular to the slit provided coverage in the other spatial direction. Such sequences were repeated in five years between 1997 and 2004. Our calibration and navigation created a four-dimensional data set, the reflectivity as function of wavelength, center-to-limb position, latitude, and time. As a check, our brightening of Titan in the spectral band y is consistent with Lockwood and Thompson (2009, 200, 616-626). In order to grasp the information contained in this complex data set, we performed a principal component analysis. For each component, the reflectivity function was separated into a product of two functions, one depending only on wavelength and center-to-limb position, and another one depending only on latitude and time. The first two principal components contained 84 % and 12 % of the total variance, respectively. They describe aspects of Titan's north-south asymmetry. Two components due to surface features contained 3 % and 1 % variance. The remaining variance of < 1 % is noise. The first component switched signs in 2004, just after solstice, the second one already in 2001, except that latitudes within 20° of the equator had a different phasing. The first component had the highest amplitudes at wavelengths probing deep into Titan's atmosphere, the second one at wavelengths probing high altitudes. At continuum wavelengths, the first component had large amplitudes at the longest wavelengths, the second one at the shortest wavelengths. The separation of Titan's seasonal north-south asymmetry into two components with different phasing, altitude, and haze characteristics gives insights into the workings of seasonal change on Titan. We plan to compare our data with radiative transfer models to quantify what is changing, when, and how. This research was supported by STScI through program AR12624.

305.06 – Seasonal variations in Titan's stratosphere observed with Cassini/CIRS: temperature, trace molecular gas and aerosol mixing ratio profiles

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Contributing teams: CIRS Team

Titan's northern spring equinox occurred in August 2009. General Circulation Models predict strong modifications of the global circulation in this period, with formation of two circulation cells instead of the pole-to-pole cell that occurred during northern winter. This winter single cell, which had its descending branch at the north pole, was at the origin of the enrichment of molecular abundances and high stratopause temperatures observed by Cassini/CIRS at high northern latitudes. The predicted dynamical seasonal variations after the equinox have strong impact on the spatial distributions of trace gas, temperature and aerosol abundances. We will present here an analysis of CIRS limb-geometry datasets acquired between 2009 and 2012 that we used to monitor the seasonal evolution of the vertical profiles of temperature, molecular (C_2H_2, C_2H_6, HCN, ...) and aerosol abundances.

305.07 – Observed Seasonal Change in Titan's Thermosphere

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Titan's upper thermosphere has exhibited structural changes throughout the Cassini mission to date. Some thermospheric structure has been tied to magnetospheric forcing (Westlake et al. 2011) and wave activity (Snowden et al. 2013). Now, after several years of observation we have evidence of clear solar forcing of Titan's thermosphere. During the time between TA (2004) and T86 (2012) N_2 and CH_4 have declined in density resulting in a factor of 3 reduction of N_2 and a factor of 5.6 reduction in CH_4 at 1000 km. This decline is in response to the solar conditions at Titan, either through a change in distance from the Sun (Titan has receded nearly 1AU from the Sun since 2004), a change in the solar activity level, or a change in the sub-solar point (season). In the most recent flybys Titan's methane has declined at an enhanced rate. We postulate that this decline is a direct response to the solar maximum conditions in 2012. Titan's N_2 responds primarily to changes in the thermal structure over a timescale of months to years, while CH_4 responds to changes in solar forcing on shorter timescales (Bell et al. 2011). We illustrate this process though analysis of the INMS data since TA and modeling studies using the T-GITM global circulation model.

305.08 – Seasonal Evolution of Titan's Atmospheric Polar Vortices

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Titan is the largest satellite of Saturn and is the only moon in our solar system to have a significant atmosphere. Titan's middle-atmosphere circulation usually comprises a single hemisphere-to-hemisphere meridional circulation cell, with upwelling air in the summer hemisphere and subsiding air at the winter pole with an associated winter polar vortex. Titan has an axial tilt (obliquity) of 26.7degrees, so during its 29.5 Earth year annual cycle pronounced seasonal effects are expected as the relative solar insolation in each hemisphere changes. The most dramatic of these changes is predicted to be the reversal in global meridional circulation as the peak solar heating switches hemispheres after an equinox. Since northern spring equinox in mid-2009, Titan's atmosphere has demonstrated dramatic changes in temperature, composition, and aerosol distribution. These changes indicate major changes to the atmospheric circulation pattern have indeed occurred. Here we use nine years of Cassini/CIRS infrared spectra to determine the temperature and composition evolution of the atmosphere through northern-fall to northern-spring. Particularly dramatic changes are observed at the poles, where a new south polar hot-spot/vortex has been forming. The north polar vortex also appears to be weakening throughout this period. Furthermore, the meridional circulation reversal, predicted by numerical models, occurred a mere six months after equinox, showing that despite Titan's long annual cycle, rapid changes are possible. This gives us new insight into vortex formation processes and atmospheric dynamics.

305.09 – Long-term chemical composition and temperature variations on Titan

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Nine years after Cassini's Saturn orbit insertion, we look at the evolution of the thermal and chemical composition of Titan's atmosphere by combining Cassini CIRS recordings and the related ground- and space- based observations. In particular, we use Cassini/CIRS data from 2004-2013 to derive the temperature structure [1,2,7] and the neutral chemistry at latitudes between 50°S and 50°N [2]. The peak in abundance is observed around the northern spring equinox, with a rapid decrease after mid-2009, indicating that the vortex has shrunk. The fulfillment of one Titanian year of space observations provides us for the first time with the opportunity to evaluate the relative role of different physical processes in the long term evolution of this complex environment, as also reported by other studies [8-10]. By comparing V1 (1980), ISO (1997) and Cassini (2010) [2-6] data we find that a return to the 1980 abundance values is achieved for most molecules at all latitudes, indicative of the solar radiation being the dominating energy source at 10 AU, as for the Earth, in agreement with predictions by GCM and photochemical models. The few exceptions set important constraints. We show that wrt V1 the stratospheric chemical composition shows higher values near the northern fall equinox (near 1997) and lower ones at the spring equinox (near 2009). The cause could be spatial changes (due to Titan's inclination) in the energy input to Titan's atmosphere as a driver for changes in the advection patterns, circulation, etc which in turn provide a stronger variability in the latitudinal abundances of photochemical species after some time. References
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306 – Sagan Medal (D. Yeomans); Urey Prize Lecture:From Pebbles to Planets, A. Johansen (Lund University)

306.01 – From Pebbles to Planets

Anders Johansen[1]
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Planets form in protoplanetary discs around young stars as dust and ice particles collide to form ever larger bodies. Particle concentration in the turbulent gas flow may be necessary to form the planetesimals which are the building blocks of both the terrestrial planets and the cores of the gas giants and the ice giants. The streaming instability, which feeds off the relative motion of gas and particles, is a powerful mechanism to create overdense particle filaments. These filaments contract under their own gravity to form planetesimals with a wide range of sizes. I will also discuss how the pebbles left over from the planetesimal formation stage can lead to rapid formation of the cores of gas giants, well within the protoplanetary disc life-time, even in wide orbits.

307 – Planets Orbiting M Dwarf Stars: The Most Characterizable Terrestrial Exoplanets are also the Most Abundant, P.S. Muirhead (Boston Univ.)

307.01 – Planets Orbiting M Dwarf Stars: The Most Characterizable Terrestrial Exoplanets are also the Most Abundant

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The study of extrasolar planets is rapidly evolving. The quest to discover ever more and ever smaller exoplanets has pushed the field in two primary directions: 1) toward a comprehensive assessment of the frequency and statistics of various types of exoplanets, used to constrain planet formation and evolution scenarios, and 2) toward characterizing the composition, atmosphere and evolution of individual exoplanets as though they were planets in our own Solar System. Exoplanets that orbit M dwarf stars have come to the forefront of both of these efforts, as M dwarfs dominate stellar populations and the atmospheres of exoplanets that transit M dwarfs can be characterized to an impressive degree with current and future telescopes. I will present a review of our current understanding of planets that orbit M dwarfs, and relay recent findings based on data from NASA's Kepler Mission that suggest 1-Earth-radius planets are extremely abundant around M dwarfs, and therefor also the galaxy and Universe as a whole.

308 – Titan's Spectacular Volte-Face, C.A. Griffith (Univ. Arizona)

308.01 – Titan's Spectacular Volte-Face

Caitlin A. Griffith[1]
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Like Earth, Titan sports lakes, storms and rainfall. These features derive from a methane cycle, reminiscent of Earth's hydrological cycle; methane exists as an ice, liquid and gas and transfers between the surface and atmosphere, according to the seasonal weather. Titan's seasons contrast Earth's. Imagine a summer trip to 70 latitude, where hurricane-sized storms burst forth out of a clear sky every few months for about 15 years. Then they vanish for another 15 years. Envision a trip to the winter polar region. Here the sky is perhaps clear except that the high haze, which filters sunlight like a translucent globe, is somewhat thicker than it is in the summer. Imperceptibly, you are blocking the diffuse organic matter, which is slowly settling out of the hazy orb, and accumulating on the polar surface. These effects are a few of the many that derive from Titan's circulation and its seasonal changes during the satellite's 29.5 Earth year orbit about the Sun. In particular, and as indicated in recent observations, Titan's circulation flip-flopped. Before equinox in 2009, on average, air rose in the southern polar region and downwelled in the northern polar region. Now the reverse appears to be happening. Here we discuss the observations ranging from the surface to ~500 km altitude that reveal the symphony of responses of Titan's surface and atmosphere to this dramatic shift. In addition we discuss the syntheses of these effects, from theoretical efforts involving microphysical models, local cloud models and general circulation models, with the question of why Titan's seasonal changes are so much more spectacular compared to those of Earth.

309 – Titan Posters

309.01 – Long-period librations of Titan

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Because of its elliptical orbit around Saturn and its non-spherical mass distribution, Titan has longitudinal librations. Here we study the long-period librations of Titan and include deformation effects and the existence of a subsurface ocean. We take into account the fact that the orbit is not keplerian and has other periodicities than the main period of orbital motion around Saturn due to perturbations by the Sun, other planets and moons (in particular Iapetus). An orbital theory is used to compute the orbital perturbations due to these other bodies. We numerically evaluate the amplitude of the long-period librations for many interior structure models of Titan constrained by the mass, radius and gravity field. Measurements of these librations may give constrains on the interior structure of the icy satellites.

309.02 – Effects of topography on the dune forming winds on Titan

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Cassini observed hundreds of dune fields on Titan, nearly all of which lie in the tropics and suggest westerly (from west to east) winds dominate at the surface. Most GCMs however have obtained easterly surface winds in the tropics, seemingly contradicting the wind direction suggested by the dunes. This has led to an active debate in the community about the origin of the dune forming winds on Titan and their direction and modality. This discussion is mostly driven by a study of Earth dunes seen as analogous to Titan. One can find examples of dunes on Earth that fit several wind regimes. To date only one GCM, that of Tokano (2008, 2010), has presented detailed analysis of its near surface winds and their dune forming capabilities. Despite the bulk of the wind being easterly, this GCM produces faster westerlies at equinox, thus transporting sand to the east. Our model, the Titan CAM (Friedson et al. 2009), is unable to reproduce the fast westerlies. Our GCM has been updated to include realistic topography released by the Cassini radar team. Preliminary results suggest our tropical wind regime now has net westerly winds in the tropics, albeit weak.
References: Tokano, T. 2008. Icarus 194, 243–262. Tokano, T. 2010. Aeolian Research 2, 113-127. Friedson, J. et al. 2009. Planet. Sp. Sci., 57, 1931-1949.

309.03 – Evaporation of Liquid Hydrocarbon Mixtures on Titan

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Besides Earth, Titan is the only other known planetary body with proven stable liquids on its surface. The hydrological cycle of these liquid hydrocarbon mixtures is critical in understanding Titan's atmosphere and surface features. Evaporation of liquid surface bodies has been indirectly observed as shoreline changes from measurements by Cassini ISS and RADAR (Hayes et al. 2011, Icarus 211, 655-671; Turtle et al. 2011, Science 18, 1414-1417.), but the long seasons of Saturn strongly limit the time span of these observations and their validity over the course of an entire Titan year. Using a novel Titan simulation chamber, the evaporation rate of liquid methane and dissolved nitrogen mixture under Titan surface conditions was derived (Luspay-Kuti et al. 2012, GRL 39, L23203), which is especially applicable to low latitude transient liquids. Polar lakes, though, are expected to be composed of a variety of hydrocarbons, primarily a mixture of ethane and methane (e.g. Cordier et al. 2009, ApJL 707, L128-L131). Here we performed laboratory simulations of ethane-methane mixtures with varying mole fraction under conditions suitable for the polar regions of Titan. We will discuss results specifically addressing the evaporation behavior as the solution becomes increasingly ethane dominated, providing quantitative values for the evaporation rate at every step. These laboratory results are relevant to polar lakes, such as Ontario Lacus, and can shed light on their stability.

309.04 – Surface energy budget from a Titan GCM with realistic radiative transfer

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The existence of Titan's seasonal convective cloud activity, despite the atmosphere's huge thermal inertia, has been explained as resulting from variations in surface temperatures that drive cloud formation. General circulation models (GCMs) that produce significant summer precipitation have typically employed simplified radiative transfer that allows the summer polar surface to receive the maximum insolation, thus allowing vigorous convection to occur there. However, surface energetics from a GCM with nongray radiative transfer that uses optical properties derived from Cassini/Huygens data, and correlated k coefficients, indicate that this may not be entirely realistic. The surface energy budget in equilibrium is a balance between net surface radiation and turbulent surface fluxes of latent and sensible energy; because the maximum surface insolation oscillates seasonally between mid-latitudes, so too do the turbulent fluxes. Thus, the destabilizing influence of surface energy fluxes into the atmosphere with respect to convection is lower than previously suggested at the poles, but higher near midlatitudes. Methane is not available in infinite supply at the surface, and therefore sensible heat flux plays an equally important role as evaporation in balancing the surface radiative imbalance. The modeled moist static energy maximum also oscillates only between midlatitudes, in part because polar surface methane is limited as a source, boosting the possibility of midlatitude clouds. This may help to explain the observed persistence of southern mid-latitude clouds as the seasons change.

309.05 – The Atmospheric Transmission and Surface Composition of Titan

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Recent advances in radiative transfer models, measurements of Titan's atmosphere from solar occultations, and specular reflections off of lakes, have improved our understanding of the atmospheric transmission and scattering in the spectral windows where the surface can be detected by VIMS. Titan's surface, in the VIMS spectral range, is seen in only a few spectral windows near 0.94, 1.1, 1.3, 1.6, 2.0, 2.68-2.78, and 4.9-5.1 microns. The transmission of Titan's 2-micron window indicates that the surface is absorbing on the long wavelength side of the 2-micron window. This new knowledge, along with the spectral shapes of the 2.68-2.78-micron, and 5-micron windows provide powerful constraints on Titan's surface composition. Significant surficial water ice is incompatible with the observed 2-micron absorption and 2.78/2.68 micron I/F ratio but likely exists below the surface. Many organic compounds have absorptions that are not seen in spectral windows of Titan, eliminating them as possible major components at the surface. We find that some ring compounds and compounds with single N-H bonds have a close match to Titan's overall spectrum and can explain the relative intensities observed in the spectral windows, including the 2.68 and 2.78-micron double window, the low 3-5 micron reflectance, and increased absorption near 2.1-microns. Glycine is the only NH_2 compound we have found that is also compatible. Some PAH compounds are compatible with the 2-micron window, but others can also be rejected due to incompatible absorptions in other windows. Combinations of coronene ($C_{24}H_{12}$), phenanthrene ($C_{14}H_{12}$), pentacene ($C_{22}H_{14}$), indole (C_8H_7N), uracil ($C_4H_4N_2O_2$), and glycine (NH_2CH_2COOH) match the overall spectral structure of Titan spectra. Indole, cytosine, and uracil, have 1.5-micron bands that are similar to the feature observed in Huygens DISR spectra of Titan's surface. These compounds, if present, can also help explain the pyrolysis results from the Huygens probe.

309.06 – Ion Composition in Titan's Exosphere from the Cassini Plasma Spectrometer

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A primary goal of the Cassini mission has been to characterize the complex interaction between Saturn's magnetosphere and Titan's ionosphere. To this end, the Cassini spacecraft carries two instruments–the Ion and Neutral Mass Spectrometer (INMS) and the Cassini Plasma Spectrometer (CAPS)–capable of energy- and mass-analysis. The Ion Mass Spectrometer (IMS), one of three instruments composing CAPS, is designed to characterize diffuse plasmas throughout the magnetosphere while the INMS is optimized for measurements within Titan's upper atmosphere. As such, mass-resolved ion compositions confirming a variety of hydrocarbons and nitriles have been extracted from INMS data for numerous Titan encounters. Similar analysis of IMS data, however, has been resolution-limited to the identification of "light" and "heavy" ion groups in the wake. Herein we present a technique for extracting Dalton-resolved ion compositions from IMS spectra acquired at altitudes below 5 Titan radii. The method is then applied to data from the T40 encounter and the resulting composition and fluxes compared with those derived from the INMS data for the same encounter.

309.07 – Analyses of the gas and solid phases of Titan aerosol simulants produced in the COSmIC/THS experiment

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Titan's atmosphere, composed mainly of N_2 and CH_4, is the siege of a complex chemistry, which occurs at temperatures lower than 200K and leads to the production of heavy molecules and subsequently solid aerosols that form the haze surrounding Titan. The Titan Haze Simulation (THS) experiment has been developed at the NASA Ames COSmIC facility to study Titan's atmospheric chemistry at low temperature. The chemistry is simulated by plasma in the stream of a supersonic expansion. With this unique design, gas is jet-cooled to Titan-like temperature (~150K) before inducing the chemistry by plasma, and remains at low temperature in the plasma discharge (~200K measured by optical emission spectroscopy). Different N_2-CH_4-based gas mixtures can be injected in the plasma, with or without the addition of trace elements present on Titan. Both the gas phase and solid phase products resulting from the plasma-induced chemistry can be monitored and analyzed using different in situ and ex situ diagnostics. Here we present and discuss the results of two recent studies. A mass spectrometry analysis of the gas phase has demonstrated that the COSmIC/THS experiment can be used to study the first and intermediate steps as well as specific chemical pathways of Titan's atmospheric chemistry due to the short residence time of the gas in the plasma discharge. The more complex chemistry, when adding trace elements to the initial N_2-CH_4 mixture, has been confirmed by an extensive study of the solid phase: scanning electron microscopy images show much bigger grains produced in N_2-CH_4-C_6H_6 mixtures (1-5 µm) compared to N_2-CH_4 mixtures (0.1-0.5 µm), and NMR supports a growth evolution of the chemistry when adding acetylene to the N_2-CH_4 mixture, resulting in the production of more complex (possibly double/triple or nitrogen-hydrogen) hydrogen bonds than with a simple N_2-CH_4 mixture. Raman spectroscopy, IR spectroscopy, and gas-chromatography mass spectrometry results will also be discussed. These complementary studies show the potential of COSmIC/THS to better understand the first steps of Titan's chemistry and the origin of aerosol formation.

309.08 – The North South Asymmetry in Titan's Haze Through Time at Equinox

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We use data from Cassini to observe the North South Asymmetry (NSA) in Titan's haze. We are continuing the work first addressed by the Hubble Space Telescope observations (Lorenz et al., 2004) with the Visual Infrared Mapping Spectrometer (VIMS) located on-board Cassini. Our goal is to find a quantitative description of the interhemispheric contrast, and the transition latitude between the two 'hemispheres'. These relationships could be used to improve current atmospheric models to better understand Titan weather phenomenon such as the Titan's recently-formed south polar vortex. With VIMS we are able to achieve both better spatial and spectral resolution and a better signal-to-noise ratio than previous Earth-based observations. Profiles of the asymmetry show

progressive brightening of the dark northern haze relative to the south, ranging in multiple wavelengths from 351 nm (ultraviolet) to 894 nm (infrared), starting in 2005. This trend continues until Titan's northern spring equinox in August of 2009 after which Titan shifts to being north-bright relative to the south, suggesting a migration of haze to the southern hemisphere as it transitions into winter. Finally, we use a differential edge detection algorithm to isolate the latitude of the NSA boundary for each Cassini flyby, and we find a systematic migration over time.

309.09 – New Results on Titan's Atmosphere and Surface from Huygens Probe Measurements

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The global Titan perspective afforded by ongoing Cassini observations, and prospects for future in-situ exploration, have prompted a re-examination of Huygens data, yielding new results in several areas. Gravity waves have been detected (Lorenz, Ferri and Young, submitted) in the HASI descent temperature data, with 2K amplitude. These waves are seen above about 60km, and analysis suggests they may therefore be controlled by interaction of upward-propagating waves with the zonal wind field. A curious cessation of detection of sound pulses by a Surface Science Package ultrasound instrument about 15 minutes after the probe landed appears to be best explained (Lorenz et al., submitted) by an accumulation of polyatomic vapors such as ethane, sweated out of the ground by the warm probe. Such gases have high acoustic attenuation, and were independently measured by the probe GCMS. A new integrated timeline product, which arranges second-by-second measurements from several Huygens sensors on a convenient, common tabulation, has been archived on the PDS Atmospheres node. Also archived is an independent retrieval of Doppler information from VLBI receivers that has a higher time resolution than the DWE archive product, and an expanded event summary product that documents when key observations, system events and anomalies occurred. Finally, a troubling discrepancy exists between radio occultation and infrared soundings from Cassini, and the lower stratospheric temperature retrieved from the HASI accelerometer record. Two factors may contribute to this discrepancy - the assumed probe mass history, and the assumed zonal wind profile. The sensitivity of the recovered temperature profile to these factors is examined : in particular it is noted that the speed relative to the atmosphere in the late part of entry, when the hypersonic entry speed has been largely bled away by drag, is particularly sensitive to assumed winds, and it is in this altitude region where the recovered density (or temperature) profile discrepancy may be highest.

309.10 – Titan 2D: Understanding Titan's Seasonal Atmospheric Cycles

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In this study, we present results from a novel two-dimensional (2D) model that simulates the physics and chemistry of Titan's atmosphere. Despite being an icy moon of Saturn, Titan is the only Solar System object aside from Earth that is sheathed by a thick nitrogen-dominated atmosphere. This vulnerable gaseous envelope—an embodiment of a delicate coupling between photochemistry, radiation, and dynamics—is Nature's laboratory for the synthesis of complex organic molecules. Titan's large obliquity generates pronounced seasonal cycles in its atmosphere, and the Cassini spacecraft has been observing these variations since 2004. In particular, Cassini measurements show that the latitudinal distribution of Titan's rich mélange of hydrocarbon species follows seasonal patterns. The mixing ratios of hydrocarbons increase with latitude towards the winter pole, suggesting a pole-to-pole circulation that reverses after equinox. Using a one-dimensional photochemical model of Titan's atmosphere, we show that photochemistry alone cannot produce the observed meridional hydrocarbon distribution. This necessitates the employment of a 2D chemistry-transport model that includes meridional circulation as well as diffusive processes and photochemistry. Of additional concern, no previous 2D model of Titan extends beyond 500 km altitude—a critical limitation since the peak of methane photolysis is at 800 km. Our 2D model is the first to include Titan's stratosphere, mesosphere, and thermosphere. The meridional circulation in our 2D model is derived from the outputs of two general circulation models (GCMs): the TitanWRF GCM (Newman et al. 2011) covering the troposphere, stratosphere, and lower mesosphere, and a thermosphere general circulation model (TGCM) covering the remainder of the atmosphere through the thermosphere (Müller-Wodarg et al. 2003; 2008). This presentation will focus on the utilization of these advances applied to the 2D Caltech/JPL KINETICS model to understand the seasonal and meridional distribution of hydrocarbons as well as other atmospheric cycles on Titan.

310 – Pluto Posters

310.01 – Recent KBO (Pluto/Charon and beyond, including Quaoar) Occultation Observations by the Williams College Team as part of the Williams-MIT Collaboration

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The Williams College–MIT collaboration has observed numerous occultations of stars by Pluto/Charon and other Kuiper-belt objects (www.stellaroccultations.info), since its establishment three decades ago with an attempted discovery of Neptune's rings in 1983. In this paper, we describe several recent occultation observations, both successful and (for reasons of path uncertainties and/or weather) unsuccessful. Light curves made or arranged by Williams College faculty and students were used together with light curves by MIT colleagues and others to study Pluto's atmosphere and Charon's size, to discover one of the highest-known solar-system albedos (KBO 55636), and to attempt to study 1000-km-diameter Quaoar. Observations discussed include light curves for KBO 55636 on 9 October 2009 from Hawaii; Pluto on 3/4 July 2010 from Chile, 22 May 2011 from Williamstown, Massachusetts, 23 June 2011 from Hawaii (in support of SOFIA observations of Pluto's atmosphere, discussed in an article in press in AJ and of the pair of Pluto/Charon occultations of the same star), and 4 May 2013 (Bosh et al., this conference) and 15 July 2013 from Williamstown; Charon on 15 June 2013 from Williamstown; Quaoar from a picket fence ranging from Chile through Venezuela (with a detection there) to Massachusetts on July 8/9 and in South Africa on 12 July 2013. This work was supported in part by NASA Planetary Astronomy grants NNX08AO50G and NNH11ZDA001N to Williams College, NNX10AB27G to MIT, and USRA grant #8500-98-003 to Lowell Observatory. We thank Steven P. Souza at Williams; Steven Levine at Lowell Obs.; Jennifer G. Winters (GSU) in Chile; Richard Rojas/Jorge Moreno in Venezuela; Scott Sheppard; Federica Bianco; David Osip; and others. ZR (Vassar '14) was a Keck Northeast Astronomy Consortium Summer Fellow at Williams College, supported by an NSF/REU grant to the Keck Northeast Astronomy Consortium. ES: partial support from Programa Nacional de Becas de Postgrado (CONICYT Grant 21110496). FF: support from FONDECYT through grant 3110042 and by the Millennium Center for Supernova Science, grant P10-064-F. funded by Programa Bicentenario de Ciencia y Tecnología de CONICYT and Programa Iniciativa Científíca Milenio de MIDEPLAN.

310.02 – Pluto: Global Modeling of 3-D Atmosphere-Surface Interactions

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Atmosphere-surface interactions on Pluto are of great importance to creating and maintaining the atmosphere variations and heterogeneous surface that have been observed in the past two decades. This work investigates these processes in a multidisciplinary fashion, using a new global climate model (GCM) for Pluto based on the terrestrial OLAM model (University of Miami). Early results from this Pluto GCM, using relatively simple configurations/initializations, will be presented. Detailed shorter-timescale interactions will be emphasized.

310.03 – A peculiar stable region around Pluto

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In a previous work Giuliatti Winter et al (2010) found several stable regions for a sample of test particles located between the orbits of Charon. Some of these particles are in orbits around Pluto and some of them are in orbits around Charon. One peculiar stable region, located at a=[0.5d, 0.65d], where d is the Pluto-Charon distance, presents large values of the particle's eccentricity e = [0.2, 0.9]. This region is associated to a family of periodic orbits derived from the circular, restricted 3-body problem (Pluto-Charon-particle). The evolution of the periodic and quasi periodic orbits associated to each value of Jacobi Constant is presented. We also analyse the evolution of this stable region for a set the initial conditions, the nominal values of the argument of pericentre and the inclination, of the particles. We concluded that region 1 is present in all the values of the inclination of the particles, I= [0,90°], and for two intervals of ω, ω=[-10°, 10°] and ω= [170°, 190°].

310.04 – Longitudinal Variation of Ethane Ice on the Surface of Pluto

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Efforts are ongoing in an attempt to understand Pluto's surface composition prior to the New Horizons flyby in July 2015. One such project is our observations of Pluto with the SpeX instrument on the Infrared Telescope Facility (Grundy et al. 2013, Icarus, 223, 710-721). Since 2001, we took and reduced a total of 70 nights. The data have been roughly divided into three separate longitude bins of 120° each (0°-120°, 120°-240°, and 240°-360°) in an effort to find longitudinal variation in ethane ice on Pluto's surface. Following the longitude convention of Grundy et. al. (2013), the actual ranges covered are 2.8°-107.3° (22 nights), 120.7°-239.3° (27 nights), and 242.4°-355.4° (21 nights). These divisions were chosen due to the currently accepted distribution of ices on Pluto's surface. The 0°-120° section is of unknown composition; the 120°-240° section is thought to be dominated by N_2 and CO ices; and the 240°-360° section is thought to be dominated by CH_4 ice. Preliminary analysis of differences between the weighted average of each longitude bin and a synthetic Hapke spectrum suggests stronger ethane absorption in areas of CH_4 concentration.

310.05 – A Database of Optical Constants for Ices and Non-Ices Expected on Pluto and its Satellites

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The New Horizons mission will reach Pluto in 2015. In anticipation of this, the project wanted a single site to manage the optical constants needed in the analysis of the flight data. This poster presents a web-based tool that provides access to optical constants for species expected on Pluto or its satellites. The laboratory data comes from public sources and personal communication. The publically available web page allows for easy searching and data retrieval of optical constants as a function of wavelength. The database contains information on pure ice species, tholins, binary mixtures and others. This poster will present the link for the web page, a description of the search parameters, sample search results, and a summary of available optical constants.

310.06 – Mass Determination of Pluto and Charon from New Horizon REX Radio Science Observations

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The anticipated 14 July 2015 New Horizons fly-through of the Pluto system provides the first opportunity to determine both the total system mass and the individual masses of Pluto and Charon by direct observation. This will be accomplished by use of: i) two-way Doppler radio frequency tracking data during intervals along the fly-in and -out trajectory, and ii) one-way uplink Doppler frequency recorded by the on-board radio science instrument, REX, during the day of closest approaches to Pluto and Charon. Continuous tracking is not feasible as a result of pointing sharing with the instruments during the encounter phase. Needed radio tracking will be obtained during time slots shared with i) two-way Doppler tracking for navigation, ii) 'plasma rolls' with the spacecraft antenna pointing to Earth, and iii) during the ingress and egress phases of the occultations. Simulations of the NH encounter indicate the potential accuracies of the combined and individual mass determinations of Pluto and Charon in the order of 0.1%.

310.07 – Atmospheric Escape from the Pluto/Charon System: Monte Carlo Simulations

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Recent hybrid fluid/molecular kinetic models for Pluto's atmosphere (Erwin et al., 2013; Tucker et al. 2012) demonstrate that Pluto's upper atmosphere is warmer and more extended than previously thought. For such an extended atmosphere we examine the effect of Charon on the molecular escape rate for approximate solar minimum, medium and maximum conditions at ~33AU. In addition we consider Pluto's primary constituent N_2 as a source of molecules for Charon that can be re-emitted and form a tenuous atmosphere. Including Charon's gravity and orbital motion in the simulations, the atmosphere on the Pluto's Charon facing hemisphere is more strongly bound to the system and becomes more extended than the atmosphere on Pluto's the anti-Charon hemisphere. Accounting for Charon's gravity the net escape from the system is reduced by ~10-15%. Most of the loss is direct from Pluto's exobase region with ~1-2% due to scattering by Charon. Less than 1%, of the flux from Pluto's exobase impinges on Charon resulting in a source rate of ~10^25 - 10^26 N_2/s. This produces thick layers of nitrogen on ice in the cold regions, which when exposed to particle radiation might account for the observed ammonia hydrides. The flux of N_2 also produces a tenuous surface-boundary layer atmosphere on Charon. If such an atmosphere is detectable during the solar occultation that will occur during the New Horizon encounter, it would provide a measure of the transfer of gas between bodies in binary systems. Finally, we consider possible cryovolcanism and surface sputtering on Charon as a source of water molecules for this system.

310.08 – Changes on Pluto's Surface Revealed with Long Timebase Photometry

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We are continuing to monitor the long-term photometric behavior of Pluto in order to constrain volatile surface migration. As Pluto passes near the center of the galaxy, the fields are too crowded for normal aperture photometric techniques. We approached this problem with a combination of point-spread function (PSF) photometry and optimal image subtraction (OIS). Our data are from the 0.8-m robotic telescope at Lowell Observatory, the 1-m robotic telescope at New Mexico State Observatory, and the Faulkes 2-m robotic telescope at Siding Spring, part of Las Cumbres Observatory. Our latest results add photometric data up through 2012 to the data collected since discovery. Our new reduction scheme consists of background catalogs, image subtraction using deep templates, and Pluto photometry extraction. We also use the known photometric properties of Charon determined with HST to remove Charon's contribution from old and new data and compare these results with the HST data where Pluto is measured by itself. Data since 2002 show marked departures from the behavior prior to that time. These results provide clear evidence for time evolution of Pluto's surface albedo. We will present these results along with implications for present-day processes that are altering the surface of Pluto. This work also provides crucial insight into the effort required to provide ground-based support observations for the upcoming New Horizons flyby of Pluto in 2015. Support for this work was provided by NASA Planetary Astronomy Program, grant number NNX09AB43G.

311 – Dust Posters

311.01 – Laboratory investigation of dust impacts on antennas in space

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Recent observations of sharp voltage spikes by the WAVES electric field experiments onboard the twin STEREO spacecraft have been attributed to plasma clouds generated by the impact ionization of high velocity dust particles. The reported dust fluxes are much higher than those measured by dedicated dust detectors at 1 AU, which leads to the interpretation that the STEREO observations are due to nanometer-sized dust particles originating from the inner solar system and accelerated to high velocities by the solar wind magnetic field. However, this interpretation is based on a simplified model of coupling between the expanding plasma cloud from the dust impact and the WAVES electric field instrument. A series of laboratory measurements are performed to validate this model and to calibrate/investigate the effect of various impact parameters on the signals measured by the electric field instrument. The dust accelerator facility operating at the University of Colorado is used for the measurement with micron and submicron sized particles accelerated to 50 km/s. The first set of measurements is performed to calibrate the impact charge generated from materials specific the STEREO spacecraft and will help to interpret electric field data.

311.02 – Hypervelocity Dust Impacts in Space and the Laboratory

Mihaly Horanyi[1]
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Contributing teams: Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS) Team

Interplanetary dust particles continually bombard all objects in the solar system, leading to the excavation of material from the target surfaces, the production of secondary ejecta particles, plasma, neutral gas, and electromagnetic radiation. These processes are of interest to basic plasma science, planetary and space physics, and engineering to protect humans and instruments against impact damages. The Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS) has recently completed a 3 MV dust accelerator, and this talk will summarize our initial science results. The 3 MV Pelletron contains a dust source, feeding positively charged micron and sub-micron sized particles into the accelerator. We will present the technical details of the facility and its capabilities, as well as the results of our initial experiments for damage assessment of optical devices, and penetration studies of thin films. We will also report on the completion of our dust impact detector, the Lunar Dust Experiment (LDEX), is expected to be flying onboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission by the time of this presentation. LDEX was tested, and calibrated at our dust accelerator. We will close by offering the opportunity to use this facility by the planetary, space and plasma physics communities.

311.03 – Nano-Dust Analyzer For the Detection and Chemical Composition Measurement of Particles Originating in the Inner Heliosphere

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The development of the Nano-Dust Analyzer (NDA) instrument and the results from the first laboratory testing and calibration are reported. The two STEREO spacecrafts have indicated that nanometer-sized dust particles, potentially with very high flux, are delivered to 1 AU from the inner solar system [Meyer-Vernet, N. et al., Solar Physics, 256, 463, 2009]. These particles are generated by collisional grinding or evaporation near the Sun and accelerated outward by the solar wind. The temporal variability reveals the complex interaction with the solar wind magnetic field within 1 AU and provides the means to learn about solar wind conditions and can supply additional parameters or verification for heliospheric magnetic field models. The composition analysis will report on the processes that generated the nanometer-sized particle. NDA is a highly sensitive dust analyzer that is developed under NASA's Heliophysics program. The instrument is a linear time-of-flight mass analyzer that utilizes dust impact ionization and is modeled after the Cosmic Dust Analyzer (CDA) on Cassini. By applying technologies implemented in solar wind instruments and coronagraphs, the highly sensitive dust analyzer will be able to be pointed toward the solar direction. A laboratory prototype has been built, tested, and calibrated at the dust accelerator facility at the University of Colorado, Boulder, using particles with 1 to over 50 km/s velocity. NDA is unique in its requirement to operate with the Sun in its field-of-view. A light trap system has been designed and optimized in terms of geometry and surface optical properties to mitigate Solar UV contribution to detector noise. In addition, results from laboratory tests performed with a 1 keV ion beam at the University of New Hampshire's Space Sciences Facility confirm the effectiveness of the instrument's solar wind particle rejection system.

311.04 – Cratering Studies in Thin Plastic Films

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Contributing teams: Colorado Center for Lunar Dust and Atmospheric Studies

Thin plastic films, such as Polyvinylidene Fluoride (PVDF), have been used as protective coatings or dust detectors on a number of missions including the Dust Counter and Mass Analyzer (DUCMA) instrument on Vega 1 and 2, the High Rate Detector (HRD) on the Cassini Mission, and the Student Dust Counter (SDC) on New Horizons. These types of detectors can be used on the lunar surface or in lunar orbit to detect dust grain size distributions and velocities. Due to their low power requirements and light weight, large surface area detectors can be built for observing low dust fluxes. The SDC dust detector is made up of a permanently polarized layer of PVDF coated on both sides with a thin layer (≈ 1000 Å) of aluminum nickel. The operation principle is that a micrometeorite impact removes a portion of the metal surface layer exposing the permanently polarized PVDF underneath. This causes a local potential near the crater changing the surface charge of the metal layer. The dimensions of the crater determine the strength of the potential and thus the signal generated by the PVDF. The theoretical basis for signal interpretation uses a crater diameter scaling law which was not intended for use with PVDF. In this work, a crater size scaling law has been experimentally determined, and further simulation work is being done to enhance our understanding of the mechanisms of crater formation. Two Smoothed Particle Hydrodynamics (SPH) codes are being evaluated for use as a simulator for hypervelocity impacts: Ansys Autodyn and LS-Dyna from the Livermore Software Technology Corp. SPH is known to be well suited to the large deformities found in hypervelocity impacts. It is capable of incorporating key physics phenomena, including fracture, heat transfer, melting, etc. Furthermore, unlike Eulerian methods, SPH is gridless allowing large deformities without the inclusion of unphysical erosion algorithms. Experimental results and preliminary simulation results and conclusions will be presented.

311.05 – Ejecta from Hypervelocity Dust Impacts Based on Light Flash Measurements

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Ejecta from hypervelocity dust impacts have been shown to depend on the impinging particles' velocity, mass, composition, etc. (J. Früchtenicht 1965, G. Eichhorn 1976). Ejecta is thought to be responsible for developing rings and dusty atmospheres of moons throughout the solar system. In order for rings to be produced, dust velocities must be greater than the moon's escape speed. To understand the dust impact yield; impact ejecta parameters (velocities, masses, angular distributions) must be well understood. Laboratory experiments provide direct information about the ejecta production rates and impactor fluxes. Using hypervelocity (1-60km/s) iron dust at the University of Colorado dust accelerator in Boulder, Colorado we measured the time characteristics and intensities of light flashes produced on a quartz disc from primary and secondary impacts. The flashes were measured with a photomultiplier tube at varying distances and angles. By analyzing the light flashes produced by such impacts we show that this method is a viable technique for measuring these parameters. These measurements provide detailed information about the secondary mass and velocity profiles, leading to insights into the formation of dusty rings and atmospheres.

311.06 – Can Ring Dust Impacts Alter the Surfaces of the Mid-sized Saturnian Moons?

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The goal of this project is to learn how E-Ring dust impacts can alter the surfaces and affect the albedos of the mid-sized Saturnian moons. In this work, we present results of a project that fits dust impact locations on a satellite-centered-coordinate albedo map of the four mid-sized Saturnian satellites (Mimas, Tethys, Dione, Rhea) with a well-supported charging and dynamics model. We will determine constraints for the orbits of the dust particles based on the satellite albedo patterns.

311.07 – Modeling Solar Wind Mass-Loading Due to Cometary Dust

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Collisionless mass-loading was first discussed to describe interactions between the solar wind and cometary atmospheres. Recent observations have led to an increased interest in coronal mass-loading due to sun-grazing comets and collisional debris by sunward-migrating interplanetary dust particles. Using three-dimensional MHD simulations with the Block-Adaptive-Tree-Solarwind-Roe-Upwind-Scheme (BATS-R-US) we have shown the impact on the solar wind from abrupt mass-loading in the coronal region. We also use the model as an application for a mass-loaded coronal wind due to a cometary source, which helps predict the impacts on solar wind acceleration and composition from past and upcoming sungrazing comets.

312 – Jovian Planets Posters

312.01 – Observations of Jovian Decametric Emission with the Long Wavelength Array Station 1

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We present new results in the study of Io-controlled Jovian decametric emission obtained using the newly commissioned Long Wavelength Array Station 1 (LWA1). The LWA1 is a low frequency radio interferometer operating in the frequency band between 10 and 88 MHz. The array consists of 256 dual polarization dipole stands and can be phased to point anywhere on the sky. Observations are possible with up to four simultaneous beams, each of which has two independent tuning frequencies and dual orthogonal polarization. The LWA1 is well suited to studying details of the Jovian phenomena due to its high sensitivity as well as high time and frequency resolution over a wide instantaneous bandwidth. We present LWA1 observations and initial analyses of Io-A/C, Io-B, and Io-D events, including many spectral features such as S-bursts and its substructures, narrow-band events (N-bursts), as well as modulation lanes and Faraday lanes.

312.02 – Infrared Emission Processes of Hydrocarbons in the Auroral Regions of Jupiter

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Radiative transfer processes for the analyses of thermal or non-thermal infrared spectra of CH4, C2H2, and C2H6 in the auroral atmosphere of Jupiter have been investigated. We developed a radiative tranfer program, which includes diffuse and auroral emission caused by scattering and direct particle excitation, respectively. The radiative transfer equations used in this program are of the form: $dI/d\tau = \omega^* J + (1-\omega^*)B + h\upsilon\omega^* V/4\pi$, where ω^* is $Aij /(Aij + n\eta ij)$ the single scattering albedos, V is the excitation by collisions with auroral particles (Kim et al. 1988), and the other terms are the usual parameters for thermal or diffuse radiation in radiative transfer equations. Since (a) the single scattering albedos, ω^*, are approximately known, (b) the local temperatures (and therefore the Planck function, B) can be derived from observed rotational lines of the hydrocarbons, and (c) Joule heating mainly leads to an increase of local temperature, then any excess emission from the polar regions above that due to the standard terms on the right side of the equation should be provided by the fouth term: excitation due to auroral particle precipitation at high altitude. The mixing ratios of the hydrocarbons in the auroral stratosphere of Jupiter are highly uncertain (e.g., Wong, A. et al. 2003). Utilizing the developed ratiative transfer program and analyzing infrared spectra of Jupiter obtained from our previous or planned observations, we will constrain the abundances of the hydrocarbons over the auroral regions of Jupiter. Reference Kim, S. et al. 1988. Icarus, 75, 399. Wong, A. et al. 2003. GRL. 30, 1447.

312.03 – The ν4, ν9, ν10 and ν6+ν11 bands of 13CH3-12CH3 between 1245 and 1550 cm-1

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To support atmospheric studies of the Jovian planets, the infrared spectrum of 13CH3-12CH3 was measured between 1245 and 1550 cm-1. Using a 99% 13C-enriched ethane sample, spectra were recorded at 0.0022 cm-1 resolution with the 125 HR Bruker FTIR configured to a temperature-controlled absorption cell of 0.204 m path length cooled to 130.3 K. From these, we obtained the first analysis of isotopic ethane for the three fundamentals (v4, v9 and v10) and one combination band (v6+v11). The spectrum itself is very complex; while torsional splitting produces two components (as in normal ethane), there are additional small splittings in both v9 and v10 wherever the normally infrared inactive v10 levels are perturbed by interaction with nearby states of v9. The spectrum was assigned and analyzed by adopting an appropriate Hamiltonian model; vibration-rotation-torsion parameters of these four bands were determined by the least squares process to model 1348 observed line positions with an RMS deviation of 3.24×10-3 cm-1. The values of rotational and torsional parameters of the vibrational ground state were also improved or determined using the new cold spectrum. The parallel band v4 has very perturbed intensity patterns (e. g. with the R-transitions markedly stronger than the P-transitions) due to its Coriolis coupling with v9, and future analysis of the intensities is needed to obtain reliable predictions of this spectrum. For the interim, an empirical linelist is being formed by combining measured positions and intensities at 130 K with lower state energies from known quantum assignments so that lines of this molecule can be identified in planetary spectra.
Part of the research described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, Connecticut College, and NASA Langley under contract with the National Aeronautics and Space Administration.

312.04 – A behavior of the molecular absorption in Jupiter's atmosphere during the Southern Equatorial Belt fade between 2009 and 2011

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An attempt of explanation of the processes happening at the Jovian upper atmosphere during the 2009-2011 whitening of the dark Jupiter's Equatorial Belt (SEB) is done from the spectral observations being carried out during this period. There are given the arguments for the fact that these processes might be caused by moving the cloud deck over SEB to the higher atmospheric levels in 2010 compared to the one in 2009 and 2011. They can be explained also by a higher density of scattering aerosols in consequence of enhanced ammonia condensation while the cooling of the SEB in 2010. Perhaps, these effects influenced simultaneously. When proceeding from the simplest atmospheric models one can interpret observational variations of the ammonia absorption band intensity as change of an equivalent path of gaseous ammonia absorption by ~ 35% (decreasing towards 2009). Variations of the equivalent widths of the 725 nm methane absorption band show the methane equivalent optical path of absorption (along a sight-line) increase by ~ 20% in this cloud belt in 2010 compared to 2009 and 2011. An attempt to analyze change of methane absorption distribution on the Jovian disk during the fade of the SEB in 2010 as compared with those in 2009 and 2011 is undertaken. This is made using the images of Jupiter in the continuum (IR) and in the CH4 889 nm. The conclusion is drawn that in 2010 an absorption optical depth of SEB (on a sight beam) relatively the disk centre, indeed, became more noticeable than in 2009. It is note that considerable active processes and changes in the effective optical absorption depth were happening on borders between SEB and EZ and also between NEB and NTrZ.

312.05 – Optical Ground-Based Spectra of Jupiter and Saturn: An Exploration of Giant Planet Chromophores

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We present and interpret ground-based optical spectra of Jupiter and Saturn recently acquired in an effort to characterize candidate coloring agents, or chromophores, in the atmospheres of the gas giant planets of our solar system. Surprisingly, despite hundreds of years of observations, we still do not know the identity of the trace chemical compounds that color the atmospheres of the giant planets. Previous analyses have attempted to identify a specific chemical that is responsible for the colors, but none has yet been conclusively proven. We acquired spatially resolved optical spectra of various regions in the atmospheres of both Jupiter and Saturn in February 2013 using the Dual Imaging Spectrograph (DIS) on the Astrophysical Research Consortium's 3.5-meter telescope at Apache Point Observatory. The spectra cover the range of 300-1000 nm, with a spectral resolution of R ~ 1200.
For the observations of both Jupiter and Saturn, we used DIS with the 6 arcminute long slit aligned with the planets' latitudinal bands and stepped the slit north-south to build up a spectral image cube with spectra at all locations on the planet. This enables the extraction of subapertures within the slit corresponding to specific locations, e.g. the Great Red Spot on Jupiter, during the data reduction process. We compare the optical spectra of various colored regions in the giant planet atmospheres to laboratory data of candidate chromophores. The characterization of chromophore materials will provide insight into the upper tropospheric dynamics and circulation patterns on Jupiter and Saturn that provide a stable environment for the creation and/or sustenance of chromophores. This will help further our understanding of the different evolutionary pathways of the gas giant planets of our solar system, providing a process-oriented view of their variations in cloud colors.

312.06 – Simulations of Wave Propagation in the Jovian Atmosphere after SL9 Impact Events

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Our previous numerical investigations into Jovian impacts, including the Shoemaker Levy- 9 (SL9) event (Korycansky et al. 2006 ApJ 646. 642; Palotai et al. 2011 ApJ 731. 3), the 2009 bolide (Pond et al. 2012 ApJ 745. 113), and the ephemeral flashes caused by smaller impactors in 2010 and 2012 (Hueso et al. 2013; Submitted to A&A), have covered only up to approximately 3 to 30 seconds after impact. Here, we present further SL9 impacts extending to minutes after collision with Jupiter's atmosphere, with a focus on the propagation of shock waves generated as a result of the impact events. Using a similar yet more efficient remapping method than previously presented (Pond et al. 2012; DPS 2012), we move our simulation results onto a larger computational grid, conserving quantities with minimal error. The Jovian atmosphere is extended as needed to accommodate the evolution of the features of the impact event. We restart the simulation, allowing the impact event to continue to progress to greater spatial extents and for longer times, but at lower resolutions. This remap-restart process can be implemented multiple times to achieve the spatial and temporal scales needed to investigate the observable effects of waves generated by the deposition of energy and momentum into the Jovian atmosphere by an SL9-like impactor. As before, we use the three-dimensional, parallel hydrodynamics code ZEUS-MP 2 (Hayes et al. 2006 ApJ.SS. 165. 188) to conduct our simulations. Wave characteristics are tracked throughout these simulations. Of particular interest are the wave speeds and wave positions in the atmosphere as a function of time. These properties are compared to the characteristics of the HST rings to see if shock wave behavior within one hour of impact is consistent with waves observed at one hour post-impact and beyond (Hammel et al. 1995 Science 267. 1288). This research was supported by National Science Foundation Grant AST-1109729 and NASA Planetary Atmospheres Program Grant NNX11AD87G.

312.07 – Properties of Slowly Moving Thermal Waves in Saturn from Cassini CIRS and Ground-Based Thermal Observations from 2003 to 2009

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Hemispherical maps of Saturn's atmosphere made both by Cassini's Composite Infrared Spectrometer (CIRS, 7-1000 μm) and ground-based mid-infrared observations (7-25 μm) were surveyed for the presence and properties of zonal thermal waves and their variability in time. The most inclusive CIRS surveys, FIRMAPs (15 cm-1 spectral resolution), covered the planet from the equator to either north or south pole, sweeping through the latitude range while the planet rotated beneath over its ~10-hour rotation. Ground-based observations were made at the Infrared Telescope Facility using the MIRSI instrument, the Very Large Telescope using VISIR and the Subaru Telescope using COMICS. We sampled spectral ranges dominated both by upper-tropospheric emission (80-200 mbar) and by stratospheric emission (0.5-3 mbar). We examined data that were taken between 2003 and Saturn's spring equinox in 2009. During this time, the strongest waves were found between planetographic latitudes of 30° - 45°S and 0° - 30°N. Some low-wavelength components cover all 360° in longitude, similar to the slowly moving thermal waves in Jupiter's atmosphere, but the strongest waves were found in "trains" that covered less than 180°. In 2005, tropospheric waves had a mean peak-to-peak variance that was the equivalent of temperature variability of about 1 K. Between 2005 and 2007, they had subsided to about 0.5 K. During and after 2008, they soared to over 3 K. During this entire period, similar waves in the northern hemisphere were never larger than 0.8 K. In the stratosphere, waves followed a similar time sequence, with southern hemisphere waves in 2005 reaching amplitudes as high as 3.5 K in brightness temperature, subsequently decreasing, then growing in 2008-2009 to over 5 K. Stratospheric waves in the northern hemisphere were nearly constant ~2 K, but with an instance of 6 K at one epoch in 2008. We were able to track the phase of some of the waves in the southern hemisphere, which moved about 0.5° of longitude per day retrograde with respect to System III. The phase of tropospheric and stratospheric waves appeared to be highly correlated with one another with little offset in longitudes but not with positions of atmospheric storms.

312.08 – Cloud Mapping in the Upper Jupiter Troposphere from JIRAM/Juno Data: Preliminary Sensitivity Study

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Contributing teams: JIRAM Team

The Jupiter InfraRed Auroral Mapper (JIRAM) on board of the Juno spacecraft is a spectro-imager operating in the 2-5 um range with a spectral resolution of 9 nm. Grassi et al. (2010, doi:10.1016/j.pss.2010.05.003) provided a quantitative assessment of the retrieval capabilities of the instrument in measuring mixing ratios of minor species in hot-spot conditions. The present study extends the previous investigations focusing on the aerosol retrieval capabilities in a variety of conditions, including daytime measurements. Namely, we confirm that JIRAM data at 2 microns can effectively map clouds opacities in the higher troposhpere (p < 500 mbar). This research is funded through an ASI grant.

312.09 – The Polar Winds of Saturn as Determined by Cassini/VIMS: Seasonally Variable or Not?

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Contributing teams: Cassini/VIMS Science Team

The high inclination of Cassini's current orbit allows VIMS to once again obtain spectacular views of Saturn's poles, not seen since 2008. We present new imagery and investigate the effect of seasonal variability on Saturn's polar winds. The north pole now basks in spring daylight and we again observe the long-enduring northern Polar Hexagon, discovered in Voyager imagery by Godfrey (Icarus 76, 335-356, 1988). This feature seemed to stay fixed in a rotational system defined by the Voyager-era radio rotation rate (Desch & Kaiser, Geophys. Res. Lett, 8, 253-256, 1981) in both original Voyager and 2008 VIMS observations. Yet new images indicate a shift, with the hexagon rotating ~10° of longitude from Nov. 2012 to May 2013. Discrete clouds still race around the edges of the 5-μm-bright hexagon at speeds of ~100 m/s, as we observed in 2008 (Baines, Momary, et al., Plan. Space. Sci 57, 1671-1681, 2009). We also recover a massive storm system residing just inside the hexagon edge at ~80° N. lat. Since 2008, this storm has shifted poleward by 1.5° and turned 5 μm dark (cloudy), where it was 5 μm bright when last observed (i.e. cloud free). It now moves zonally faster at ~25 m/s vs. ~14 m/s in 2008. This enduring 'shepherd' storm may force and maintain the hexagon shape. We also recover twin 5-μm-dark storms (Snake Eyes) moving slowly at ~15 m/s near 67° N lat. However, while the two features appear to maintain a relatively constant zonal separation on average (14°), with the trailing feature remaining near 67° N lat., the leading storm appears to oscillate ~1° in latitude and drift in longitude. At the south pole, discrete clouds whirl, now in darkness, around a hurricane-like vortex consisting of a cloudless 'eye' extending at least 1 bar deeper than surrounding rings of clouds. These clouds still appear to be moving as a classical vortex with winds reaching a maximum of ~200 m/s near 87° S lat. and then falling off to zero at the pole. In contrast, clouds near 75° S. lat. are nearly stationary, consistent with 2008 observations. Our preliminary results suggest limited seasonal variability of Saturn's polar winds.

312.10 – Zonal Wind Speeds, Vortex Characteristics, and Wave Dynamics in Saturn's Northern Hemisphere

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We examine images returned from Cassini spacecraft's ISS camera between 2007 and 2012 to analyze zonal wind speeds, vortex characteristics, and wave dynamics in Saturn's northern hemisphere. Our analysis focused on datasets that provided near-simultaneous coverage in the near-infrared continuum band at 752 nm (CB2 filter) and the methane bands at 727 and 890 nm (MT2 and MT3 filters). We measure the zonal wind speeds by analyzing cloud motions using one-dimensional correlation method similar to Limaye (1986). Our goal is to determine the vertical wind shear on Saturn in a manner similar to that done for Jupiter by Li et al (2006). Because the images captured in the methane bands are sensitive to higher altitudes than those in the continuum band, we are able to measure wind speeds at different altitudes. Next, we study the characteristics of multiple northern

hemisphere vortices using methods similar to the analysis of a long-lived cyclonic spot in the southern hemisphere of Saturn (del Rio-Gatztelurrutia et al, 2010). We analyze the interactions and evolutions of the vortices, and compare them with the Voyager-era northern hemisphere study (Sromovsky et al, 1983). Finally, we analyze the dynamics of the wave propagating at 45 degree N planetocentric latitude in the northern flank of an eastward zonal jet that peaks at 42 degree N. This new wave is located to the north of the Ribbon wave at 42 degree N originally found during Voyager (Sromovsky et al, 1983; Godfrey and Moore, 1986); the Ribbon wave was not present in our 2007-2012 images. We calculate the Fourier components of the new wave, and compare our findings with previous analyses and prediction of the Ribbon wave (Sromovsky et al, 1983; Godfrey and Moore, 1986; Sanchez-Lavega, 2002; Sayanagi et al, 2010).

312.11 – Temporal Evolution of Vortices with the 2010 Giant Storm on Saturn

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Cassini's long-term observations offer a unique opportunity to explore the 2010 giant storm on Saturn and the related atmospheric dynamics in the unprecedented detail. Based on the multiple images from the Imaging Science Subsystem (ISS) on Cassini, we are exploring the interaction between the giant storm and the vortices on Saturn. Our preliminary exploration, which was based on the processed ISS global maps at different times, suggests the total number of the relatively larger vortices (i.e., > 1000 km) varied from 23 to 8 during a period of October 2004 - August 2010, which is just before the eruption of the giant storm in December 2010. The temporal variation of the total number of the vortices also displays some differences between the two hemispheres on Saturn. It is not clear if the temporal variation of the total number of vortices is related to the eruption of the 2010 giant storm or seasonal variations, which will be explored further. In addition, we are processing more global maps to explore the temporal variation of the vortex activity after the eruption of the 2010 giant storm to help characterize behavior throughout the storms lifetime. Furthermore, we will combine observations from the multiple instruments (ISS, CIRS, and VIMS) on Cassini to investigate the interaction between the vortices and the 2010 giant storm on Saturn at different levels to help understand global, long-term variations.

312.12 – Oxygen Compounds in Saturn's Stratosphere During the 2010 Northern Storm

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The massive eruption at 40N (planetographic latitude) in December 2010 has produced significant and long-lived changes in temperature and species abundances in Saturn's northern hemisphere (Hesman et al. 2012a, Fletcher et al. 2012). The northern storm region has been observed on many occasions between January 2011 and June of 2012 by Cassini's Composite Infrared Spectrometer (CIRS). In this time period, temperatures in regions referred to as "beacons" (warm regions in the stratosphere at certain longitudes in the storm latitude) became significantly warmer than pre-storm values of 140K. In this period hydrocarbon emission greatly increased however this increased emission could not be attributed due to the temperature changes alone for many of these species (Hesman et al. 2012b, Bjoraker et al 2012). In order to build a comprehensive picture of the changes to the stratosphere due to the 2010 northern storm we are now investigating the oxygen compounds in Saturn's stratosphere to determine if similar changes in these species were measured. The time evolution of stratospheric CO_2 and H_2O abundances in the beacon regions throughout 2011 and 2012 will be presented. References: Bjoraker, G., B.E. Hesman, R.K. Achterberg, P.N. Romani. 2012, "The Evolution of Hydrocarbons in Saturn's Northern Storm Region," AAS DPS Conference, Vol. 44, #403.05. Fletcher, L.N. et al. 2012, "The Origin and Evolution of Saturn's 2011-2012 Stratospheric Vortex," Icarus, 221, 560-586. Hesman, B.E. et al. 2012a, "Elusive Ethylene Detected in Saturn's Northern Storm Region," The Astrophysical Journal, 760, 24-30. Hesman, B.E. et al. 2012b, "Ethylene Emission in the Aftermath of Saturn's 2010 Northern Storm," AAS DPS Conference, Vol. 44, #403.06.

312.13 – Hydrocarbon and oxygen photochemistry on Uranus as revealed from Spitzer/IRS observations

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Due to the very low atmospheric temperatures and hydrocarbon column abundances on Uranus, the planet appears very faint at mid-infrared wavelengths, making determinations of atmospheric composition difficult. The Spitzer Space Telescope Infrared Spectrometer (IRS) is two orders of magnitude more sensitive than previous space-based instruments, favoring the detection of faint molecular emission features from Uranus' atmosphere (e.g., Burgdorf et al. 2006, Icarus 184, 634). Global-average Spitzer/IRS spectra acquired just days after the planet's 2007 northern vernal equinox (Orton et al. 2013, manuscript submitted to Icarus) exhibit molecular emission features from CH_4, C_2H_2, C_2H_6, C_3H_4, C_4H_2, and CO_2 in Uranus' stratosphere. We use these Spitzer/IRS observations to constrain new 1-D photochemical models for Uranus. Although the upper-stratospheric methane abundance is well determined from the observations, there is a range of model parameter space in terms of eddy diffusion coefficients Kzz and tropopause methane relative humidities that can reproduce the observed methane emission. However, all such models possess Kzz values that are considerably smaller than those on the other giant planets; the observations show no convincing evidence for significant changes in low-latitude Kzz values with time since the Voyager era. We highlight the differences in atmospheric chemistry and mixing between Uranus and the other giant planets (including the reasons behind the lower C_2H_6/C_2H_2 ratio on Uranus), discuss the implications of the observed C_4H_2 emission with respect to the vapor pressure of C_4H_2 over diacetylene ice at low temperatures, and summarize the implications with respect to the influx of external oxygen compounds and their corresponding upper-atmospheric haze components. This research was supported by the NASA Planetary Atmospheres program.

312.14 – The origin of CO in the stratosphere of Uranus

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Oxygen-rich deep interiors of the Giant Planets cannot explain the discovery of H_2O and CO_2 in the stratospheres of the Giant Planets by Feuchtgruber et al. (1997) because these species are trapped by condensation around their tropopause levels (except CO_2 in Jupiter and Saturn). Therefore, several sources in the direct or far environment of the Giant Planets have been proposed: icy rings and/or satellites, interplanetary dust particles and large comet impacts. CO does not condense at the tropopauses of Giant Planets, so that oxygen-rich interiors are a valid source. An internal component has indeed been observed in the vertical profile of CO in Jupiter (Bézard et al., 2002) and in Neptune (Lellouch et al., 2005), while an upper limit has been set on its magnitude by for Saturn (Cavalié et al., 2009). In addition to interiors, large comets seem to be the dominant external source, as shown by various studies: Bézard et al. (2002) for Jupiter, Cavalié et al. (2010) for Saturn and Lellouch et al. (2005) for Neptune. The first detection of CO in Uranus was obtained by Encrenaz et al. (2004) from fluorescent emission at 4.7 microns. Assuming a uniform distribution, a mixing ratio of 2x10-8 was derived. Despite this first detection almost a decade ago, the situation has remained unclear ever since. In this paper, we will present the first submillimeter detection of CO in Uranus, carried out with Herschel in 2011-2012. Using a simple diffusion model, we review the various possible sources of CO (internal and external). We show that CO is mostly external. We also derive an upper limit for the internal source. And with the thermochemical model of Venot et al. (2012), adapted to the interior of Uranus, we derive an upper limit on its deep O/H ratio from it. Acknowledgments T. Cavalié acknowledges support from CNES and the European Research Council (Starting Grant 209622: E3ARTHs). References Bézard et al., 2002. Icarus, 159, 95-111. Cavalié et al., 2009. Icarus, 203, 531-540. Cavalié et al., 2010. A&A, 510, A88. Encrenaz et al., 2004. A&A, 413, L5-L9. Feuchtgruber et al., 1997. Nature, 389, 159-162. Lellouch et al., 2005. A&A, 430, L37-L40. Venot et al., 2012. A&A, 546, A43.

312.15 – Photochemistry in Saturn's Ring-Shadowed Atmosphere: Venetian Blinds, Atmospheric Molecules and Observations

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Cassini has been orbiting Saturn for over nine years. During this epoch, the ring shadow has moved from covering a relatively large portion of the northern hemisphere to covering a large swath south of the equator and continues to move southward. At Saturn Orbit Insertion in 2004, the ring plane was inclined by ~24 degrees relative to the Sun-Saturn vector. The projection of the B-ring onto Saturn reached as far as 40N along the central meridian (~52N at the terminator). At its maximum extent, the ring shadow can reach as far as 48N/S (~58N/S at the terminator). The net effect is that the intensity of both ultraviolet and visible sunlight penetrating into any particular latitude will vary depending on both Saturn's axis relative to the Sun and the optical thickness of each ring system. In essence, the rings act like venetian blinds. Our previous work [1] examined the variation of the solar flux as a function of solar inclination, i.e. ~8 year season at Saturn. Here, we report on the impact of the oscillating ring shadow on the photolysis and production rates of hydrocarbons in Saturn's stratosphere and upper troposphere, including acetylene, ethane, propane, and benzene. Beginning with methane, we investigate the impact on production and loss rates of the long-lived photochemical products leading to haze formation are examined at several latitudes over a Saturn year. Similarly, we assess its impact on phosphine abundance, a disequilibrium species whose presence in the upper troposphere is a tracer of convection processes in the deep atmosphere. Comparison to the corresponding rates for the clear atmosphere and for the case of Jupiter, where the variation of solar insolation due to tilt is known to be insignificant (~3 degree inclination), will be presented. We will present our ongoing analysis of Cassini's CIRS, UVIS, and VIMS datasets that provide an estimate of the evolving haze content of the northern hemisphere and we will begin to assess the implications for dynamical mixing. [1] Edgington, S.G., et al., 2012. Photochemistry in Saturn's Ring Shadowed Atmosphere: Modeling, Observations, and Preliminary Analysis. Bull. American. Astron. Soc., 38, 499 (#11.23).

312.16 – Atmospheric Variation on Saturn: From Voyager to Cassini

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Contributing teams: Cassini CIRS,ISS, and VIMS teams

Here we report the combined spacecraft observations of Saturn acquired over one Saturnian year (~ 29.5 Earth years), from the Voyager encounters (1980-81) to the new Cassini reconnaissance (2009-10). The combined observations reveal a strong temporal increase of tropic temperature (~ 10 K) around the tropopause of Saturn (i.e., 50 mbar), which is one order-of-magnitude stronger than the seasonal variability (~ 1-2 K). We also provide the first estimate of the zonal winds at 750 mbar, which is close to the zonal winds at 2000 mbar. The quasi-consistency of zonal winds between these two levels provides observational support to a numerical suggestion inferring that the zonal winds at pressures greater than 500 mbar do not vary significantly with depth. Furthermore, the temporal variation of zonal winds decreases its magnitude with depth, implying that the relatively deep zonal winds are stable with time.

312.17 – The Long and Short of It: Saturn's Atmospheric Variability

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Saturn's atmospheric responses to seasonal and non-seasonal energy inputs, ranging from change in solar insolation to localized disturbances, have led to discoveries of a warm south polar region/hot south polar vortex (SPV) (Orton and Yanamandra-Fisher, 2005, Science, 307) and low-latitude oscillations (Orton et al., Nature, 453). We now report on our current study of the evolution of a Saturnian season by the characterization of global large-scale variability of temperatures, clouds and local short-scale variability of discrete, episodic events, such as storms and vortices in Saturn's atmosphere. We will present results on the emerging taxonomy of 5.1-micron hot spots, their variability and correlation with the visible cloud field; and the atmospheric response to rapid episodic changes, followed by the gradual relaxation of the perturbed atmosphere to its equilibrium state in terms of physical parameters. Our study utilizes ground-based mid- and near-infrared observations spanning at least half a Saturnian year (approximately 15 years), acquired at the NASA/InfraRed Telescope Facility (IRTF) and Cassini/near-infrared (VIMS) data in the overlapping time period of 2005 – 2011.

312.18 – Uranus in 2012 from HST STIS: Methane depletion in north polar region indicates nonseasonal origin.

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On 28 September 2012, Hubble's Space Telescope Imaging Spectrograph (STIS) observed Uranus (GO 12894, L. Sromovsky PI). The result is a hyperspectral data cube of one half of the planet with spectral coverage of 300-1000 nm. The observations were designed to characterize latitudinally (from about 50 deg S to the north pole) the vertical structure of aerosols and global distribution of methane after the planet's 2007 equinox. These observations form a unique counterpart to similar observations made in 2002 (GO 9035, E. Karkoschka PI) when Uranus' south pole was in view. In 2002, Uranus was found to have a depletion of methane in southern mid-to-high latitudes (Karkoschka and Tomasko 2009, Icarus 202, 287-309; Sromovsky et al. 2011, Icarus 215, 292-312). Characterizing this distribution is possible by the simultaneous sounding of both hydrogen and methane spectral absorption regions (hydrogen CIA peaks near 825 nm). As Uranus' northern hemisphere came into view, it became apparent from near-IR observations of the troposphere (sensing to about 10 bars), that the north and south hemispheres were asymmetric in brightness, and that unexpectedly rapid seasonal changes were taking place (Sromovsky et al. 2009, Icarus 203, 265-286). The north polar region also has what appear to be many small convective features poleward of 60 deg N, in stark contrast to the south polar region (Sromovsky et al. 2012, Icarus 220, 694-712). Sromovsky et al. 2012 speculated this difference could be due to a seasonally-forced methane abundance asymmetry. However, 2007 NICMOS F108N and Keck NIRC2 PaBeta (1271 nm) equinox imagery suggest that the north polar region is also depleted in methane, as do 2009 IRTF SpeX observations (Tice et al. 2013, Icarus 223, 684-698). We can now confirm this northern hemispheric methane depletion appears symmetric rather than a seasonal phenomenon, thanks to the new STIS observations with an excellent view of Uranus northern latitudes. We will also present preliminary results of radiative transfer modeling of the current vertical structure of aerosols, and compare the current state to that of 2002. This work was supported by STScI and the NASA Planetary Astronomy program.

312.19 – Clouds, Hazes, and Rings: Keck Observations of Uranus

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We present models of the Uranian atmosphere and rings based on near-infrared (H- and K-band) observations of Uranus taken with the OSIRIS integral field spectrograph at the W.M. Keck Observatory in 2010 and 2011. In July 2010 we observed the Uranian atmosphere with spatial and spectral resolution at latitudes ranging from the north polar region to mid southern latitudes. We

demonstrate radiative transfer models used to characterize the properties and vertical & latitudinal distribution of clouds and hazes. We also present spectra of a discrete cloud feature observed in July 2011, alongside radiative transfer models used to constrain the cloud altitude and properties. Finally, we present near-infrared spectra of the Uranian ring system, which we find to be gray. We determined ring particle reflectivities for each ring group based on this data, and find reflectivities consistent with previous results with the exception of the 456 ring group, which we find to be slightly fainter.

312.20 – Multi-wavelength Observations of Neptune's Atmosphere

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We conducted a multi-wavelength observing campaign on Neptune between June and October, 2003. We used the 10-m Keck telescope at near- and mid-infrared wavelengths and the VLA at radio wavelengths. Near infrared images were taken in October 2003 in broad- and narrow-band filters between 1 and 2.5 micron, using the infrared camera NIRC2 coupled to the Keck Adaptive Optics system. At these wavelengths we detect sunlight reflected off clouds in the upper troposphere and lower stratosphere. As shown by various authors before, bright bands of discrete cloud features are visible between 20°S and 50°S and near 30°N, as well as several distinct bright cloud features near 70°S, and the south polar "dot". Mid-infrared images were taken on September 5 and 6 (2003) using the Keck LWS system in atmospheric windows at 8, 8.9, 10.7, 11.7, 12.5, 17.65, 18.75 and 22 micron. At these wavelengths we detect thermal emission from Neptune's stratosphere due to the presence of hydrocarbons, and from near the tropopause due to collision induced opacity by hydrogen. At all wavelengths the South polar region stands out as a bright spot. At 17 - 22 micron also the equatorial region is slightly enhanced in intensity. These characteristics are consistent with later imaging at similar wavelengths (Hammel et al. 2007; Orton et al. 2007). Microwave images were constructed from NRAO VLA data between 0.7 and 6.0 cm. At these wavelengths depths of several up to >50 bar are probed. An increase in brightness indicates decreased opacity of absorbers (e.g., NH3, H2S), since under such circumstances deep, and hence warm levels (adiabatic temperature-pressure profile), will be probed. The multi-wavelength observing campaign in 2003 was focused on obtaining images that probe different altitudes in Neptune's atmosphere. Indeed, this set of data probes altitudes from about 0.1 mbar down to ~50 bar, and hence can be used to constrain the global atmospheric circulation in Neptune's atmosphere. At the meeting we will show our results and interpretation of the findings.

312.21 – Chemical Abundances in Neptune's Troposphere as Determined from Microwave Observations

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The microwave spectrum of Neptune is shaped primarily by the planet's tropospheric temperature profile, and by absorption and emission from chemical species, particularly H_2S and NH_3. Better constraints on these properties benefit studies of the composition of Neptune's atmosphere, and by extension provide insight into the similarities and differences with fellow ice giant Uranus, and to the formation and evolution of Neptune itself. To this end, we have developed a radiative transfer code that simulates the Neptunian atmosphere to generate synthetic microwave spectra. We compared the spectra produced by these models to a compilation of 32 previous full-disk observations of Neptune between 0.7 and 20 cm. This dataset spans from 1967 to 2006, and includes four observations not yet published. Our models address absorption and emission from NH_3, H_2S, H_2O (both vapor and condensed), PH_3, and H_2 (collision-induced). We treated the abundance profile of each condensible species as dependent primarily upon two variables: the relative humidity above the condensation level, and the mixing ratio beneath. H_2S and NH_3 were influenced by the presence of a NH_4SH cloud which exhausted the supply of the less abundant molecule of the two. After sensitivity testing, we limited our investigation to seven variables: the relative humidity of H_2S or NH_3, and the deep mixing ratios of He, CH_4, NH_3, H_2S, H_2O, and PH_3. Our tests found that while the best model spectra involved more H_2S than NH_3, there were NH_3-dominant cases that produced spectra that fit observations almost as well. Because of this, we report constraints on H_2S and NH_3 abundances in both scenarios. While the model by itself was unable to constrain the profiles of He, CH_4, H_2O, and PH_3 beyond physically reasonable values, the abundances of these molecules do exert influence over the resultant spectra. By applying sensible ranges to these abundances, we were able to further limit the mixing ratios of H_2S and NH_3.

312.22 – Atmospheric confinement of jet streams on Uranus and Neptune

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The observed cloud-level atmospheric circulation on the outer planets of the solar-system is dominated by strong east-west jet streams. The depth extent of these winds is a crucial unknown in constraining their overall dynamics, energetics, and internal structures. There are two approaches to explain the existence of these strong winds. The first suggests that the jets are driven by shallow atmospheric processes near the surface, while the second suggests that the atmospheric dynamics extend deep into the planetary interiors. Here we show, that on Uranus and Neptune, the depth of the atmospheric dynamics can be revealed by the low-order gravity field. We show that the measured fourth gravity harmonic from Voyager and HST observations, J4, constrains the dynamics to the outermost 0.15% of the mass on Uranus and 0.2% on Neptune. These constraints are obtained by placing an upper limit to the difference between the observed J4 and the J4 contribution of a static planet over a wide range of interior structures, and comparing this difference to the dynamical contribution to J4 obtained from models with dynamics. We thus provide a much stronger limitation to the depth of the dynamical atmosphere than previously suggested, and show therefore that the dynamics are confined to a thin weather layer of no more than 1000 km on both planets. For Jupiter and Saturn, more accurate gravity data is required to calculate precise limits. This is likely to be obtained in 2016 when the Juno and Cassini spacecraft perform close flybys of these planets, measuring for the first time the high order gravity spectrum of these planets. While the low order gravity harmonics of Jupiter and Saturn are dominated by the oblateness and radial mass distribution of the planets, the high (n>10) and odd gravity harmonics contain information about the dynamics, via the dynamical balance between the density anomalies and the flow field, and north-south hemispherical asymmetries in the circulation. We will discuss how these constraints on the interior flow affect the possible driving mechanisms of the atmospheric jets for all four giant planets.

312.23 – Inhibition of Diffusive Convection in the Water Condensation Zone of the Ice Giants

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We explore the conditions under which ordinary and double-diffusive thermal convection may be inhibited by water condensation in the hydrogen atmospheres of the ice giants and examine the consequences. The saturation of vapor in the condensation layer induces a vertical gradient in the mean molecular weight that stabilizes the layer against thermal instability when the abundance of vapor exceeds a critical value. In this instance, the layer temperature gradient can become superadiabatic and heat must be transported vertically by another mechanism. On Uranus and Neptune, water and methane are both inferred to be sufficiently abundant for inhibition of ordinary convection to take place in their respective condensation zones. Here we explore the inhibition of diffusive convection by water condensation. We find that the suppression of diffusive convection is sensitive to the microphysics of the condensate. In the limit where the vertical velocity associated with buoyancy oscillations is small in comparison to the sedimentation velocity of the condensed particles, the layer will be stable to diffusive convection. In the opposite extreme, in which the sedimentation velocity of the particles is small in comparison to the characteristic velocity of the buoyancy oscillations, diffusive convection can occur, but it takes the form of weak, homogeneous, oscillatory convection, which is a relatively inefficient mechanism for transporting heat, characterized by Nusselt numbers only slightly above unity. Layered convection, which is characterized by much larger Nusselt numbers, is not favored to occur in this limit. Consequently, because ordinary and diffusive convection are both suppressed, we expect that the heat flux transported through the water condensation zone of an ice giant will be only slightly greater than that which can be carried by radiative transport, implying that a significant superadiabatic temperature gradient will develop in this zone. This result may have important consequences for thermal evolution models of the ice giants and for understanding Uranus' anomalously low intrinsic luminosity. This research is supported by the NASA Outer Planet Research Program.

312.24 – Dynamic coupling of magnetic fields, thermal emissions, and zonal flows in ice giant planets

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Magnetic fields are ubiquitous in the solar system, yet their characteristics are as diverse as the planets themselves. These fields are thought to result from dynamo action driven by thermochemical convection in electrically conducting fluid regions. The multipolar dynamos of Uranus and Neptune provide a unique opportunity to test hypotheses for magnetic field generation. Since no sharp structural boundaries in the ice giants between the ionic ocean and overlying molecular envelope are expected, it is possible that these regions are linked dynamically. Thus, an understanding of the coupling between magnetic fields, heat flow, and atmospheric winds is crucial to determine what controls the strength, morphology, and evolution of giant planet dynamos. Here we present numerical simulations of turbulent convection in spherical shells to test the hypothesis that poorly organized turbulence will generate ice giant-like magnetic fields, thermal emissions, and zonal flows. We find that this style of convection leads to small-scale, fluctuating dynamo action that generates a multipolar magnetic field, Hadley-like circulation cells that promote equatorial upwellings to create low latitude peaks in internal heat flux, and homogenized absolute angular momentum that drives three-jet zonal flows. This qualitative agreement with observations suggests that the internal dynamics of ice giant planets may be characterized by three-dimensional convective turbulence with dynamic coupling between the dynamo region and electrically insulating envelope above playing an important role as well.

312.25 – Observation of ion temperature anisotropy on the Io plasma torus using a high-dispersion spectrograph with an integral field unit

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Atoms and molecules originated from volcanic eruption on Jovian satellite Io are ionized and form a donut-shaped region along Io's orbit which is called Io plasma torus. Although ion pickup in the plasma torus is expected to maintain high temperature anisotropy, the value of anisotropy, its longitudinal distribution and variability have not been clear yet. A new high-dispersion spectrograph with an integral field unit (IFU) enables to measure line width of ion emission and its latitudinal scale height distribution simultaneously which derive ion temperatures parallel and perpendicular to the magnetic field. The observation of sulfur ion emission, [SII] 671.6nm and 673.1nm, was made at Haleakala Observatory in Hawaii from March 1st through 20th, 2013 using the high-dispersion spectrograph (R = 67,000) with the IFU coupled to a 40-cm telescope. The IFU consist of 96 optical fibers. The fibers are arranged in 12 by 8 array at a telescope focus corresponding to 41'' by 61'' with a spatial resolution of 5.1'' on the sky. Based on a preliminary result from the observation that produced 40 spectral datasets, there is a System III variation on the parallel ion temperature which is derived from north-south distribution of torus emission. There is also a System III variation on the torus brightness at the equator showing an anti-correlation with the parallel ion temperature. System III variation of total flux-tube contents (FTCs) was relatively small compared to the variation of ion parallel temperature and torus brightness at the equator. As for an ion thermal anisotropy, it varied from 1 through 5 at a radial distance of 5.9 Jovian radii depending on System III longitude. Average values of anisotropy were 2.4 on dusk ansa and 2.0 on dawn ansa. However, as for the absolute value of parallel ion temperature and thermal anisotropy, we need to consider about line-of-sight (LOS) integration effect at the torus edge which causes an overestimate of ion parallel temperature. More accurate analysis including correction of LOS effect using a torus emission model will be presented at the meeting.

313 – Mars Posters

313.01 – The Observed Gravity Field of Phobos and an Extrapolation of its Interior

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The mass of the Mars moon Phobos has been determined by spacecraft close flybys, by solving for the Martian gravity field and by the analysis of secular orbit perturbations. The absolute value and accuracy is sensitive on the actuality of the Phobos ephemeris, the accuracy of the spacecraft orbit, other perturbing forces acting on the spacecraft and the resolution of the Martian gravity field besides the measurement accuracy of the radio tracking data. The mass value and its error improved from spacecraft mission to mission or from the modern analysis of "old" tracking data. The global geophysical parameters total mass GM = (0.7071 ± 0.0063) x10^{-3} km^3 s^2 , C_{20} , and the bulk density (1876 ± 20) kgm^3 of the Mars moon Phobos derived from the close Mars Express flyby in 2010 are consistent with a loosely consolidated body of a grossly inhomogeneous mass distribution. The modelling of the moon's interior by a randomly selected mass distribution of given porosity and water ice content let the simulated C_{20} decrease with increasing porosity and water ice content indicating an increasingly inhomogeneous mass distribution. This gives further evidence that Phobos re-accreted in orbit from a debris disk and is not a captured asteroid. The current knowledge of Phobos gravity field obtained from different spacecraft observations will be reviewed and the results from the very close flyby performed by Mars Express in 2010 will be presented.

313.02 – Mars Atmospheric Argon Isotopes Measured by the SAM Instrument Suite on MSL

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Contributing teams: The MSL team

The Sample Analysis at Mars (SAM) Suite (Mahaffy et al. 2012, SSR 170) is one of the science packages on the Mars Science Laboratory (MSL) "Curiosity" rover. The SAM is comprised of a Quadrupole Mass Spectrometer (QMS), a Tunable Laser Spectrometer (TLS) and a Gas Chromatograph (GC). Together these instruments, along with the solid sample manipulation and gas processing system, are able to measure directly the composition of the Mars atmosphere as well as gases thermally evolved from the rock samples delivered to SAM. During the first 200 sols of the mission, the QMS carried out three nighttime in situ atmospheric measurements, providing an initial determination of the chemical and isotopic composition of the Mars atmosphere. These direct atmospheric experiments determine the atmospheric 40Ar/36Ar ratio to be 1900 ± 300 (Mahaffy et al. 2013, Science, in press). A subsequent experiment on sol 232 examined an enriched sample of Mars atmosphere, with CO2 and H2O removed, increasing the signal-to-background ratio at m/z 36 by a factor of ~5. The SAM enrichment experiment confirms that MSL measures a Mars atmospheric ratio that is much lower than the 3000 ± 500 determined by the Viking landers (Owen et al. 1977, JGR 82). This finding agrees with the analyses of martian meteorites (made between the times of the Viking and MSL landings) suggesting that the Viking 40Ar/36Ar ratio was overestimated (e.g., Bogard and Garrison 1999, Met. & Pl. Sci. 34). The MSL 40Ar/36Ar measurement (as well as other isotopic ratios) constrains atmospheric escape and evolution, crustal degassing, and interpretation of martian meteorite composition. Recent experiments with the SAM QMS in the sol 200–360 range include daytime atmospheric measurements and a gas enrichment experiment in which the abundance and isotopic composition of Kr, Xe and 38Ar/36Ar was measured. Results of these experiments will be presented.

313.03 – Early Evolved Gas Results from the Curiosity Rover's SAM Investigation at Gale Crater

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The Mars Science Laboratory Mission is designed to explore the habitability of the selected landing site at Gale crater. The Sample Analysis at Mars (SAM) instrument suite contributes to this study with a search for organic compounds, an analysis of the composition of inorganic volatiles, and measurements of the isotopic composition light elements. Both atmospheric and solid samples are analyzed. The layers in the central mound (Mt. Sharp) of Gale crater are important targets for the MSL mission. However, in situ measurements made during the past year of interesting regions close to the Bradbury landing site have revealed a diverse geology and several primary mission objectives have already been realized. SAM is located in the interior of the Curiosity rover. The MSL cameras, a laser induced breakdown spectrometer, and elemental analysis instrumentation serves to locate sampling sites and interogate candidate materials before solid sample is collected either with a drill or a scoop for delivery to SAM and the XRD instrument CheMin. SAM integrates a quadrupole mass spectrometer (QMS), a tunable laser spectrometer (TLS), and a 6-column gas chromatograph (GC) with a solid sample transport system and a gas processing and enrichment system. Results of SAM atmospheric composition analyses have already been reported (1,2). To date, multiple SAM evolved gas experiments have examined samples from fines scooped from an aeolian drift and from two drilled samples of a mudstone. Major evolved gases are H2O, CO2, O2, SO2, H2S, H2, and a number of minor species. These data help confirm the likely presence of perchlorates, the presence of phylosillicates, and both reduced and oxidized compounds evolved from the same sample. 1) P.R. Mahaffy et al., Abundance and Isotopic Composition of Gases in the Martian Atmosphere from the Curiosity Rover, Science 343, (2013). 2) C.R. Webster et al., Isotope Ratios of H, C and O in Martian Atmospheric Carbon Dioxide and Water Measured by the Curiosity Rover, Science 343, (2013).

313.04 – Maps of [HDO]/[H2O] near Mars' Aphelion

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We report maps of HDO and H2O taken at three seasonal points before and near Mars' aphelion (Ls = 71°). These observations were taken at Ls = 357° (15 January 2006), Ls = 50° (26 March 2008) and Ls = 72° (2/3 April 2010) using CSHELL at the NASA Infrared Telescope Facility. For these three seasonal dates, the entrance slit of the spectrometer was positioned N-S on Mars centered at the sub-Earth point; on 3 April 2010, the slit was positioned E-W. Data were extracted at 0.6 arc-second intervals from the spectral-spatial images. Individual spectral lines were measured near 3.67 μm (HDO) and 3.29 μm (H2O). The column densities were obtained by comparing the observed lines to those of a multi-layered, radiative transfer model. The model includes solar Fraunhofer lines, two-way transmission through Mars' atmosphere, thermal emission from Mars' surface and atmosphere, and a one-way transmission through the Earth's atmosphere. Latitudinal maps of HDO, H2O, and their ratios were then constructed. The [HDO]/[H2O] ratios have been found to be larger than those on Earth and they vary with both latitude and season. For the Ls = 357° and 50° observations, the ratio peaks near the sub-solar latitude ([HDO]/[H2O] ~ 6.9 VSMOW) and decreases towards both the North and South polar-regions. At Ls = 72°, column densities of both HDO and H2O and their ratios increase from the Southern hemisphere to the North polar-region. Observations from 3 April 2013 show diurnal variations of both the column densities and their ratio. Specific points on Mars' surface were tracked for four hours. It is believed that this variation is caused by the vaporization of ground frost and water ice clouds that are formed during the night and disappear during daytime. Our results for H2O column densities will be compared to TES results. The results for HDO and the [HDO]/[H2O] ratios will be compared to model results.This work was partially funded by grants from NASA's Planetary Astronomy (344-32-51-96) and Astrobiology Programs (344-53-51), and the NSF-RUI Program (AST-805540). We thank the administration and staff of the NASA IRTF for awarding observing times and coordinating our observations.

313.05 – Surface Reflectance Modeling for Martian Cloud Optical Depth Retrievals from CRISM Multispectral Image Cubes

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In order to retrieve the ice optical depth of martian clouds using a radiative transfer model, one needs to have an independent spectral model of the surface reflectance. Presented here is a comparison of three methods used to model the surface reflectance and the effects on the retrieved ice and dust optical depth. In order to reduce the complexity of the radiative transfer modeling, a fixed set of aerosol optical constants and single aerosol size parameters were used. The retrieval uses DISORT subroutines in an atmosphere modeling program tuned for martian atmospheres to create model reflectance spectra which are then compared to CRISM data. The parameters of total optical depth of ice and dust and surface reflectance are methodically adjusted until the chi-squared between model and data is minimized. This is done over all spatial points to create maps of dust and ice optical depth which are compared to MGS-TES and MO-THEMIS results to assess the effectiveness of the particular surface model. Three types of surface models were tested: a spectrally gray surface, a two-element linear combination of spectral endmembers chosen from the data cube itself, and a two-element linear combination of endmembers recovered from the data cube using principle components analysis and target transformation.

313.06 – Timescales are short for the formation of water ice clouds on Mars

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A common problem encountered when simulating the Martian water cycle with general circulation models (GCM) is the formation of optically thick clouds over the North Polar Residual Cap (NPRC) during summer that are not observed. This is particularly difficult to resolve because of the highly coupled nature of cloud formation to radiative transfer, dust, atmospheric dynamics, etc. Recent developments in the NASA Ames Mars GCM show that cloud formation can be inhibited by using short timescales for the microphysics calculations. This reduces cloud opacities by more than an order of magnitude. The same strategy has been used in other GCMs to achieve similar results. We will present these results and discuss possible causes and implications for future research.

313.07 – Martian dust aerosols and clouds in the North Polar summer: size and sedimentation

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Martian dust aerosols control an important part of the energy transport in the Martian atmosphere. Ice aerosols, especially in the North Polar summer, play an important role in energy transport, scavenge the atmosphere of dust, and play a role in the vertical and horizontal transport of water away from the sublimating polar cap. Their physical properties, such as size and shape, have not been directly measured, and are only measureable through remote sensing. We report two novel measurements of dust and ice aerosol physical properties with data from the Phoenix Lander's Surface Stereo Imager. First, the scoop on the Phoenix Robotic Arm was used as an occultation instrument, blocking the Sun and allowing images of the near-Sun sky without contamination from the much-brighter direct sunlight. This allows the use of diffraction scattering to measure the dust size distribution. The general technique has been used frequently, but the shading of the Sun allows much more precise and accurate probing, especially of the larger end of the size distribution. Second, direct solar images on many occasions show scattered sky light significantly above the instrument background during cloudy times. These measurements, corrected for the dust background, show light diffracted by cloud particles. Statistics of the magnitude and width of the diffraction peak demonstrate the common presence of 30-micron scale ice crystals above the Phoenix site, consistent with estimates made from the observation of fall streaks by the Lidar.

313.08 – Martian dust aerosols in the North Polar summer: scattering properties and shape

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Martian atmospheric dust appears to be largely homogenized. However, there are a continuum of sources that are accessed by seasonally distinct processes: Southern summer dust storms, polar cap edge storms, and dust devils. The Phoenix landing site was

in a region that fell within the northern seasonal ice cap; its mission began while the receding cap edge was north of the site. The Phoenix Lander's Surface Stereo Imager performed several cross-sky brightness surveys to characterize atmospheric dust in the Martian north polar environment. These surveys, comparable to those by the Viking and Pathfinder landers and the Mars Exploration Rovers, constrain the size distribution and scattering and absorption properties of the airborne dust. We analyze a set taken in early summer in order to compare the results to those of previous missions and constrain the size of dust in a near-cap-edge environment. The spectrophotometric data from 440-1000 nm were taken shortly after a period of local dust storms and during a period of active dust-devil lifting, and thus approximate a measurement of the lifted dust. We will present a discussion of constraints on the size distribution, spectral single scattering albedo and imaginary index of refraction of the dust. We also present the first polarimetric observations from inside the Martian atmosphere. These observations show the dust is weakly polarizing in a way that is, as expected, inconsistent with Mie scattering.

313.09 – Mesoscale Modeling of Water and Clouds in the Northern Martian Summertime

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Early northern summer on Mars (Ls~120) is a critical season for the water cycle. Observations reveal this season to be the time of the annual maximum for water vapor and a minimum for clouds in the northern polar region. GCMs tend to simulate very thick polar clouds in this season. This problem becomes worse when the water ice clouds are radiatively active. The polar region is highly complex; it is not sufficiently resolved in any standard GCM. A carefully designed mesoscale investigation has been carried out to explore the importance of resolving the various complex processes in this region during early summer. The Oregon State University Mars Mesoscale Model has been used extensively in studies of atmospheric circulations in the northern polar region of Mars (from late spring to late summer). In this study the focus is on Ls~120, with two levels of two-way nesting to a resolution of ~15 km. A great deal of effort was put into developing high-resolution albedo and thermal inertia maps. Model temperatures agree very well with observations, as does the simulated vapor distribution. The cloud scheme being used in our model does not include a nucleation phase, and predicts only the mean cloud particle size. The number density of dust particles is prescribed and consistent with that used in the radiation scheme. This approach allows an assessment of the fraction of dust particles that actually nucleate (serve as ice nuclei). This modeling provides a high-resolution depiction of the vigorous polar circulation, and its role in the sublimation and transport of water. Resolution is found to be extremely important in relation to polar cloudiness. Even though ice sublimation is ~26% more, the mass of cloud ice is smaller by ~10x when both nests are active. The circulation is crucial to this result. As suggested by laboratory work and 1-D modeling, nucleation fractions are very small. Good agreement with the Phoenix LIDAR observations and further reduction of column ice amounts requires a severe limitation on the fraction of dust particles allowed to act as ice nuclei, ~3-5%. Model results exhibit the seasonally appearing annular cloud, and the dynamics of this are investigated.

313.10 – The Effect of Limb Staring on Mars Climate Sounder Observations of Convective Instabilities

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Mars Climate Sounder (MCS), an instrument aboard Mars Reconnaissance Orbiter (MRO), is a nine-channel infrared radiometer/spectrometer that records limb, nadir, and off-nadir radiance measurements of the Mars atmosphere. Vertical temperature-pressure profiles are then retrieved through modeling and fitting of these radiance measurements. Retrieved MCS temperature profiles in the first half of 2007, northern fall of Mars Year (MY) 28, indicated an increased number of convective instabilities at high altitudes/low pressures in the northern latitudes, and lower temperatures at high altitude/low pressure (~0.1 Pa) northern tropical latitudes when compared to other MYs observed by MCS. A causal link was suggested with global dust storm development because of the MY 28 global dust storm that was on going by June 25, 2007 (Ls 264.0) [Heavens' et al. 2010]. MCS was also operated abnormally in limb staring mode for the time between February 9 and June 14, 2007 (Ls 180.7-257.1). During this time MCS was unable to view space. The orientation of the instrument relative to the limb also drifted vertically during the orbit. This abnormal operation introduced offset error into the radiance measurements, and has not been fully accounted for by previous studies of the MY28 convective instabilities. We have searched and identified potential instrumental biases when observing convective instabilities during this limb staring mode. We have attempted to explain how the instrumental bias could have developed within the retrieved temperature profiles and the potential impact on the observations of convective instabilities. In addition an updated temperature retrieval suite (version 4) has been implemented, and we report on how this new suite has affected the observations of convective instabilities and 0.1 Pa tropical temperatures. The analysis conducted likely provides valuable information to other research utilizing the MCS data at high altitudes low pressures during this limb staring mode.

313.11 – Coupling Mars' Dust and Water Cycles: Investigating the effects of water ice cloud formation on dust lifting and the vertical distribution of atmospheric dust.

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The dust cycle is an integral component of Mars' current climate system because airborne dust has a significant influence on the thermal and dynamical structure of the atmosphere. Dust is present in the atmosphere of Mars year-round, but the dust loading varies with season and exhibits variability on a range of spatial and temporal scales. Until recently, interactive dust cycle studies that include the lifting, transport, and sedimentation of radiatively active dust have not included the formation of water ice clouds or their radiative effects. While the predicted behaviors of dust lifting and global dust loading from these simulations of the dust cycle in isolation reproduce some characteristics of the observed dust cycle, there are also marked differences in the predicted and observed dust cycles. Water ice clouds can influence the dust cycle by scavenging dust from the atmosphere and by interacting with solar and infrared radiation, thereby modifying the thermal structure of the atmosphere and its circulation. Our goal is to investigate how cloud formation influences and/or controls specific aspects of the dust cycle. We show that including water ice clouds and their radiative effects greatly affects the magnitude, spatial extent and seasonality of dust lifting. Additionally, we explore the effects of water ice cloud formation on the vertical distribution of dust in the Martian atmosphere.

313.12 – Wave phenomena comparison between Mars and Titan upper atmospheres

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We will examine the presence of waves in the neutral atmospheres of two terrestrial bodies: Mars and Titan. We will examine the aerobraking datasets from both the Mars Global Surveyor (MGS) and Mars Odyssey (ODY) missions, analyzing the neutral densities to characterize the planetary tides and/or smaller-scale internal gravity waves present in the data. While several studies have examined these features before at Mars (e.g., Forbes et al. [2002] and Fritts and Tolson [2006]), we will be focusing on examining whether or not the wave features observed in the thermosphere could be explained primarily with planetary tides, as posted recently in Klienbohl et al. [2013]. In addition to this, we will also examine the neutral densities obtained by the Cassini Ion-Neutral Mass Spectrometer (INMS) in order to determine if planetary tides can explain the numerous wave-like features that have been interpreted as gravity waves propagating vertically (cf., Mueller-Wodarg et al. [2008], Cui et al. [2013], and Snowden et al. [2013]).

313.13 – Semi-Stationary Waves Masquerading as Stationary Waves in the Martian Atmosphere

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Contributing teams: MCS Team

Stationary waves are a fundamental feature of the martian atmosphere. These waves have zero zonal frequency and are forced by flow over topography and/or zonal inhomogeneities in the thermal forcing of the atmosphere (e.g., solar input). They play a crucial role in the redistribution of heat from the equator to the high latitudes, significantly impact the atmosphere's stability (i.e., its resistance to vertical motion), and accelerate/decelerate the mean flow of the middle-to-upper atmosphere (~30-130 km altitude). While the seasonal behavior of stationary waves at Mars has been well-studied, the short-timescale (less than a day) behavior of these waves has not. Using orbital observations of temperature from the Mars Climate Sounder radiometer onboard the Mars Reconnaissance Orbiter, we show that what have previously been called stationary waves, though persistent on seasonal timescales, are not persistent on sub-diurnal timescales. These waves behave in a semi-stationary manner, exhibiting large amplitudes on the nightside and nearly disappearing on the dayside. Analyses of the temperature and wind fields simulated (by the Mars Climate Database) at unobserved local times reveal that these temperature waves reach their peak amplitudes near local midnight and are well-correlated with the negative phase of similar waves in the meridional wind field. We close with a discussion of the implications of semi-stationary waves for atmospheric transport.

313.14 – Seasonal Variations in the CO Line Profile and the Retrieved Thermal/Pressure Structures in the Atmosphere of Mars

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We report retrievals of temperature vertical profiles up to 100 km over Tharsis and Syrtis regions on Mars obtained by inverting the strong rotational (3-2) line of carbon monoxide (CO) at 346 GHz. Observations of CO were made from mid Northern Spring to early Northern Summer on Mars (Ls= 36°-108°, 23 Nov, 2011 – 13 May, 2012) using the Caltech Submillimeter Observatory's (CSO) high-resolution heterodyne receiver (Barney) on top of Mauna Kea, Hawai'i. The temperature profiles were derived using our radiative transfer model that considers the latest spectroscopic constants for CO collisionally broadened by CO_2. We observe notable changes of the line profile for different dates, which are directly related to seasonal variations in the thermal/pressure structure of the atmosphere. The seasonal variability of the martian CO line profile, the extracted temperature profiles, and comparisons with modeled profiles from the Mars Climate Database (Lewis et al, 1999) will be presented. We gratefully acknowledge support from the NASA Planetary Astronomy Program , NASA Astrobiology Institute, Planetary Atmospheres programs. This material is based upon work at the Caltech Submillimeter Observatory, which is operated by the California Institute of Technology under cooperative agreement with the National Science Foundation, grant number AST-0838261.

313.15 – Analyzing HST observations of the Martian Corona with different modeling techniques

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We present an analysis of HST ACS/SBC UV images of the extended H Ly alpha emission from the Martian corona obtained over Oct/Nov 2007, using different models for the Martian exosphere. In this study we have used the number density curve generated by a 3D Monte Carlo model, presented previously, along with a simple radiative transfer code developed by our group, to simulate intensity profiles, which have then been compared to the HST data. The radiative transfer code accounts for multiple scattering in the optically thick Martian atmosphere. By varying the total number of H atoms and the mean temperature of their Maxwellian velocity distribution, we obtain the best fit to the HST data. Our work will also highlight the difference between intensity curves generated by the 3D Monte Carlo model and a standard Chamberlain model for the Martian exosphere. Through this analysis we have attempted to provide constraints on the escape flux of hydrogen atoms from the Martian atmosphere, which has relevance to the loss of water from Mars.

313.16 – Auroral current systems near Mars

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Aurora have been reported in the small scale Martian crustal magnetic fields based on a variety of observations made over the last ~10 years. Examples of enhanced ultraviolet emission near crustal fields strongly suggest that charged particles bombard the neutral atmosphere in cusps, exciting it. Charged particle measurements confirm that energized electrons travel toward the atmosphere in cusp regions, and planetary ions are accelerated upward in cusps - similar to terrestrial aurora. A number of processes have been proposed to explain Martian aurora, and a leading mechanism suggests that, similar to Earth, current systems form along cusp magnetic field lines that accelerate electrons downward (creating aurora) and ions upward. But significant questions remain about the viability of this mechanism, including how frequently and to what degree currents can be established that allow the transport of particles between the Martian upper atmosphere and its surrounding environment. Here we preset an analysis of magnetic field data recorded by the Mars Global Surveyor spacecraft over a 9-year period. These data show small-scale perturbations in magnetic field, predominantly in cusp regions. The field perturbations are predominantly identified in locally horizontal magnetic field components, consistent with the presence of near-vertical (and thus aligned with the magnetic field) current systems. We present a combination of case studies and statistical studies that reveal the distribution and intensity of field-aligned currents near Martian crustal fields, as well as some of the external factors that control the observations.

313.17 – Unexpected Time-Variability of Martian Hydrogen Loss

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Mars today is much drier than the Earth, though they likely began with similar relative amounts of water. One potential cause for this discrepancy is hydrogen loss from surface water to space, which may have removed one-third of Mars' initial water. For forty years, this water loss has been assumed to be indirect and constant: the result of molecular hydrogen produced at the surface being transported into the ionosphere, where it is partially converted into atomic hydrogen that subsequently escapes. The centuries-long lifetime of molecular hydrogen in the atmosphere of Mars supposedly prevents hydrogen loss from varying significantly year-to-year or across the solar cycle. In contradiction of this model, we present strong evidence of seasonal or dust-driven variation in the escape of hydrogen from Mars. We analyze 121.6 nm (hydrogen Lyman-alpha) airglow observations made by the ultraviolet spectrometer SPICAM on ESA's Mars Express spacecraft over the second half of 2007, observing a factor of two decrease in the brightness of the exosphere of Mars at this wavelength. We find a near-exponential decrease in the escape rate of hydrogen over the study period, demonstrating an order-of-magnitude decline in hydrogen escape flux. These results are incompatible with the current model of molecular hydrogen as the carrier of Martian water from surface to ionosphere, and suggest that water escape may proceed directly through injection of water vapor into the upper atmosphere at concentrations greater than any previously observed. This scenario potentially octuples previous estimates of the total amount of water lost to space over Martian history, exacerbating the problem of non-thermal oxygen loss (with implications for the redox state of the atmosphere and surface), and indicates that brief periods of enhanced escape may dominate Martian water loss.

313.18 – Thermal Effects from Comet 2013 A1 (Siding Spring) on Mars' Upper Atmosphere

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The Comet 2013A1 (Siding Spring) will pass within 123,000 km of Mars on October 19, 2014 at a relative velocity of 56 km/s. The comet coma will impinge directly on the Martian upper atmosphere, causing significant perturbations. We examine the thermal effects of the encounter with a first principle model of the upper atmosphere (100-200 km) that solves for the time-dependent thermal structure. The thermal model includes solar EUV heating, radiative cooling, thermal conduction, and heating due to the impact of H2O molecules from the coma. Assuming a H2O production rate of 10^28 molecules/s, the thermal pulse due to comet passage lasts approximately 5 hours and deposits on the order of 10^13 Joules in the Martian upper atmosphere. The peak energy deposition is at an altitude of 140 km for a H2O-CO2 collisional cross section of 1E-16 cm2. Altitudes above 140 km experience temperature increases that exceed 10 K over timescales of several hours with altitudes above160 km having the greatest temperature increases of 25 K. Thermospheric temperatures return halfway to their initial values roughly 8 hours after the comet encounter with thermal effects due to the comet becoming negligible 54 hours post-encounter.

313.19 – Hot Carbon Corona in Mars' Upper Thermosphere and Exosphere

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The production of energetic particles results in the formation of the hot corona, where the most of the escape of neutral atoms occur, in the Martian upper atmosphere. In order to investigate the dynamics of these energetic neutral atoms, we have carried out a study that provides a self-consistent global description of the hot corona in the upper thermosphere and exosphere by employing a self-consistent global kinetic model coupled with a thermosphere/ionosphere model. In this work, we evaluate the carbon atom inventory by studying the production and distribution of energetic carbon atoms. The most important source reactions for hot atomic carbon are expected to be photodissociation of CO and dissociative recombination of CO^+, which are highly sensitive to solar activity and occur mostly deep in the dayside of the thermosphere. The latest available branching ratios is adopted, and appropriate choices of the rate coefficient and the photodissociation frequencies are made. In this study, we simulate the variations of the hot carbon corona over the solar cycle and seasons. The spatial distributions and profiles of density and temperature, atmospheric loss rates are discussed for the cases considered. The total global escape of hot carbon from all dominant photochemical processes is computed and compared with those from other previous models. To describe self-consistently the upper thermosphere and exosphere, a combination of our 3D Direct Simulation Monte Carlo (DSMC) model [Valeille, A., Combi, M., Bougher, S., Tenishev, V., Nagy, A., 2009. J. Geophys. Res. 114, E11006. doi:10.1029/2009JE003389] and the 3D Mars Thermosphere General Circulation Model (MTGCM) [Bougher, S. W., Bell, J. M., Murphy, J. R., Lopez-Valverde, M. A., Withers, P. G., 2006. Geophys. Res. Lett. 32, doi: 10.1029/2005GL024059. L02203] is used. Finally, our computed global total escape rate of hot carbon ranges ~ $(5.2 – 57.1) \times 10^{23}\ s^{-1}$ for the aphelion solar low to perihelion solar high case.

313.20 – Large-Scale, Synoptic-Period Weather Systems in Mars' Atmosphere

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During late autumn through early spring, extratropical regions on Mars exhibit profound mean zonal equator-to-pole thermal contrasts associated with its waxing and waning seasonal polar ice caps. The imposition of this strong meridional temperature gradient supports intense eastward-traveling, synoptic-period weather systems (i.e., transient baroclinic/barotropic waves) within Mars' extratropical atmosphere. These disturbances grow, mature and decay within the east-west varying seasonal-mean middle and high-latitude westerly jet stream (i.e., the polar vortex) on the planet. Near the surface, such weather disturbances indicated distinctive, spiraling 'comma'-shaped dust cloud structures of large scale, and scimitar-shaped dust fronts, indicative of processes associated with cyclo- and fronto-genesis. The weather systems are most intense during specific seasons on Mars, and in both hemispheres. The northern hemisphere (NH) disturbances appear to be significantly more vigorous than their counterparts in the southern hemisphere (SH). Further, the NH weather systems and accompanying frontal waves appear to have significant impacts on the transport of tracer fields (e.g., particularly dust and to some extent water species (vapor/ice) as well). Regarding dust, frontal waves appear to be key agents in the lifting, lofting, organization and transport of this atmospheric aerosol. A brief background and supporting observations of Mars' extratropical weather systems is presented. This is followed by various modeling studies (i.e., ranging from highly simplified, mechanistic and fully complex global circulation modeling investigations) that we are pursuing. In particular, transport of scalar quantities (e.g., tracers and high-order dynamically revealing diagnostic fields) are investigated. A discussion of outstanding issues and future modeling pursuits is offered related to Mars' extratropical traveling weather systems.

313.21 – Statistical studies on the sputtering responses preparing for the MAVEN mission

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Since the MAVEN mission will obtain information on the pick-up ion densities and speeds, atmospheric neutrals and ions, and UV emission profiles, the atmospheric sputtering by the re-impact of the heavy pick-up ions incident on Mars can be evaluated and compared with photo-induced loss processes under a variety of solar conditions occurring during the mission. Based on the simulation results from a 3D Monte Carlo model coupled to a molecular dynamic calculation, the atmospheric sputtering efficiencies due to pick-up O+ for a number of energy and angle spectra are studied statistically. The sputtered hot neutrals populating the extended corona and the escape components are estimated when various solar wind conditions and solar cycle variations are considered. We find that the sputtering efficiencies can be characterized by the total incident fluxes as weighted with different incident energies. The dependencies between the incident pick-up ions and the sputtered hot neutrals lead to certain "response relations". These can be utilized to predict the sputtering rate when incident pick-up O+ fluxes become available. A sputtered hot neutral corona can then be constructed as a reference before modeling results are generated.

313.22 – The response of the Mars ionosphere to solar flares

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During a flare, the increase in solar flux at X-ray and EUV wavelengths causes an enhancement in electron densities in planetary ionospheres. Here we identify and analyze a set of 12 Mars Global Surveyor (MGS) radio occultation electron density profiles which have been affected by solar flares. These profiles coincide with flares in GOES XL flux (0.1-0.8 nm), and exhibit electron densities which are significantly enhanced above the daily average, at altitudes where X-ray and EUV flux is absorbed. With an ensemble of flares and enhanced electron density profiles, we investigate the dependence of the ionospheric response on the enhancement in the solar flux at X-ray and EUV wavelengths, and on optical depth. We characterize the relationship between these quantities with a suitable function, and show that the flare-induced enhancement in electron density increases with increasing enhancement in solar flux and with increasing optical depth. We similarly analyze the results of a 1D photochemical model of the response of the Mars ionosphere to a solar flare. We show that the enhancement in model electron densities exhibits the same dependence on solar flux and optical depth as observed in the flare-affected MGS profiles.

313.23 – Hot Oxygen Transport Model for Martian Coronal Retrievals with MAVEN's IUVS Instrument

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One of the primary goals of the upcoming Mars Atmosphere and Volatile EvolutioN (MAVEN) mission is the study of non-thermal escape of atomic oxygen to space. In support of this goal, the Imaging Ultraviolet Spectrograph (IUVS) instrument will make regular observations of the gravitationally bound O corona surrounding the planet. Interpreting these measurements requires a computationally efficient forward model to calculate collisional transport of hot O through the exosphere. To accurately treat the strong forward scattering of O at energies of a few eV, we are developing a model which applies the Δ-M approximation from radiative transport theory. This method consolidates the strong forward peak of the scattering phase function into a Δ-function, leaving the residual as a sum of smoothly varying Legendre polynomials. Preliminary Monte Carlo results with this approach show great promise, producing coronal O densities and escape rates with accuracies of ~5% or better. Our objective is to integrate this Δ-M technique into a Markov-Chain transport model. The Markov-Chain method produces hot O particle densities and velocity distributions as a function of altitude by quantizing all possible particle states and calculating the probabilities of state transition, then solving for equilibrium using standard matrix routines. This allows for forward model run-times on the order of seconds, enabling real-time pipeline retrievals from IUVS measurements. The general method is applicable to rapidly calculating the transport of any strongly forward scattering species through a background medium.

313.24 – Ion Outflow At Mars Using MEX Ion And Electron Data

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How Mars lost it's water and atmosphere is still an important question. Many studies have investigated high-energy ion fluxes (>10 eV) surrounding the planet and derived ion outflow rates in order to determine atmospheric loss. These rates suggest that the outflow from high-energy ions is not the dominant escape path for atmospheric loss. Over the years increasing evidence has indicated that the loss of low-energy ions is more important than the high-energy ion loss. In this presentation ion observations (down to the spacecraft potential) from the Mars Express (MEX) mission (2010/11), are used to describe the ion altitude distribution at Mars. The focus of this study is below the altitude of ~2000 km. Within the Mars environment, using the MEX electron observations different plasma regions were identified. Supported by electron identification, different altitude profiles of ion fluxes have been analyzed from the different plasma regions. The altitude profiles of the ion fluxes observed below the photoelectron boundary and in the sheath transition region in this study show large asymmetries between the northern and southern hemispheres. The ion distributions, resulting altitude profiles, the influence of the crustal magnetic field at Mars, and the implications relating to plasma outflow will be discussed in this presentation.

313.25 – Hot Oxygen in the Thermosphere of Mars

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One process through which water escapes the martian atmosphere is via the escape of atomic hydrogen and atomic oxygen from the upper thermosphere. Hydrogen's dominant loss process is thought to be thermal. Escape of oxygen has been predicted to occur mainly through non-thermal escape of a supra-thermal population of atomic oxygen from dissociative recombination, though few observations have confirmed this. Presented in this poster are spatial profiles of UV emissions across the martian limb compared with radiative transfer model fits (using a similar method used in Chaufray 2009) for the oxygen (130.4nm). There will be a comparison with other UV emissions for other species. The datasets were taken using the HST Space Telescope Imaging Spectrograph (STIS) in 2003 near opposition and martian perihelion. The spatial profile for the 130.4 nm oxygen emission shows a change in slope of the profile at approximately 500km tangent altitude, with an excess above the modeled thermal emission at higher altitudes. This noticeable deviation from the modeled emission provides strong evidence for a supra-thermal population. We expect to present an analysis of the hot O population needed to fit the HST data.

313.26 – Investigating the asymmetry of Mars' South Polar Cap using the NASA Ames Mars General Circulation Model with a CO_2 cloud microphysics scheme

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Contributing teams: NASA Ames Global Climate Modelling Group

One of the most intriguing and least understood climate phenomena on Mars is the existence of a high albedo perennial south polar CO_2 ice cap that is offset from the pole in the western hemisphere (SPRC). Colaprete et al. (2005) hypothesize that since the process by which CO_2 surface frost accumulates (i.e., precipitation or direct vapor deposition) affects the albedo of the ice, the atmosphere can play a role in the stability and asymmetry of the cap. They show that the basins of Hellas and Argyre force a stationary wave resulting in a colder western hemisphere in which atmospheric CO_2 condensation and precipitation is favored. Because precipitated CO_2 is brighter than directly deposited CO_2, this could maintain the asymmetry of the southern ice cap. We build on their study with a version of the NASA Ames GCM that includes a newly incorporated CO_2 cloud microphysics scheme. Simulated results compare well to observed temperatures, pressures and cap recession rates. Observed mesospheric and polar night clouds are well reproduced by the model, and a third unobserved type of cloud is predicted to form close to the surface of the subliming caps. As hypothesized by Colaprete et al. (2005), we find that the zonally asymmetric topography forces a stationary wave in the atmosphere resulting in an asymmetric cloud cover over the south pole during fall and winter and maximizing snowfall over a region encompassing the SPRC. These positive results open to further studies including a mesospheric simulation to refine the horizontal grid around the SPRC as well as the implementation of an ice albedo scheme dependent both on the amount and size of aerosols falling onto the cap during fall and winter (snow, frost and dust), and on surface metamorphism processes due to sintering and incoming solar radiation. The goal of this work is to develop a more complete understanding of the existence of the SPRC and of the Martian CO_2 cycle.

313.27 – Lava Tubes as Martian Analog sites on Hawaii Island

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The existence of geologic features similar to skylights seen in Mars Reconnaissance Orbiter HIRISE imagery suggest Martian lava tube networks. Along with pit craters, these features are evidence of a past era of vulcanism. If these were contemporary with the wet Mars eras, then it is suggestive that any Martian life may have retreated into these subsurface oases. Hawaii island has numerous lava tubes of differing ages, humidity, lengths and sizes that make ideal analog test environments for future Mars exploration. PISCES has surveyed multiple candidate sites during the past summer with a team of University of Hawaii at Hilo student interns. It should be noted that Lunar features have also been similarly discovered via Lunar Reconnaissance Orbiter LROC imagery.

400 – Mars 1: Surfaces

400.01 – Disappearance of the Propontis Regional Dark Albedo Feature on Mars

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The appearance of Propontis, one of many distinct classical dark albedo features on Mars, has been documented by ground-based observers for well over a century; Propontis was once thought to be the location of a "typical Martian canal". The roughly circular feature (centered at 38°N, 179°W) covers about 500km in north-south extent. Modern spacecraft observations have shown the northern plains in which Propontis is located to include many subdued craters, knobs, and troughs. Observations by the Mars Color Imager (MARCI) onboard the Mars Reconnaissance Orbiter (MRO) have documented dramatic changes in the Propontis feature during August 2009. Daily MARCI mosaics (spatial resolution of 1 km/pixel) revealed extensive dust storm activity in this region over a ten day period (August 16–25, L_s ~ 322°–327°). At this time, the north polar seasonal ice cap was at maximum extent (reaching southward to about 55°N), and dust storm activity was frequently observed southward of the seasonal cap. These storms apparently led to sufficient deposition of bright dust to effectively "erase" the dark Propontis feature – yielding one of the most significant changes in regional albedo since Mars Global Surveyor began routine global mapping in 1997. Only minor changes have been detected over the course of repeated MARCI observations of this region since late-2009 – Propontis has not yet "recovered" to its previous extent and appearance. MRO is expected to provide ongoing MARCI mapping, enhanced with regular Context Imager (CTX, spatial resolution of 6 m/pixel) monitoring. An overview of the accumulated observations to date will be presented, along with interpretation of the magnitude of sediment transport required to account for the observed changes in Propontis.

400.02 – Characteristics and Origin of Martian Low-Aspect-Ratio Layered Ejecta (LARLE) Craters

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An unusual crater morphology is found primarily at high latitudes on Mars. These craters display an extensive outer deposit beyond the normal layered ejecta blanket. This outer deposit extends up to 20 crater radii from the rim, terminates in a sinuous flame-like edge, and is extremely thin, leading to a low aspect ratio (A = thickness/length). These craters are thus called Low-Aspect-Ratio Layered Ejecta (LARLE) craters. We have conducted a survey of all LARLE craters 1-km-diameter and larger on Mars. We find 139 LARLE craters ranging in diameter from 1.0 to 12.2 km with a median of 2.8 km. Most (97%) are found poleward of 35N and

40S, with the remainder primarily found in the equatorial Medusae Fossae Formation. The surfaces of the freshest LARLE layers commonly exhibit radial, curvilinear ridges and dune-like landforms, and the LARLE deposit typically drapes over pre-existing terrain. We propose that the LARLE deposit is formed by a different mechanism than that responsible for the normal layered ejecta patterns. We suggest that impact into relatively-thick fine-grained ice-rich mantles enhances the formation of a base surge that is deposited after formation of the inner layered ejecta deposits. This base surge is similar to the density-driven, turbulent cloud of suspended fine-grained particles produced by impact erosion and mobilization of the surrounding surface material by ejecta from shallow-depth-of-burst nuclear and high-explosion craters. We have applied a base surge equation developed for terrestrial explosive events to two fresh LARLE craters. After adjustment of the equation for Martian conditions, it predicts runout distances that are within 99% of the observed values. All Martian craters likely produce a base surge during formation, but the presence of the obvious LARLE deposit is attributed to crater formation in thick, fine-grained, sedimentary deposits. These sediments are the source of the extra particulate debris incorporated into and deposited by the base surge.

400.03 – Chemical Compositional Indications of Aqueous Alteration for Whitewater Lake Boxworks, Veneers and Veins at Cape York, Mars

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Contributing teams: Athena Science Team

An area of partially-veneered, flat-lying rocks which also includes boxwork and linear veins contains a variety of compositions which are each indicative of minor to major aqueous alteration processes in the Cape York rim of Endeavour Crater. As analyzed by APXS x-ray fluorescence spectroscopy, the sets of unique elemental compositions correspond variously to Al-Si rich clays in boxwork veins, with Fe- and Cl-enriched salt veneers (Esperance samples); swarms of Ca sulfate veins (Ortiz samples); and, as indicated by remote sensing, mafic smectite alteration products in veneers (Chelmsford covering Azilda samples). Multiple offset analyses by APXS reveal clear trends and associations of certain elements, allowing inferences of mineralogies. In contrast to the acidic environment deduced for the genesis of the multiple-sulfate Burns formation sediments and shallow ferric-rich sulfate deposits beneath soils, these alteration products formed at more near-neutral pH, often with major chemical segregations and requiring high water-rock ratios comparable to a wide range of eminently habitable terrestrial environments. Several of these compositions are also rated high with respect to their potential for preservation of organic materials and biomarkers. Within distances of just tens of meters inside this so-called Whitewater Lake unit, this broad diversity exemplifies the tantalizing opportunities as well as challenges for future sample return missions to the red planet, which in this case could also be expanded to include nearby samples of Burns Fm sandstones, hematite concretions, light-toned spherules (Kirkwood), large gypsum veins (Homestake), martian global soils and surface dust.

400.04 – Deliquescence Of Calcium Perchlorate: An Investigation Of Stable Aqueous Solutions Relevant To Mars

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Perchlorate has been found by the Phoenix and Viking landers, and potentially by the Mars Science Laboratory rover. Calcium perchlorate is known for its highly deliquescent properties and low eutectic point, potentially having an impact on the local water cycle. The deliquescence and efflorescence of this salt, though, have not yet been quantified. We used a Raman microscope equipped with an environmental cell to determine the deliquescence relative humidity (DRH) and efflorescence relative humidity (ERH) as a function of temperature and also hydration state. Under all temperature conditions, $Ca(ClO_4)_2$ efflorescence is found to occur at relative humidity values below where deliquescence occurs. DRH increases from an average 23% RH to 55% RH as you decrease the temperature from 263 K to 223 K, with ERH values averaging 16%. This result confirms that all perchlorate salts studied thus far exhibit a significant hysteresis effect during crystallization and thus $Ca(ClO_4)_2$ readily forms supersaturated, metastable solutions. Results were compared to a thermodynamic model for three hydration states of $Ca(ClO_4)_2$. As predicted, the higher hydration states were less deliquescent and the experimental results are in good agreement with the model. To better predict the stability of aqueous $Ca(ClO_4)_2$ solutions in the martian subsurface, we conducted a diurnal cycle experiment. Results showed that $Ca(ClO_4)_2$ can remain aqueous when exposed to the subsurface temperature and RH conditions expected at the Phoenix landing site. Present-day fluvial features, such as RSL, have been attributed to brine flows; thus, understanding RH-driven phase transitions for $Ca(ClO_4)_2$ aqueous solutions may be important for characterizing present-day water on Mars.

400.05 – The Radiolytic Destruction of Glycine Diluted in H2O and CO2 Ice: Implications for Mars and Other Planetary Environments

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Future missions to Mars and other planetary surfaces will probe under the surfaces of these worlds for signs of organic chemistry. In previous studies we have shown that glycine and other amino acids have radiolytic destruction rates that depend on temperature and on dilution within an H_2O ice matrix (Gerakines et al., 2012; Gerakines and Hudson 2013). In the new work presented here, we have examined the destruction of glycine diluted in CO_2 ice at various concentrations and irradiated with protons at 0.8 MeV, typical of cosmic rays and solar energetic particles. Destruction rates for glycine were measured by infrared spectroscopy in situ, without removing or warming the ice samples. New results on the half life of glycine in solid CO_2 will be compared to those found in H_2O ice matrices. The survivability of glycine in icy planetary surfaces rich in H_2O and CO_2 ice will be discussed, and the implications for planetary science missions will be considered. References: Gerakines, P. A., Hudson, R. L., Moore, M. H., and Bell, J-L. (2012). In-situ Measurements of the Radiation Stability of Amino Acids at 15 - 140 K. Icarus, 220, 647-659. Gerakines, P. A. and Hudson, R. L. (2013). Glycine's Radiolytic Destruction in Ices: First in situ Laboratory Measurements for Mars. Astrobiology, 13, 647-655.

400.06 – Analysis of chlorocarbon compounds identified in the SAM Investigation of the Mars Science Laboratory mission

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Contributing teams: SAM and MSL science team

The gas chromatograph mass spectrometer (GCMS) mode of the Sample Analysis at Mars (SAM) experiment was designed for the separation and identification of the chemical components of the gases released from a solid sample or trapped from the atmosphere. Gases from solid samples are either produced by heating a cell from ambient to >800-1100oC (EGA mode) or by wet chemistry extraction and reactions (not yet employed on Mars). Prior to EGA analysis of portions of the first 3 solid samples (Rocknest, John Klein and Cumberland) collected by MSL and delivered to SAM, an internal SAM blank run was carried out with an empty quartz cup. These blank analyses are required to understand the background signal intrinsic to the GCMS and its gas manifolds and traps. Several peaks have been identified as part of SAM background, some of them below the nmol level, which attests of the sensitivity of the instrument and as-designed performance of the GCMS. The origin of each peak has been investigated, and two major contributors are revealed; residual vapor from one of the chemicals used for SAM wet chemistry experiment: N-methyl-N-tert-butyldimethylsilyl-trifluoroacetamide (MTBSTFA), and the Tenax from the hydrocarbon trap. Supporting lab experiments are in progress to understand the reaction pathways of the molecules identified in the SAM background. These experiments help elucidate which molecules may be interpreted as indigenous to Mars. Of the three solid samples analyzed on 11 runs, it was possible to detect and identify several chlorinated compounds including several chlorohydrocarbons. The chlorine is likely derived from the decomposition of martian perchlorates or other indigenous Cl-containing species while the origin of the carbon is presently under investigation for each detected molecule. To date, a subset these molecules have been identified in lab

studies and a terrestrial contribution to the observed products are more easily explained. The combined results from SAM and the associated laboratory studies represent a significant step forward in the search for near-surface organic compounds on Mars.

400.07 – ChemCam Exploration of the rocks and soils of Gale Crater from "Rocknest" to "Yellow Knife Bay".

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Contributing teams: MSL Science Team

At the Rocknest location in Gale Crater, ChemCam collected measurements of the rocks surrounding the sandsheet. These rocks are potential in place outcrop related to the larger Yellowknife Bay exposure. ChemCam utilizes Laser Induced Breakdown Spectroscopy to provide elemental composition at distances up to 7 m from the rover. Analysis spot size ranges from 350 μm to 550 μm depending on range. A given analysis spot is fired upon repeatedly by the laser (generally from 30-50 laser shots) and the emission spectra from each laser shots is recorded. Elemental compositions are derived from the spectra vial a Partial Least Squares analysis model based a spectral library of ~70 certified standards collected on the flight instrument before launch. To date more than 60,000 spectra have been obtained on close to 2,000 observation points covering several hundred rock and soil samples. At Rocknest, even though each rock had a variety of textures, the chemistry of each rock varied in a similar manner. The rocks showed no evidence for widespread coatings or rinds. However, there was evidence for calcium sulfate (based on a linear relationship between CaO and SO4), and excess iron oxides (based on increased FeO not associated with SiO2 in specific rock targets). The detection of sulfates, ferric iron oxides and the overall chemistry of the rocks suggest that nearby felsic and olivine-rich material were cemented together by iron oxide cement. Results from the Rocknest area will be compared to other ChemCam results from other rocks at Yellowknife Bay and their geochemical/geological relationship will be presented. Implications for habitability of these deposits will also be discussed. Acknowledgement: This work has been conducted at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration. Funding from the Canadian Space Agency for King and Schmidt.

400.08 – Composition and Physical Properties of Salt-Bearing Surfaces on Mars

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Chloride salts have been identified on Mars using the Mars Odyssey Thermal Emission Imaging System (THEMIS) and Mars Reconnaissance Orbiter Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). They are identified in THEMIS data by the presence of a distinctive blue slope over the 8-12 μm spectral range. These same deposits show a featureless red slope relative to the surrounding terrain over the ~1-2.6 μm range in CRISM data. The identification of chloride salt-bearing deposits on Mars has been somewhat controversial due to the lack of diagnostic spectral features of anhydrous chlorides in both the VNIR and MIR spectral ranges. Despite this, these materials have spectral properties that are quite distinct from most other materials present on planetary surfaces. For example, the distinctive blue slope of chloride deposits in MIR data is due to the low emissivity of chloride salts. Although low emissivity in the MIR is unusual, it is not unique to chlorides. However, the transparency of anhydrous chlorides results in other unusual spectral properties that can also be used to confidently identify and distinguish these materials. For example, where transparent chlorides are mixed with fine-grained absorbing materials (such as silicates), the associated spectra contain inverted absorption features. These features are found where fine-grained martian dust is mixed with the chloride deposits. At VNIR wavelengths, laboratory data show that the characteristic CRISM spectra for these regions can be matched by mixtures of anhydrous chloride salts and silicates. We will present new analyses of THEMIS and CRISM data as well as advanced theoretical calculations and laboratory experiments that help us to constrain (1) the abundance of salt in martian chloride deposits, (2) the grain sizes and porosity of salt and admixed silicates, and (3) the presence or absence of minor phases of interest, such as sulfates, carbonates, nitrates, and phyllosilicates. Advanced atmospheric correction of remote spectral data, factor analysis and target transformation techniques, and our hybrid T-matrix/Hapke scattering model allow us to place much tighter constraints on these properties than have been previously established.

400.09 – On Chlorine Salts: Their Detection, Stability and implications for Water on Mars and Europa

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Chlorine salts (e.g. chlorides, chlorates and perchlorates) are an important factor in the stability of water on the surfaces of planetary bodies. Here we have shown that perchlorate and chlorate salts will lower the freezing point of water, allowing it to be liquid down to ~204 K. These salts will also slow down the evaporation rate, extending the lifetime of the liquid water solution. Chlorine salts have been detected on Mars, which has significant implications for the stability of water and hence its habitability. To study their effects on the stability of water on planetary surfaces, we need to first locate where these chlorine salts exist; this is typically done by remote sensing. To date, only anhydrous chlorides have been remotely detected, mostly due to the lack of hydrated chlorine salts in the spectral libraries used to identify features. To address this deficit, we measured reflectance spectra for numerous chlorine salts. Hydration bands were most common in near-infrared spectra, with band depth and width increasing with increasing hydration state. In the mid-infrared, oxychlorine salts exhibit spectral features due to Cl-O vibrations. We also investigated the spectral features of these salts at low temperature (80 K) to compare with remote sensing data of the outer satellites, specifically Europa. At low temperature, water bands become narrower and shallower than their room temperature counterparts. We show that chlorine salts do possess distinct spectral features that should allow for their detection by remote sensing, though care must be taken to acquire laboratory spectra of all hydrated phases at the relevant conditions (e.g. temperature, pressure) for the planetary body being studied.

401 – Asteroids 7: Searches

401.01 – Finding and Characterizing Candidate Targets for the Asteroid Redirect Robotic Mission (ARRM)

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The Asteroid Redirect Robotic Mission (ARRM) is a proposed technology demonstration mission which would use high-power Solar Electric Propulsion to rendezvous with a 4-to-10-meter Near-Earth Asteroid, capture and despin it, and then guide it back towards one or more encounters with the Moon which would place it into a distant retrograde lunar orbit. Astronauts could then visit and explore the asteroid using the Orion spacecraft. Simulations suggest that the asteroid population includes thousands of candidate targets which are in the right size range and have the necessary Earth-like low delta-v orbits. Fourteen known asteroids satisfy the orbit and rough absolute magnitude requirements for ARRM candidates, including 2009 BD, which is the current baseline target. With several asteroid survey enhancements in process and new surveys coming online within the next 2 years, the ARRM candidate discovery rate should increase to ~5 per year. Accurate physical characterization of ARRM candidates is required to reduce uncertainties in size, mass and rotation state. Only 4 of the 14 known ARRM candidates have been (or will be) characterized so far, but little priority was placed on this activity until this year. Rapid response after discovery is critical, while a candidate is still very near the Earth. Radar is virtually essential to characterize size and rotation state, while long-arc high-precision astrometry can help characterize mass through estimation of the area-to-mass ratio. The rapid response characterization process was successfully demonstrated for ARRM candidate 2013 EC20, which turned out to be smaller than the desired size range.

401.02 – The Pan-STARRS search for Near Earth Objects: recent progress and future plans

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The Pan-STARRS1 telescope (PS1), located on Haleakala, Maui, Hawaii, is a 1.8-meter diameter telescope equipped with a 1.4 Gigapixel camera that delivers a 7 square degree field of view. PS1 is conducting a diverse survey that includes searching for Near Earth Objects (NEOs). Most of the PS1 observations are acquired in a manner suitable for detection of moving objects; 11% of the observing time is presently dedicated to a search for NEOs. PS1 is presently discovering approximately 40% of the Potentially Hazardous Asteroids, and has become the leading NEO discovery telescope. PS1 delivers excellent astrometry and photometry. The second Pan-STARRS telescope (PS2) on Haleakala achieved first light in July 2013, and is expected to be fully operational by July 2014. We are proposing to use 100% of the observing time on both PS1 and PS2 for a much enhanced survey for NEOs. The new survey will cover much of the accessible sky multiple times each lunation, and is expected to produce a large increase in the NEO discovery rate. It will lead to a much better understanding of the size and orbit distributions of NEOs. The enhanced survey will also improve the discovery rate of asteroids suitable for the NASA asteroid retrieval mission.

401.03 – Minimoon Discovery with Ground-based Radar Facilities

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The detection of small asteroids by their reflected radar signals is a routine operation at the Arecibo and receiving at another telescope, such as the Greenbank radio telescope. We find that it is possible to discover minimoons that are in geocentric orbit (Granvik et al., 2012, Icarus 218) with these facilities. The minimoon model predicts a steady-state population of 1 or 2 one meter diameter minimoons (and many more smaller ones) within about 10 lunar distances (LD) with average geocentric distances between 2 and 4 LD. They have an average orbital lifetime of about 300 days, although some minimoons survive for decades. Detecting one-meter-diameter or smaller objects at these distances is within the capability of Arecibo running in bistatic mode with a smaller antenna like the Greenbank 100 meter radio telescope though the detectability is strongly dependent on an object's rotation rate and size. We calculate the minimoon radar sensitivity according to Renzetti et al. (1988, The Telecommunications and Data Acquisition Report) using the rotation rates predicted for small asteroids by Farinella et al. (1998, Icarus 134) with the observed asteroid rotation rate distribution from Werner et al. (2009, Icarus 202), and the size distribution of impactors from Brown et al. (2002, Nature 420). We find that these facilities used in bistatic operations can discover a 1.0-0.5 diameter minimoon over weeks of operation.Thus, radar facilities can provide a stream of minimoon discoveries as targets for human or robotic spacecraft.

402 – Dust

402.01 – Dust Measurements in the Outer Solar System by the Student Dust Counter

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The Student Dust Counter (SDC) is an impact dust detector on board the New Horizons Mission to Pluto. SDC was designed to resolve the mass of dust grains in the range of 10^-12 < m < 10^-9 g, covering an approximate size range of 0.5-10 um in particle radius. The measurements can be directly compared to the prediction of a grain tracing trajectory model of dust originating from the Edgeworth-Kuiper Belt. SDC's results are compared to our model to derive estimates for the mass production rate and the ejecta mass distribution power law exponent. Through October 2013, the New Horizons spacecraft reached approximately 27.5 AU, enabling SDC to map the dust density distribution of the solar system farther than any previous dust detector.

402.02 – Composition of Exogenous Dust at Saturn from Cassini-CDA Mass Spectra

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Over 99% of impact ionization mass spectra recorded by Cassini's Cosmic Dust Analyser (CDA) at Saturn are water dominated E-ring grains. However, there are hundreds of spectra that indicate a purely mineral composition. A thorough search combining directional and velocity information show that a substantial part of these non-water particles must be originated from outside the Saturnian system. Here we report of a refined investigation of the composition of the exogenous dust by CDA's time-of-flight mass spectrometer. A comprehensive data set from the latest CDA observational campaigns for the first time allow detailed insights into the composition of endogenous and exogenous non-water dust populations. Interstellar dust (ISD) particles crossing the Saturnian system could be dynamically and compositionally separated. The ISD spectra exhibit a surprisingly homogenous silicateous composition which is quite distinct from the non-water dust bound to the Saturnian system.

402.03 – Understanding Asteroid Disruptions Using Very Young Dust Bands

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Zodiacal dust bands are structures that result from the dynamical sculpting of the dust particles released in the catastrophic disruption of an asteroid. Partial dust bands are the recently discovered younger siblings of the dust bands, ones that are still forming and due to very recent disruptions within the last few hundred thousand years. During the early stages of formation, these structures retain information on the original catastrophic disruptions that produced them (since the dust has not yet been lost or significantly altered by orbital or collisional decay). The first partial dust band, at about 17 degrees latitude, was revealed using a very precise method of co-adding the IRAS data set. We have shown that these partial dust bands exhibit structure consistent with a forming band, can be used to constrain the original size distribution of the dust produced in the catastrophic disruption of an asteroid, and these very young structures also allow a much better estimate of the total amount of dust released in the disruption. In order to interpret the observations and constrain the parameters of the dust injected into the cloud following an asteroid disruption, we have developed detailed models of the dynamical evolution of the dust that makes up the band. We model the dust velocity distribution resulting from the initial impact and then track the orbital evolution of the dust under the effects of gravitational perturbations from all the planets as well as radiative forces of Poynting-Robertson drag, solar wind drag and radiation pressure and use these results to produce maps of the thermal emission. Through the comparison of our newly completed dynamical evolution models with the coadded observations, we can put constraints on the parameters of dust producing the band. We confirm the source of the band as the very young Emilkowalski cluster (<250,000 years; Nesvorny et al., 2003) and present our most recent estimates of the size-distribution and cross-sectional area of material in the band and discuss the implications of these constraints on the temporal evolution of the zodiacal cloud and to the structure of the parent asteroid.

402.04 – Dynamical Model for the Toroidal Source of the Sporadic Meteoroid Complex

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The sporadic meteoroid complex (SMC) represents a major part of the meteoroid population in the near-Earth space. Studies conducted over the past decades identified six apparent SMC sources on the sky: (i) north/south apex source, (ii) helion/anti-helion source, and (iii) south/north toroidal source. Nesvorný et al. (2011a) presented a steady-state dynamical model for north/south apex source considering Oort Cloud Comets being the main source of these dust particles. Similarly, Nesvorný et al. (2011b) modeled helion/anti-helion source using a steady-state population of dust released from Jupiter Family Comets. The parent population of the toroidal dust particles remained undetermined so far. Here we overcome this problem and we present a consistent dynamical steady-state model for the toroidal source of the SMC. In particular, we show that sub-mm to mm particles

released from Halley-type comets (HTCs), when eventually colliding with Earth, explain all observable properties of the background average of the toroidal component of SMC, including their typically small eccentricities. Interestingly, the toroidal component of SMC shows the largest yearly variations. We show that the major variations may be due to prolific activity of individual sources such as comet 96P/Machholz. Our steady-state model includes the following parts: (i) dust particles with sizes in the 0.1 – 1 mm range released from a population of HTCs consistent with Levison et al. (2006) model, (ii) dynamical evolution of these particles tracked by a numerical integrator taking into account gravitational and radiative forces, and in the same time allowing them to be dynamically swept out of the Solar System, thermally or collisionally destroyed, and (iii) evaluation of the collisional probability with Earth using our new code appropriate for impactors at large eccentricity and inclination orbits (Vokrouhlický et al. 2012). Results from our model are compared and calibrated to the observations of Canadian Meteor Orbit Radar (CMOR). This allows us to perform additional consistency checks, such as contribution of the HTC dust particles into the other SMC sources or their contribution to the IR flux of the zodiacal cloud observed by IRAS spacecraft.

403 – Enceladus

403.01 – Self-Consistent Generation of Single-Plume State for Enceladus Using Non-Newtonian Rheology

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The thermal dichotomy of Enceladus suggests an asymmetrical structure in its global heat transfer [1]. So far, most of the models proposed that obtained such a distribution have prescribed an a priori asymmetry, i.e. a mechanical anomaly in the south polar ice shell surface [2], at its base [3], or in core topography [4]. We present here the first set of numerical simulations of convection that yield a stable single-plume state for Enceladus without prescribed mechanical asymmetry. Using the convection code StagYY [5,6] in a 2D-spherical annulus geometry [7], we show that a non-Newtonian rheology is sufficient to create a localized, single hot plume surrounded by a conductive ice mantle. Using a grain size-dependent rheology [8,9], we obtain a self-sustained state in which a region of small angular extent has a sufficiently low viscosity to allow convection to occur due to the stress-dependent part of the rheological law. We find that the single-plume state is very unlikely to remain stable if the rheology is Newtonian. For simplicity, we neglect tidal heating effects. Despite this, our preferred model yields a south polar heat flux which is about half the recently revised observational value [10]. References: [1] Spencer and Nimmo, 2013, An. Rev. Earth Plan. Sci., 41, 693-717 [2] Han et al., 2012, Icarus, 218, 320-330 [3] Běhounková et al. 2012, Icarus, 219, 655-664 [4] Han and Showman, 2012, LPSC, 2028 [5] Tackley, 1993, GRL, 20, 2187-2190 [6] Tackley, 2008, PEPI, 171, 7-18 [7] Hernlund and Tackley, 2008, PEPI, 171, 48-54 [8] Rozel, 2012, GGG, 13, Q10020 [9] Barr and McKinnon, 2007, JGR, 112, E02012 [10] Spencer et al., 2013, EPSC Abstract, 8, EPSC2013-840-1

403.02 – Water-rock interactions in warm Enceladus inferred from silica formation and hydrothermal experiments

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A plume of vapour and water ice particles rich in sodium salts erupting from warm fractures near the south pole of Saturn's icy moon Enceladus suggest the presence of a liquid-water reservoir in the interior, which is or has been in contact with the moon's rocky core. Cassini's findings of silica nanoparticles in the E-ring originating from the plumes imply active geochemistry involving hydrothermal water-rock interactions. However, the particular conditions of temperature and mineral compositions that can sustain the formation of silica inside Enceladus are yet unconstrained. Here we report laboratory experiments and numerical calculations of hydrothermal reactions simulating Enceladus' interior. To achieve silica concentrations in the fluids, which are sufficient for the formation of colloidal silica nanoparticles, hydrous silicates of Enceladus' core would be composed mainly of serpentine and saponite/talc, consistent with a chondritic composition of its rocky core. Fluid temperature needs to reach ≥ ~100°C, suggesting extensive hydrothermal activity. Our experimental results suggest that, in contrast to previous reports, a lack of N2 in the plumes is in good agreement with a hot interior because decomposition of primordial NH3 to N2 would have been kinetically inhibited even at high temperatures (i.e., ~400°C). These results support the idea that deep hydrothermal circulation in a warm core drives hotspots in the ice mantle, possibly causing large tidal dissipation and anomalous heat flux from the south-pole region. Furthermore, to achieve such high temperatures in Enceladus, the Saturnian system might have formed in ~3–5 Myrs after the CAIs formation in the protoplanetary disk, consistent with the proposed formation age for another moon of Saturn, Iapetus.

403.03 – A New Estimate of the Power Emitted by Enceladus' Tiger Stripes

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The heat flow from the south pole of Enceladus is a fundamental constraint on its tidal dissipation mechanisms, orbital evolution, and the physical processes that generate the plumes. Cassini Composite Infrared Spectrometer (CIRS) observations of the integrated 17 - 1000 micron thermal emission from the south pole have produced an estimated heat flow of 15.8 +/- 3.1 GW (Howett et al. 2011). This is a surprisingly high value, about 10x higher than can be generated by steady-state tidal heating (Meyer and Wisdom 2007). The estimate includes all sources of south polar endogenic emission, but is model-dependent because the observation also includes passive re-radiation of absorbed sunlight, which must be modeled and subtracted from the observed radiation. An alternate approach is to use higher spatial resolution CIRS observations in which emission from the tiger stripes, which is certainly endogenic, is spatially separated from emission from the surrounding terrain, which consists of passive emission plus a possible endogenic component. Tiger stripe emission is thus a lower bound on total endogenic emission, and is itself important as a constraint on plume generation and transport. CIRS has several observations of 9 - 16 micron emission with sufficient resolution to resolve the tiger stripes, but only limited resolved observations at longer wavelengths where most heat is radiated. Combining the best resolved data at all wavelengths, with reasonable assumptions about the ratio of long to short wavelength emission, we obtain preliminary estimates of tiger stripe thermal emission of roughly 4.2 GW, to which must be added ~0.5 GW of plume latent heat (Ingersoll and Pankine 2009), for a total tiger stripe power of about 4.7 GW. We are investigating whether the discrepancy between the new tiger stripe heat flow estimate, and the earlier estimate for the entire south pole, results from a large heat flow component that is not from the tiger stripes, or possible inaccuracies in the earlier modeling of passive emission.

403.04 – Baghdad Suchus on Enceladus: Constraints on the Temperature and Width at the Fissure Mouth

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A Cassini VIMS spectrum of an active location along Baghdad Sulchus is best fit by a fissure 9 m wide at T=197 K (Goguen et al. 2013, Icarus, accepted). We show that narrower and hotter fissures are unstable due to the exponential increase of the vapor pressure of ice for T greater than 200 K. Ice at 230 K will erode 1 meter/day due to sublimation, so a narrower and warmer fissure will quickly erode to meter widths. The same strong T dependence of the vapor pressure also means that wider fissures at T ~180 K cannot supply to total mass loss rate constraint from Cassini UVIS occultation data. The mass loss rate can be supplied if a significant fraction (~190 km) of the total length of the fissures is active as a 9 m wide fissure with T=197 K. The contribution of this hottest component of the fissure emission contributes only a small fraction of the total observed radiated power from the fissures which is dominated by much larger areas at lower T and is best characterized using the CIRS instrument. Copyright 2013 California Institute of Technology.

403.05 – Modeling the Temporal Variability of the Enceladus Plume

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The Cassini mission to Saturn has found the small icy moon, Enceladus, to be geologically active, with ~ 100 tall geysers erupting from the 4 prominent fractures that cross the moon's south polar terrain [1]. Over Enceladus' orbital period of 1.37 days, horizontal stresses at any one locale will cycle between tension and compression, and include a shearing component. The geysering activity has been attributed to tidally-driven shear heating on one hand [2], and tidally-modulated opening and closing of fractures on the other [3,4]. In light of recent indications that normal, and not shear, stresses are controlling the jetting activity [5,6], we examined the time variability of the spatially-integrated brightness of the jets in Cassini ISS images taken over 6+ years and compared these results to several models. One predicts the variation of normal stresses along the jet-active fractures arising from diurnal tidal modulation; three others predict the variation of additional stresses arising from forced longitudinal librations [7,8]. We favor the tidal modulation model. The best fit to the data yields a phase lag in the response of the ice shell to diurnal tidal forcing of ~ 4 hours, indicating an ice viscosity of ~3x10^14 Pa-sec and substantial dissipation. These results are consistent with a wide range of models, including a thin ice shell over a regional sea. Such a lag is potentially detectable by measuring the tidal gravity response of Enceladus, as has been done at Titan [9]. References: 1. Porco C.C. et al., 2012, AGU Abst P32A-11; 2. Nimmo F. et al., 2007, Nature 447, 289; 3. Hurford T. et al., 2007, Nature 447, 292; 4. Hurford T. et al., 2012, Icarus 220, 896; 5. Porco C. et al., 2013, LPSC Abstr 44, 1775; 6. Gossmeyer, C. et al., 2013, AAS #221, #353.16; 7. Wisdom J., 2004, Astron. J. 128, 484; 8. Hurford T. et al, 2009, Icarus 203, 541; 9. Iess L. et al., 2012, Science 337, 457.

403.06 – Enceladus' Emission at 2cm: an Anomaly Near the Equator?

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The Cassini spacecraft flew by Enceladus on 5 November 2011, configured to acquire SAR imaging of most of the surface with the RADAR instrument. While not optimized for acquiring radiometer data, the pass nonetheless recorded thermal emission from most of the surface. We report on global patterns of thermal emission. The thermal emission is consistent with dielectric constants of pure water or methane ice, but cannot discriminate between the two. The emissivity is low (≈0.5), consistent with substantial volume scattering. The most intriguing result, however, is an anomaly in the thermal emission on Enceladus' leading hemisphere. This anomaly is at a similar location to anomalies previously detected with the CIRS instrument on Mimas and Tethys (Howett et al, 2011, 2012, Schenk et al 2011). Whether or not the anomaly on Enceladus is the same phenomenon remains to be seen. Possible origins and implications are discussed.

404 – Pluto 2: Atmosphere

404.01 – The State of Pluto's Atmosphere in 2012-2013

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We observed two stellar occultations on UT 4 May 2013 and UT 9 September 2012, with the aim of measuring Pluto's atmospheric parameters. Both of these events were a world-wide collaboration of many observers, and both occurred within one month of Pluto's stationary point. For the May 2013 occultation of an R=14.0 star, observations were attempted from several sites in Chile, Venezuela, Arizona, and Massachusetts. Positive detections were made from the DuPont 2.5-m at Las Campanas, the SMARTS 1-m at Cerro Tololo, and the 0.45-m telescope at Cerro Calan, all in Chile. For the September 2012 occultation of an R=15.2 star, observations were attempted from many sites along the east coast of the U.S., and in Arizona, New Mexico, and Texas. Successful atmosphere occultation light curves were obtained from the MONET 1.2-m at the McDonald Observatory and the FIT Ortega 0.8-m in Melbourne, Florida. From these data, we find that Pluto's atmosphere has maintained the basic parameters of the 2011 measurement (Person, et al., in press) with some small but significant structural changes. The atmospheric temperature and pressure are similar to 2011 values, while the 'knee' structure at half-light has continued to evolve and has been further modified since 2011. This light curve evolution maps to changes in the temperature structure and/or haze distribution in the lower atmosphere approximately 1-2 scale heights above the surface. We will present these recent data and discuss their implications for atmospheric change on Pluto as well as extrapolations toward the New Horizons encounter in 2015. This work was supported in part by NASA Planetary Astronomy grants to MIT (NNX10AB27G) and Williams College (NNX08AO50G, NNH11ZDA001N), as well as grants from USRA (#8500-98-003) and Ames Research (#NAS2-97-01) to Lowell Observatory. The observations made at FIT were partially supported by the James and Sara Ortega Endowment.

404.02 – The May 4, 2013 Stellar Occultation by Pluto and Implications for Pluto's Atmosphere

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On May 4 2013, Pluto passed in front of a V~14 star and the shadow was well observed from multiple occultation groups. This paper presents results from the three light curves observed at Las Cumbres Observatory Global Telescope Network (LCOGT) from their Cerro Tololo site. The three LCOGT telescopes have 1.0 m apertures and used identical frame-transfer cameras. The cameras currently have a 2 second readout time therefore autonomous observations were scheduled with different exposure times to give good time resolution of the event. We will present results of this occultation and compare occultation results from 1988 to 2013 with volatile transport models.

404.03 – Atmospheric CO on Pluto: Limits from Millimeter-wave Spectroscopy

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Well-detected on Pluto's surface, CO should also be present in its atmosphere. Initial non-detections ([1], [2]) have recently been followed by reported identifications in the near-IR ([3], hereafter L2011), and mm ([4], hereafter G2011), which are strikingly different. From near-IR spectroscopy L2011 find CO at ~500 ppm for a 17 μbar molecular nitrogen atmosphere, and show that this can be compatible with the observed ratios of surface ices. For a 'standard' 100 K well-mixed atmospheric model with this CO abundance, the expected mm CO(2-1) emission line is ~60 mJy peak and ~1 MHz FWHM. In contrast, G2011 report the CO(2-1) line to be ~591±110 mJy peak, a factor of 10 stronger, yet so narrow (~200 kHz FWHM) that if it is CO from Pluto, it must be significantly colder (~50 K) than expected. At this temperature, to fit the observed line flux density requires that the CO τ=1 surface extends to ~5-6 Pluto radii, implying that CO is more abundant than N_2 in the upper atmosphere. Further, the

G2011 feature exceeds by a factor ~4 the upper limit for the same CO line reported in [2], suggesting that the CO abundance has increased by an immense amount, through an unknown process, over just 10 years. To explore the CO abundance question further, we have reanalyzed our lower spectral resolution (~800 and 200 kHz) CO(2-1) observations from 2005 [5], and 2010 [6], and obtained new observations in 2013, with the Submillimeter Array (SMA) located on Mauna Kea. The two earlier data sets show no evidence for CO emission and are inconsistent with G2011, though only at the ~3-σ level (combined). In 2013, as of July 15 we have another 12.4 hours on Pluto at a more appropriate 100-kHz resolution, and expect more time during late July/August. We will present our initial analysis of all the SMA observations and discuss their implication in the context of the L2011 and G2011 observations of CO in Pluto's atmosphere. [1] Young et al. (2001), Icarus 153, 148-156. [2] Bockelée-Morvan et al. (2001), A&A 377, 343-353. [3] Lellouch et al. (2011) A&A 530, L4-L7. [4] Greaves, Helling, & Friberg (2011), MNRAS 414, 36-40. [5] Gurwell & Butler 2005, BAAS, 37, 743. [6] Gurwell, Butler & Moullet 2010, BAAS, 42, 1014.

404.04 – The Effect of Surface Albedo on Pluto's Atmospheric Circulation

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Previous work by Hansen and Paige (1996, Icarus 120, 247) has revealed that the value of surface albedo can have significant effects on Pluto's atmospheric temperature, surface pressure, and N2 frost distribution. While this model provided valuable insight into the Pluto surface-atmosphere system, it lacked a realistic atmosphere, which is important for the transport of heat and volatiles. We build on this work by using a state-of-the-art Pluto general circulation model (PGCM) to include a more complex atmosphere. We have improved the the PGCM since recent prior publications most notably by allowing surface-atmosphere mass exchange (i.e., a condensation cycle), a surface temperature that is allowed to vary, and a state-of-the-art atmospheric radiative-conductive heating/cooling scheme that includes heating by the 2.3 micron methane band and CO radiative cooling. We have performed a variety of experiments spanning the years 2000 to 2015 with different initial surface pressures (8, 16, ad 24 microbar), fixed methane mixing ratio of 1%, and fixed CO mixing ratio of 0.05%. Several cases of initial surface frost distributions were considered: surface albedo entirely land (i.e. no initial surface ice), surface albedo entirely N2 ice (i.e. surface entirely covered with frost), and a surface albedo map derived from observations by Buie et al. (2010, Astron. J. 139, 1128). In all cases, the meridional and vertical velocity fields are dominated by noise. The cases with initial albedo entirely land immediately have the atmosphere begin freezing out, thus causing the surface to be ice covered. Consequently, these to cases are highly similar in temperature and zonal wind structure. The heterogeneous albedo distribution of the Buie et al. map causes small distortions in the temperature and wind fields as high as several hundred kilometers altitude. This work was supported by NASA grants NNX12AK41G and NNX12AI70G.

404.05 – Hybrid model of Pluto's full atmosphere

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We developed a one-dimensional model of Pluto's atmosphere from the surface to above the exobase by connecting a fluid solution of the lower and middle atmosphere to a kinetic solution of the upper atmosphere. In this way we consistently model the transition from the collisional lower atmosphere where solar heating occurs to the near-collisionless, escaping, upper atmosphere. IR heating and cooling are included using a detailed non-LTE model for methane and carbon monoxide previously used for the lower atmosphere of Pluto. UV heating of methane and nitrogen is included in the middle atmosphere. Direct-Simulated Monte-Carlo (DSMC) is used to model the transition from the fluid to rarified flow. Jeans escape can also be used to approximate the upper boundary conditions for the fluid model, but does not yield the same description of the upper atmosphere as the DSMC. The resulting atmosphere is highly extended, with the exobase varying between 5 and 10 planetary radii depending on the solar activity, and the total molecular escape rate does not exceed 10^{28} s^{-1}. The upper atmospheric structure and the escape rate are highly variable due to the solar UV heating. While the adiabatic cooling due to escape is found to be non-negligible in the lower atmosphere, the density below 500km in altitude does not vary more than 5%. Results are presented for various solar UV heating rates, and sensitivity to methane and carbon-monoxide mixing ratio as well as orbital radius will be discussed.

405 – Mars 2: Surface and Atmospheric Composition

405.01 – The Full Seasonal/Global Variation of Mars Ozone from MARCI 2006-2013 Daily Global Mapping Retrievals

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The Mars Color Imager (MARCI) onboard the Mars Reconnaissance Orbiter (MRO) employs ultraviolet imaging bands within (260nm) and longward (320 nm) of Hartley band ozone absorption, in support of daily global mapping retrievals for Mars atmospheric ozone columns. We present the first release of this unique global atmospheric mapping data set, consisting of 1010 ozone column retrievals spanning MY29-31 on a daily global grid of 8x8 km spatial resolution. Coincident 320nm cloud optical depth retrievals are obtained in conjunction with the MARCI ozone columns (Wolff et al, 2011). The MARCI ozone column detection limit (~1 μm-atm) is appropriate to mapping elevated ozone abundances at low latitudes around Mars aphelion, and over mid-to-high latitudes during fall/winter/spring seasons. MARCI ozone maps for these regions reveal the detailed spatial and temporal behaviors of water vapor saturation conditions that force large variations in water vapor photolysis products (HOx) responsible for the catalytic destruction of ozone in the Mars atmosphere. In the context of full temporal/spatial resolution, we present aphelion increases in low latitude ozone and potential cloud and topographic correlations, high latitude ozone maxima associated with planetary waves and weather fronts during northern early spring, and surprising (yet to be explained) winter season ozone variations within the Hellas basin. Comparisons are provided for MARCI ozone measurements to ozone simulations from the Laboratory of Meteorology and Dynamics General Circulation Model (LMDGCM; Lefevre et al., 2006) and ozone measurements by the SPICAM ultraviolet spectrometer on Mars Express (Perrier et al, 2006).

405.02 – MSL/SAM Measurements of Nitrogen Isotopes in the Mars Atmosphere

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Contributing teams: the MSL Team

The Sample Analysis at Mars (SAM) instrument suite on the Mars Science Laboratory (MSL) measured the Mars atmospheric $\Delta^{15}N$ value on sol 232 of the mission. This value falls within the uncertainty of the Viking aeroshell mass spectrometer measurement, which was 619‰ ± 182‰ (Neir and McElroy 1977). The SAM measurement achieved about a factor of two smaller uncertainty than the Viking value, and about a factor of two higher signal to background ratio (S/BG). The MSL/SAM value was based on Quadrupole Mass Spectrometer measurements of an enriched sample of Mars atmosphere, with CO_2 and H_2O removed. We used the m/z 14/14.5 ratio, from doubly-ionized nitrogen, because it had higher S/BG than other relevant count ratios in the experiment. The m/z 28/29 ratio confirms the isotopic ratio with slightly lower precision. The enrichment experiment, and several direct atmospheric experiments, gave a range of $\Delta^{15}N$ values from 813‰ to 528‰, where the measurements with the highest S/BG gave values most consistent with the enrichment experiment. The direct measurements also used data at m/z 14 and 14.5, to avoid confusion from CO ions at m/z 28 and 29. We will report the SAM $\Delta^{15}N$ value at the meeting, pending confirmation by an additional enrichment experiment on Mars to be completed just days after the abstract submission deadline. Trapped gases in martian meteorite glasses have previously been interpreted as mixtures of two components, based on ratios of $^{15}N/^{14}N$ and $^{40}Ar/^{14}N$ (e.g., Becker and Pepin 1984). One component is thought to have martian atmospheric composition, as measured by Viking. Recent MSL/SAM measurements (Mahaffy et al. 2013) of the $^{40}Ar/^{14}N$ ratio (~0.5) are incompatible with the Viking ratio (~0.3), complicating the interpretation of the meteorite gases. The slope of the meteorite mixing line is less consistent with Viking atmospheric composition if alternative assumptions are used for meteorite cosmic ray exposure ages, cosmogenic ^{15}N production rates, and trapped gas evolution temperatures, yet these assumptions still cannot place the meteorite data on a mixing line with the martian atmosphere as measured by SAM. The SAM argon and nitrogen results may lead to new understandings of martian meteorites.

405.03 – Remotely Measured Boundary Layer Temperature and Carbon Dioxide Isotopes in Mars Atmosphere

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Retrieving accurate abundances for trace species and isotopic ratios from remote spectroscopic measurements requires knowledge of the temperature-pressure profile in the region measured. Temperature profiles on Mars have been measured from orbiting spacecraft such as MGS/TES, but not at the Mars local time or location of subsequent studies. We present results from fully resolved spectroscopic measurements near 10.6 micron of both the normal and singly substituted oxygen-18 CO2 lines, taken with the Goddard Space Flight Center Heterodyne Instrument for Planetary Winds And Composition (HIPWAC) at the NASA Infrared Telescope Facility on Mauna Kea, Hawaii. Measurements with spectral resolving power R=10,000,000 were obtained in October 2007 with an instantaneous field-of-view on the planet of 1 arcsec near mid-day on the planet. The normal isotope of CO2 is near uniformly mixed in the atmosphere and its strong absorption line is used to retrieve temperature information. Surface pressure is constrained by the altitude relief of the surface in regions probed. Surface temperature is constrained using the calibrated continuum radiance between the measured line profiles. Using these constraints and a MGS/TES profile for a comparable Mars location, a thermal profile at the time and location of the 18OCO2 line can be retrieved. The retrieved profile can be used in turn to extract a more accurate 18OC16O/16OC16O ratio at the time and location of the ground-based measurements or to accurately retrieve other trace constituents, such as ozone or water. A description of the analytic process and results of the temperature and isotopic ratio retrievals will be described.

405.04 – Martian Atmospheric Plumes: Behavior, Detectability and Plume Tracing

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We will present our recent work simulating neutrally buoyant plumes in the martian atmosphere. This work is primarily directed at understanding the behavior of discrete plumes of biogenic tracer gases, and thus increasing our understanding of their detectability (both from orbit and from in situ measurements), and finally how to use the plumes to identify their precise source locations.
We have modeled the detailed behavior of martian atmospheric plumes using MarsWRF for the atmospheric dynamics and SCIPUFF (a terrestrial state of the art plume modeling code that we have modified to represent martian conditions) for the plume dynamics. This combination of tools allows us to accurately simulate plumes not only from a regional scale from which an orbital observing platform would witness the plume, but also from an in situ perspective, with the instantaneous concentration variations that a turbulent flow would present to a point sampler in situ instrument. Our initial work has focused on the detectability of discrete plumes from an orbital perspective and we will present those results for a variety of notional orbital trace gas detection instruments. We have also begun simulating the behavior of the plumes from the perspective of a sampler on a rover within the martian atmospheric boundary layer. The detectability of plumes within the boundary layer has a very strong dependence on the atmospheric stability, with plume concentrations increasing by a factor of 10-1000 during nighttime when compared to daytime.
In the equatorial regions of the planet where we have simulated plumes, the diurnal tidal "clocking" of the winds is strongly evident in the plume trail, which similarly "clocks" around its source. This behavior, combined with the strong diurnal concentration variations suggests that a rover hunting a plume source would be well suited to approach it from a particular azimuth (downwind at night) to maximize detectability of the plume and the ability to trace the plume to its precise source.

405.05 – Material ejection through basal sublimation of the CO2 ice on Mars: temporal evolution, thickness evolution and implications for Mars polar sedimentary records

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As the seasonal CO2 ice polar caps of Mars retreat during spring, dark spots appear on the ice in some specific regions. These features are thought to result from basal sublimation of the CO2 ice followed by ejection of regolith-type material that covers the ice. We present here a coupled THEMIS/CRISM data analysis of several areas in the south seasonal cap exhibiting dark spots, following the temporal evolution of these exotic processes. Numerical modeling tools have also been developed to simulate the thermal behavior of these areas and estimate the thickness of the ejected material that covers the ice. Observations show that the dark spots are associated with both weaker CO2 ice signature and higher surface temperature than that of CO2 ice, consistent with the presence of a 'thick' layer of dark material on top of the ice. Using numerical modeling, we have demonstrated that the temperature of such covering layer is expected to remain at first close the condensation point, followed by a progressive rise from typically 5 to 30 K above the CO2 ice temperature as the insolation increases, which is in agreement with THEMIS observations. Diurnal variations of a few K are also expected. Data analysis suggests an active period of material ejection (with at least several events), accumulation around the ejection points, and spreading of part of the ejected material over the whole area during the first weeks after the end of the polar night, followed by a period where only CO2 gas is ejected. Temperature retrievals show that (at least) some material remains on top of the ice until complete sublimation of the ice, suggesting that after initial material ejection, wind and small scale irregularities in the surface (surface roughness) tend to make this material accumulate in specific locations, leading to some sub-pixel spatial mixtures. Material thickness is estimated to range from a few hundreds of microns to a few mm in the warmest spots (with possible high heterogeneity at small scale). Thus a yearly material vertical transport of at least the same amplitude is expected in the polar regions of Mars, leading to an alteration of the sedimentary records.

405.06 – Physical Properties of CO2 Frost Formed by Radiative Cooling in a Mars Simulation Chamber

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We have performed realistic laboratory simulations of the thermal and radiative environment at the surface of Mars to produce the first samples of carbon dioxide ice formed as it does on Mars, by radiative cooling from a near-pure CO2 gas. It is important to determine the physical characteristics of Mars' seasonal CO2 polar ice caps because these determine their radiative properties which, in turn, control the polar energy balance and the seasonal variation in global surface pressure. It is not known whether they form as fluffy fine-grained deposits, dense solid ice, or something in between. Previous simulations have used conductive cooling, condensing CO2 onto a substrate cooled by liquid nitrogen (Kieffer 1968, Ditteon and Kieffer 1979). This technique favors the growth of grains having the best thermal contact with the surface, resulting in large grain sizes and a coarse texture. On Mars, however, the latent heat released by condensation must be lost radiatively to space. For this experiment, we have constructed a Mars simulation chamber containing low thermal conductivity analog regolith and low pressure CO2 gas. To grow radiation frost in the laboratory requires simultaneous containment of the atmosphere/vapor while allowing infrared radiation to escape (to balance the latent heat of condensation). Planets accomplish this using gravity to hold down the atmosphere. The key to our simulation is the use of a thin polypropylene film that is largely transparent in the thermal infrared yet strong enough to maintain the required pressure differential between our Mars-like 'atmosphere' and the vacuum-enclosed space simulator (a liquid-nitrogen cooled plate). We use internal and external light sources to briefly illuminate the frost and obtain high resolution images of its physical morphology and texture using an in situ fiberscope with an articulated tip. Initial results will be presented.

405.07 – Resolving The Great Drying of Mars: Sequence Stratigraphy of The Aeolis-Zephyria Trough

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At Aeolis-Zephyria, the unsteady drying-out of Mars can be resolved using unconformity-bounded stratigraphic units. Mars rocks record long term climate evolution and habitability deterioration. However, the sedimentary rocks can only rarely be subdivided into unconformity-bounded packages (sequence stratigraphy / allostratigraphy) or correlated to fluvial activity. This impairs correlation of lander ground-truth to global spectroscopic and imaging datasets. Here we map unconformity-bounded sequences containing embedded river and stream deposits of the Aeolis-Zephyria trough on the Mars highland-lowland boundary. We document at least four unconformity-bounded packages in this 10^6 km^2 region, including two packages containing river and stream deposits. Having used the unconformities to place the stratigraphic packages in relative time order, we trace climate proxies up through the sequences so defined. River dimensions suggest wet-dry cycles at both long and short timescales, superimposed on an overall drying-upwards trend. Meander deposits record generally NNW-converging meander migration, suggesting NNW-converging paleoflow. We propose that the large-scale transitions between erosion and deposition recorded in Aeolis Dorsa were forced by climate and/or mean-obliquity changes that would have had a global effect on surface liquid water availability and therefore habitability. This correlates stratigraphy, runoff, habitability, and orbital change.

405.08 – Constraints on the Compositions of Phobos and Deimos from Visible/Near Infrared Observations

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Mapping of mineral absorptions on Phobos and Deimos using recently acquired visible and near infrared observations from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) shows that Fe2+ electronic absorptions diagnostic of olivine and pyroxene are absent, indicating the moons' surfaces are inconsistent with a composition like that of bulk Mars or Mars crustal material. There is a broad absorption centered around 0.65 μm within the redder spectral unit on Phobos and ubiquitously present on Deimos, and the occurrence of this feature is independently confirmed by telescopic spectra of Phobos collected from the Mayall 4-m telescope. A comparable 0.65 μm feature is also found to be present among numerous other low-albedo solar system bodies. Thermally corrected CRISM spectra additionally show a 2.7 μm feature present in spectra collected across all of Phobos and Deimos, and this feature is generally stronger in red unit material. The shape and position of the 2.7 μm band are consistent with an OH related feature. The origin of the 0.65 um feature is uncertain, and we will discuss evidence for or against it being one of several candidate phases including a mixture of microphase and nanophase metallic iron that may have formed on the moons' surfaces through space weathering, as has been proposed for dark material on Iapetus, or an Fe-bearing phyllosilicate, a common mineral in the moons' closest spectral analogs CM chrondrites. Overall, the CRISM observations indicate Phobos and Deimos most likely have a composition consistent with a primitive, hydroxyl-bearing material everywhere, with a variation in the phase that is responsible for the 0.65 μm band. Spectral data with a greater spectral range, including into the vacuum ultraviolet, could help further constrain the 0.65 μm phase, although in situ investigation will be necessary for definitive identification off the responsible material.

405.09 – The Martian Soil: A Planetary Gas Pump

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The transport of gas through the Martian soil plays an important role in processes like the global cycle of water. Until now, in the absence of an active pumping system, diffusion was assumed to be the most efficient transport mechanism. Here, we present a new mechanism of forced convection within porous soils, which occurs naturally on Mars. In the low pressure environment of Mars, thermal creep within the insolated surface can act as an efficient pump in the porous soil. The pores of the dust act as micro-channels, where the gas flows from the cold to the warm side. We proved this concept in drop tower experiments. In microgravity thermal convection is absent and only thermal creep is visible. By illuminating a basaltic dust bed in microgravity, it was possible to trace the gas flow by embedded particles, moving towards the dust bed within shadowed regions with inflow velocities on the order of cm/s. These observations are consistent with a model of forced flow through the porous medium. Scaled to Martian conditions the experiments show that this transport mechanism can be very efficient and atmospheric gas can be pumped into the soil in shadowed parts and be transported underground to insolated places. This natural planet wide pump is unique in the Solar System as only the Martian surface conditions (mbar pressure) are suitable for this effect.

406 – Other Icy and Irregular Satellites

406.01 – Possible Plasma Tori of Inert Kronian Satellites: Composition and Structure

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We consider the hypotheses that a) the inert icy satellites of Saturn, Rhea, Dione and Tethys might contribute to the plasma population of the magnetosphere, independent of the output of Enceladus, b) that in addition to the water group ions expected to be emitted from their surfaces, they also input nitrogen to the magnetosphere and c) that these mini-tori might cause proton injections. We use CAPS data acquired on orbits in which the variations of density are real and not a result of changes in the viewing geometry of the instrument. We find that whereas density enhancements appear to be associated with all virtual encounters, i.e. with crossings of the satellite orbit in the absence of the satellite itself, Rhea shows no nitrogen in the environment nor in the satellite itself (VIMS finding), while Dione and Tethys appear to be sources of nitrogen. All three of them have exospheric type atmospheres which insert particles into the magnetosphere where they are ionized and form local plasma-enhanced regions in the vicinity of the orbit. The mini-tori are somewhat displaced from the orbit by motions of the magnetosphere as is to be expected. In some,but not all, virtual encounters we see injections of protons up to energies above 10 keV.

406.02 – Far-Ultraviolet Phase Curve Analysis Of Mimas, Tethys And Dione And Implications For The Exogenic Processes

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The Cassini probe orbiting in the Saturn system since 2004 provides the first opportunity to observe the midsize icy satellites of Saturn in the Far-UV wavelengths, between 118 and 190 nm, thanks to the UVIS (UltraViolet Imaging Spectrograph) instrument. Data collected over these 9 last years allow to study much more in details the photometric properties and exogenic processes acting on the surface of the icy satellites. To date, very few things are known about these satellites and their environment, the E-ring. We present here he first far-UV phase curves of three midsize Saturnian satellites: Mimas, Tethys and Dione. The photometric characteristics of Tethys and Dione, exterior to the orbit of Enceladus, are compared and contrasted with the ones of Mimas, inside the orbit of Enceladus, the source of the E-ring. While the leading/trailing hemisphere patterns on Tethys and Dione correspond to the expectations previous by the model of repartition of the E-ring grains inside the E-ring (Hamilton and Burns, 1994), Mimas exhibits an unexpected behavior being much brighter than expected, especially at low phase angles. Exogenic processes acting on the surface are thus questioned. E-ring grains, energetic electrons, cold plasma ions and neutrals are known to impact these icy surfaces. The Hapke an Buratti models applied to our dataset provide some supplementary details to understand the ring-satellite-magnetosphere interactions in the Saturnian System.

406.03 – Coherent Backscattering Effect in Icy Satellites: Model, Cassini VIMS, and Ground-Based Near-Infrared Spectra

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Compositional mapping of icy satellite surfaces is usually based on correlating spectral absorption band depths with the abundance of ice/non-ice species and/or particle size alone. However, absorption band depths and shapes also depend on observation geometry, specifically the solar phase angle α. The constructive interference of light that is responsible for the coherent backscattering effect (CBE) should significantly alter the interpretation of spacecraft spectra obtained at $\alpha < 2$ degrees in particular (Helfenstein et al. 1997 Icarus 128, 2-14), but the magnitude of the CBE on band depth has not yet been quantified or studied in detail. In this work, we explore the relationship between α, spectral band depth and shape caused by CBE for both Cassini Visual & Infrared Mapping Spectrometer (VIMS) and ground-based near-infrared observations of bright and dark satellites. We report numerical CBE modeling performed using the publicly available multisphere T-matrix (MSTM) computer code to simulate the change in absorption bands with the solar phase angle seen in the spectra of icy bodies. We compare these models to Cassini VIMS extracted I/F spectra for selected icy satellites (e.g., Rhea, Iapetus, Enceladus) as well as ground-based $\lambda = 0.9 - 2.4$ μm spectra of Tethys, Dione, Iapetus, Rhea, and Enceladus acquired using Triplespec (R=3000) at Apache Point Observatory, New Mexico. Such results ultimately place limits on the size and packing fraction of icy satellite regolith particles and aid in interpretations of the structure, composition, and evolution of icy satellites. This work is supported by NASA's Outer Planets Research program (NNX12AM76G; PI Pitman), Planetary Astronomy program (NNX09AD06G; PI Verbiscer), and NASA's Advanced Supercomputing Division. Calibrated Cassini VIMS data cubes appear courtesy of B. J. Buratti and the Cassini VIMS team.

406.04 – The Opposition Surge of Icy Moons at 3.6 Microns: New Data from Cassini VIMS

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The opposition surge is the huge increase in brightness that is exhibited by nearly every planetary surface as it becomes fully illuminated to an observer. The classic explanation of the surge is that mutual shadows cast by particles in the regolith rapidly disappear as the body approaches a solar phase angle of zero. Additional optical effects such as coherent backscatter or a sharply peaked particle phase function may add to the effect, particularly at solar phase angles less than one degree. The quantitative modeling of the surge yields important information about the compaction state of the surface and particle sizes, which in turn offers clues to the geophysical processes at work on the surface. The study of the opposition surge has centered mainly on visible radiation. Spacecraft observations offer a window into new wavelengths that enable greater understanding of the mechanisms of the surge as well as the physical nature of the surface itself. The Cassini Visual Infrared Mapping Spectrometer gathered measurements of the solar phase curves of the icy moons of Saturn – Mimas, Enceladus, Tethys, Dione, Rhea, and Iapetus – throughout the wavelength range of 0.35-5.1 microns and through a full excursion in solar phase angles. This entire spectral range is free of contamination by thermal emission. We find that the nature of the curve changes dramatically longward of the water-ice absorption band at three microns. We attribute this effect to the disappearance of multiple scattering at this wavelength, where the albedo of the moons is low. Without the confounding effect of multiply scattered photons, the compaction state of the surface can be directly measured at this wavelength. We find the derived porosities to be ~95%, similar to lightly packed terrestrial snow. An alternative explanation of the change may be the "disappearance" of small particles that cannot be detected at wavelengths a few times larger than their size. Funded by NASA

406.05 – Rhea and Dione: Variations in Surface Thermal Properties

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Thermal inertia variations have been observed on icy satellite surfaces throughout the Saturnian system, resulting in night and daytime temperature variations across the satellites. The most notable are the two 'Pac-Man' anomalies on Mimas and Tethys (Howett et al., 2011, 2012): distinct regions of high thermal inertia at low latitudes on the leading hemisphere of both satellites, resulting in warmer nighttime and cooler daytime temperatures (by ~15 K) than their surroundings. High-energy electrons are the likely cause of this surface alteration, which preferentially bombard low latitudes of the leading hemisphere of Mimas and Tethys, effectively gluing the grains together and thus increasing their thermal inertia. Cassini's CIRS (Composite Infrared Spectrometer) has returned a plethora of night- and day-time data for both Dione and Rhea. Using these data, with the same analysis techniques that discovered the 'Pac-Men', the spatial variations in thermophysical properties across Rhea and Dione have been mapped. The results are intriguing: for the first time we see a decrease in the thermal inertia across Rhea's Inktomi crater ejecta blanket and hints at a high thermal inertia region at low latitudes on Dione's leading hemisphere. If Dione's high thermal inertia region is formed by the same mechanism as the 'Pac-Men' on Mimas and Tethys (and nothing similar is observed on Rhea), then this sets an important bound in the electron energy able to produce this type of surface alteration. Rhea's Inktomi crater (14 S/112 W, diameter 48 km) is a bright young ray crater. A similar crater (i.e. young, morphologically fresh) exists on Dione: Creusa (49 N/76 W, diameter 40 km). Preliminary results show that no significant change in the thermal inertia is observed over Creusa. Why should thermal inertia vary over Inktomi, but not Creusa? Rhea and Dione's subsurface may be different enough to explain this inconsistency (Schenk et al., 2011), or maybe the older Creusa ejecta are more modified, or Creusa's smaller ejecta blanket is just more difficult to separate accurately from the background surface values. This work is supported by the Cassini Data Analysis Program.

406.06 – Crater Relaxation and Heat Flow on Dione and Tethys: Near Cousins of Enceladus?

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Evidence for relaxation of impact crater topography has been observed on many icy satellites, including those of Saturn, and the magnitude of relaxation can be related to past heat flow. We have used stereo- and photoclinometry-derived global digital elevation models (DEMs) of the surfaces of eight Saturnian satellites that we have generated from Cassini data to obtain depth and diameter measurements for more than 500 craters. We have previously reported on relaxation simulations performed to determine what heat flow magnitudes and durations are necessary in order to achieve the current morphologies of certain relaxed and unrelaxed craters on Rhea and Iapetus (White et al., 2013). Combined with age estimates based on crater counting, we found that Iapetus has not experienced heat flows above radiogenic levels since formation of its basins, but that Rhea appears to have undergone a period of global elevated heat flow reaching 20-30 mW m^{-2} that caused the relaxation of its largest impact basins. We now return our attention to Dione and Tethys, two satellites that show a more complex history of relaxation across their surfaces than either Rhea or Iapetus, with some areas showing extensive relaxation across a wide range of crater diameters, and other areas showing relatively little relaxation. Such a distribution would indicate a history of strongly differential heat flow across these satellites. New simulations of crater relaxation and associated heat flow on these satellites using crater profiles measured from our DEMs, in conjunction with new crater age estimates for the basins, allow us to map the history of heat flow variation across their surfaces. The results suggest that Tethys and especially Dione have been geologically active in their pasts, and that both may represent geologically less evolved cousins of Enceladus. Reference: White, O., P. Schenk, & A. Dombard (2013) Impact basin relaxation on Rhea and Iapetus and relation to past flow. Icarus, 223, pp. 699-709, doi:10.1016/j.icarus.2013.01.013.

406.07 – The inner small satellites of Saturn: Their varied surfaces tell dynamic tales

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According to images from the Cassini Imaging Science Subsystem (ISS), the surface forms and overall shapes of Saturn's inner small satellites occur in groups that populate different orbital niches. Co-orbitals Janus and Epimetheus are the most lunar-like of the small satellites; ring moons Atlas, Pan, and Daphnis have latitude-dependent morphology likely related to how ring material is supplied (Charnoz et al., 2007). The shepherding moon Prometheus may show a stripped mantle/core structure. Arc/ring embedded moons are small, smooth ellipsoids, unique among well-imaged small solar system objects. The Trojan satellites (Calypso, Telesto, Helene) have deep coverings showing multi-step histories of deposition and erosion, and include branching networks of downslope transport. We report the quantitative characteristics of these bodies' shapes, mean properties, and surface characteristics. The differences may arise from the amounts of loose material available to cover the surfaces. Modeling of ejecta sources from large icy satellites in addition to interactions with ring particles may be required to explain all the variation among these small, icy bodies. The semi-global drainage patterns on the Trojans are especially enigmatic. Why is there nothing comparable on other small satellites? The tapered albedo markings on the Trojans suggest process-specific surface properties. Cassini ISS UV3/IR3 color ratios show that, for Helene, erosion and downslope motion result in a surface that is bluer in color; or a less active surface remains/becomes redder. Sustained exogenic processes such as E-ring particle impacts and charged-particle bombardment compete with geological processes, but on the Trojans, both leave strong signatures. The different amounts of interconnected surfaces on the small satellites range from the cratered landscapes of Janus and Epimetheus, through the semi-global drainage patterns of the Trojans, to complete smoothing of the arc/ring embedded objects. Further work on the systematics of cratering and ejecta motion in the inner Saturn system may elucidate why the "drainage pattern" result is so unusual.

406.08 – Irregular Saturnian Moon Lightcurves from Cassini-ISS Observations: Update

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Cassini ISS-NAC observations of the irregular moons of Saturn revealed various physical information on these objects. 16 synodic rotational periods: Hati (S43): 5.45 h; Mundilfari (S25): 6.74 h; Suttungr (S23): ~7.4 h; Kari (S45): 7.70 h; Siarnaq (S29): 10.14 h; Tarvos (S21): 10.66 h; Ymir (S19, sidereal period): 11.92220 h ± 0.1 s; Skathi (S27): ~12 h; Hyrrokkin (S44): 12.76 h; Ijiraq (S22): 13.03 h; Albiorix (S26): 13.32 h; Bestla (S39): 14.64 h; Bebhionn (S37): ~15.8 h; Kiviuq (S24): 21.82 h; Thrymr (S30): ~27 h; Erriapus (S28): ~28 h. The average period for the prograde-orbiting moons is ~16 h, for the retrograde moons ~11½ h (includes Phoebe's 9.2735 h from Bauer et al., AJ, 2004). Phase-angle dependent behavior of lightcurves: The phase angles of the observations range from 2° to 105°. The lightcurves which were obtained at low phase (<40°) show the 2-maxima/ 2-minima pattern expected for this kind of objects. At higher phases, more complicated lightcurves emerge, giving rough indications on shapes. Ymir pole and shape: For satellite Ymir, a convex-hull shape model and the pole-axis orientation have been derived. Ymir's north pole points toward $\lambda = 230° \pm 180°$, $\beta = -85° \pm 10°$, or RA = 100°±20°, Dec = -70°±10°. This is anti-parallel to the rotation axes of the major planets, indicating that Ymir not just orbits, but also rotates in a retrograde sense. The shape of Ymir resembles a triangular prism with edge lengths of ~20, ~24, and ~25 km. The ratio between the longest (~25 km) and shortest axis (pole axis, ~15 km) is ~1.7. Erriapus seasons: The pole direction of object Erriapus has probably a low ecliptic latitude. This gives this moon seasons similar to the Uranian regular moons with periods where the sun stands very high in the sky over many years, and with years-long periods of permanent night. Hati density: The rotational frequency of the fastest rotator (Hati) is close to the frequency where the object would lose material from the surface if its bulk density would be less than ~1 g/cm^3. This indicates that at least Hati is probably not an underdense object among Saturn's irregulars.

406.09 – Capture of irregular satellites due to gas drag from circumplanetary disk

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Many irregular satellites are orbiting about the giant planets in the solar system. They have highly eccentric and inclined orbits, thus, they are thought to be planetesimals captured by the planets through some energy dissipation. Although several energy dissipation mechanisms for capturing irregular satellites have been proposed by previous works, most of them seem to have difficulty in explaining capture of the irregular satellites of Jupiter. Cuk & Burns (2004) argued that a cluster of prograde irregular satellites of Jupiter would be collisional fragments of a single planetesimal captured by gas drag from the circumjovian disk at the final stage of the formation of Jupiter. They integrated orbits of this parent body backward in time, and found that the parent body experienced a period of temporary capture by Jupiter before it became gravitationally bound by the planet. If planetesimals with low energy are temporarily captured by Jupiter for an extend period of time near the end of Jupiter's formation, they may survive for a long time and even weak energy dissipation may be sufficient for capturing them as irregular satellites or their progenitors. Recently, we investigated temporary capture of planetesimals by a planet in detail using three-body orbital integration. We found that temporary capture orbits can be classified into four types and evaluated the rates of temporary capture (Suetsugu et al. 2011, Suetsugu & Ohtsuki 2013). In the present work, we examine the process where temporarily captured planetesimals turn permanently captured satellites due to gas drag from circumplanetary disk. We will discuss capture and orbital evolution of irregular satellites due to gas drag from circumplanetary disk.

407 – Comets 1: ISON and Garradd

407.01 – Sungrazing Comet Potpourri: Dust Studies of SOHO/STEREO Comets and an Update on ISON (C/2012 S1)

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The set of comets observed by SOHO and STEREO provides us with a large (>2500 comets) and unique database for studying cometary properties. Sungrazing comets are discovered in SOHO or STEREO images on average every few days, with individual comets typically observable for up to a few days. We compiled photometry of 23 comets observed simultaneously by the same telescope on both STEREO spacecraft to construct the first dust scattering phase function ever directly computed from simultaneous observations of the same object from two vantage points, thus removing uncertainty caused by changing heliocentric distance between observations. The collective dust scattering phase function spans phase angles from 28-153 deg and agrees reasonably well with the theoretical curve from Marcus 2007 (ICQ 29, 39), however, individual comets deviate from the predicted curve by varying amounts during their apparition. This may suggest that the dust properties of individual comets change on the timescale of hours due to the dramatically different heliocentric distance or that the number of dust grains in the coma is changing due to nucleus activity, rotation, and/or erosion. We have also begun a study of the dust tails of selected well-observed comets in our database. This project utilizes the 3-D aspects of the combined SOHO and STEREO dataset to constrain the dust properties and time of release better than is possible with observations from a single location. We will present ongoing results of these investigations and place them into the wider context of sungrazing comet studies. We will also present new results of our ongoing observing campaign of dynamically new sungrazing Comet ISON (C/2012 S1) at Lowell Observatory. We imaged ISON regularly from January-June 2013 with Lowell Observatory's 4.3-m Discovery Channel Telescope and 1.1-m Hall Telescope. We observed a sunward-facing coma enhancement in R-band images in March, April, and May that is similar in orientation and extent as that reported by Li et al. 2013 (CBET 3496) with the Hubble Space Telescope. We will resume observations when ISON re-emerges from solar conjunction in September and will present first results at the meeting.

407.02 – Early pre-perihelion characterization of Comet C/2012 S1 (ISON)

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Comet C/2012 S1 (ISON) is a dynamically new comet on a sungrazing orbit. As such, C/ISON represents a unique opportunity to study both the cosmic-ray-irradiated surface, produced during the comet's long residence in the Oort cloud, and much deeper layers in the nucleus, exposed when the comet passes 1.7 solar radii from the Sun's surface at perihelion. During the first phase of our investigation, we collected broadband images of C/ISON on April 10, 2012 at a heliocentric distance of 4.15 AU, using the Hubble Space Telescope WFC3/UVIS. We used the F606W and F438W filters in three HST orbits covering a total span of ~19 hrs. The comet shows a well delineated coma in the sunward direction extending about 2′ from the nucleus, and a dust tail at least 25′ long. The coma has an average red color of 5%/0.1 micron within 1.6′ from the nucleus, becoming redder towards the tail. Both the color and the size of the coma in the sunward direction are consistent with outflow of micron sized dust. Broadband photometry yielded $Af\rho$ of 1376 cm at 589 nm, and 1281 cm at 433 nm, measured with a 1.6′ radius aperture. The total brightness of the comet within a 0.12′ radius aperture remained unchanged within 0.03 mag for the entire duration of the observations. A well defined sunward jet is visible after removing the $1/\rho$ brightness distribution. The jet is centered at position angle 290 deg (E of Celestial N), with a cone angle of 45 deg, a projected length of 1.6′, and a slight curvature towards the north near the end. No temporal change in the morphology is observed, suggesting the jet is circumpolar. Under this assumption, the jet's apparent position constrains the rotational pole to lie within 30 deg of (RA, Dec) = (330, 0), and an obliquity of 50-80 deg. Preliminary analysis using a coma-nucleus separation technique suggests a nuclear radius less than 2 km. The survival of such a small nucleus during its sungrazing perihelion is certainly questionable.

407.03 – Development of Activity in Comet C/2012 S1 ISON

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We report photometric observations for comet C/2012 S1 ISON obtained immediately after discovery (22 Sep. 2012; r = 6.28 AU) until moving into solar conjunction in mid-June 2013 using the UH2.2m, and Gemini North 8-m telescopes on Mauna Kea, the Lowell 1.8m in Flagstaff, the Calar Alto 1.2m telescope in Spain, and the VYSOS-5 and VYSOS-20 telescopes on Mauna Loa Hawai'i. An additional pre-discovery data point from the Pan STARRS1 survey extends the light curve back to 28 Jan. 2012 (r = 8.4 AU). The images showed similar tail morphology throughout this period, largely because of projection effects. Additional observations at sub-mm wavelengths using the JCMT on 15 nights between 9 March (r = 4.52 AU) and 16 June 2013 (r = 3.35 AU) were used to search for CO J(3-2), CO J(2-1), HCN J(4-3), and HCN J(3-2) rotation lines. No gas was detected, with preliminary upper limits for CO during 14-15 June (r = 3.3 AU) of Q < 6.4 x 10^27 molec/s based on the observations of the CO J(2-1) line. Using these production rates, the Q(H2O) published by Schleicher (2013; IAUC 9254), and the preliminary radius from the HST measurements (J.-Y. Li et al., 2013; STScI-2013-14) we have generated ice sublimation models consistent with the photometric light curve. The inbound light curve is likely controlled by sublimation of CO or CO2; at these distances water is not a strong contributor to the outgassing. Without more sensitive limits on CO, we cannot yet constrain which of these volatiles is controlling the activity. It is clear from the photometric light curve that the fractional active area of the nucleus increased linearly by about a factor of 2 from Jan. 2012 until mid Jan. 2013 (r ~ 5 AU) at which point the activity decreased by 30% by early May 2013. This suggests that a limited supply of volatile material was driving the current activity.

407.04 – The Early Inbound Activity of Comet ISON (C/2012 S1)

Michael F. A'Hearn[1], Nicolas Biver[2], Dennis Bodewits[1], Tony L. Farnham[1], Lori M. Feaga[1], Paul D. Feldman[3], Matthew M. Knight[4], Laurence O'Rourke[5], David G. Schleicher[4], Harold A. Weaver[6]
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We have assembled a variety of data on the early behavior of comet ISON through early June 2013, including V magnitudes from the ground and from spacecraft (SWIFT, DIFlyby), upper limits on gas from the DIFlyby, Herschel, and Hubble, and ground-based detections of CO and CN. We argue that the comet's activity was steadily increasing from the pre-discovery observations in 2011 through late 2012. The activity then flattened and remained constant until January 2013, at which point it started to decrease and continued decreasing until earliest June. We interpret this in the classical picture (e.g., Whipple 1978 Moon and Planets 18, 343) of a dynamically new comet from the Oort cloud having a totally irradiated crust of order 3-10 meters thick from 4.5 billion years of galactic cosmic rays outside the heliosphere. The irradiated layer is released at very large distances due to the presence of free radicals and other chemically active species. As this crust is depleted the activity decreases and in early June we are awaiting the onset of "normal" cometary activity, which should be detected by fall at the latest.

407.05 – Narrowband Observations of Comets ISON (2012 S1) and 2P/Encke: Extremes of the New and the Old

David G. Schleicher[1], Matthew M. Knight[1], Allison N. Bair[1]
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We report on narrowband filter observations of Comets ISON (2012 S1) and 2P/Encke obtained from Lowell Observatory. Observations of dynamically new Comet ISON include the first successful gas measurements of the apparition on March 5 (r = 4.57 AU) with a CN production rate of $1.3x10^{24}$ molecules/s, implying a water production rate of $1\text{-}10x10^{26}$ molecules/s for a normal range of CN-to-OH abundance ratios. Two months later the measured CN and inferred water values were about 70% higher. During the same interval the apparent dust production more than doubled, with $Af\rho$ increasing from 120 cm to 270 cm. Further observations, both photometry and imaging, are scheduled for early September and early October, and the results from these will be presented. In contrast to ISON, Comet Encke is highly evolved both thermally and physically, having made hundreds of close passages by the Sun. As a result, only a small fraction of its surface remains active and almost no micron-sized dust particles are released during outgassing. This fall's apparition will be the ninth for which we will have obtained gas production rates. The existing data imply a strong secular decrease in water production but a much smaller decrease for the minor species. These and new observations will be presented and we will examine whether or not these trends continue and the possible meaning. This research is supported by NASA's Planetary Astronomy and Planetary Atmospheres Programs.

407.06 – Observing Comet C/2012 S1 (ISON) With Spitzer

Carey M. Lisse[1], Ron J. Vervack[1], Harold A. Weaver[1], James M. Bauer[2], Yanga R. Fernandez[3], Mike S. Kelley[4], Matthew M. Knight[5], Dean C. Hines[6], Jian-Yang Li[7], William T. Reach[8], Mike L. Sitko[9], Padma Yanamandra-Fisher[10], Karen J. Meech[11], John T. Rayner[11]
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In this talk we discuss the design, implementation, and reduction of observations of Comet ISON from space using the Spitzer Space Telescope on 13.00 – 13.96 Jun UT and from the ground at Lowell Observatory on Jun 11.16 UT and from APO on 14.13 Jun UT. The comet was at distance r_h = 3.34 AU from the Sun, distance $\Delta_{Spitzer}$ = 3.29 AU and 17.4° phase from SST, and distance Δ_{Earth} = 4.25 AU and 6.8 – 7.3° phase at the time of observation. Preliminary analyses show ISON's Spitzer coma morphology was relatively compact and simple, with a linear anti-solar dust tail > $3x10^5$ km in length and a 1/p profile gas coma extending > 10^5 km from the nucleus. Afp values in an 18,200 km radius aperture of 840, 890, and 840 ± 80 cm were found at VRI, and 650 ± 100 cm were found at 3.6 micron. Together, the ground-based and Spitzer photometry imply near-neutral dust scattering from the visual through the infrared. An excess at 4.5 μm due to emission from a neutral gas coma is clearly found both morphologically and photometrically. The gas coma total flux and spatial profile and ISON's discovery distance imply a coma dominated by the stronger CO_2 line emission at 4.67 μm, but we cannot rule out a preponderance of CO emission at 4.26 μm. No variability in our Spitzer photometry at the 0.03 mag level over 24 hrs was seen. We present our imagery, spectrophotometry, and lightcurves, and discuss the physical implications of these measurements of the comet made well outside the ice line.

407.07 – The Onset of Comet C/2012 S1 ISON's Volatile Activity as Observed by the Deep Impact HRI-IR Spectrometer

Lori M. Feaga[1], Jessica M. Sunshine[1], Michael F. A'Hearn[1], Tony L. Farnham[1], Silvia Protopapa[1], Dennis D. Wellnitz[1], Kenneth P. Klaasen[2], Terry W. Himes[2]
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In February 2013, the Deep Impact Flyby (DIF) spacecraft observed comet C/2012 S1 ISON when the comet was ~4.7 AU from the Sun. As expected, the High Resolution Instrument Infrared Spectrometer (HRI-IR) did not detect the comet between 1.05 and 4.85 microns, a wavelength range where ro-vibrational bands of H_2O, CO_2, and CO, can be measured simultaneously. These measurements provide upper limits for the volatile activity. Additional pre-perihelion observations are scheduled for July/August 2013 when ISON is visible to the DIF, but unobservable from Earth. During this window, ISON is close to the water snow line (~2.5 AU) and measurable activity is predicted. ISON, a dynamically new Oort Cloud comet, will be compared to the dynamically young comet C/2009 P1 Garradd, which was observed in March 2012. In those observations, HRI-IR detected H_2O, CO_2, and an unusually high abundance of CO post-perihelion at 2 AU. Results will also be compared to DI narrow-band measurements acquired in the same time period for both comets.

407.08 – Imaging Comets ISON and Garradd With the Deep Impact Flyby Spacecraft

Tony Farnham[1], Dennis Bodewits[1], Lori M. Feaga[1], Michael F. A'Hearn[1], Jessica M. Sunshine[1], Dennis D. Wellnitz[1], Kenneth P. Klaasen[2], Terry W. Himes[2]
1. Univ. of Maryland, College Park, MD, United States. 2. Jet Propulsion Laboratory, Pasadena, CA, United States.

The Deep Impact flyby spacecraft (DI) is currently operating as a remote observatory, studying bright comets from a different perspective than can be achieved from Earth. Images are obtained with the Medium Resolution Imager (MRI) using a broadband CLEAR filter to capture the continuum, and narrowband filters to capture OH, CN and C2 gas bands (Farnham et al., Icarus 147, 180, 2000). Sequences consist of continuum images sampled every 15 minutes, interspersed with gas-band images that are sampled at least every hour. These sequences continue for up to 6 days, providing a continuous baseline of high-frequency observations. Comet ISON (C/2012 S1) is a dynamically new comet in a sungrazing orbit (perihelion less than 3 solar radii) that was discovered at > 6 AU from the Sun. These circumstances offer a unique opportunity to characterize the physical properties and progression of activity of this comet on its first passage into the solar system, which can be done over a wide range of heliocentric distances up to and including its close approach to the Sun. DI observed ISON in January 2013, when the comet was at a heliocentric distance of 5 AU. A second window of opportunity occurs between July and September 2013, as the comet crosses the ice line from 3 to 2 AU. This window also covers a segment of the orbit where the comet is not easily observable from Earth. Comet Garradd (C/2009 P1) is a long-period comet that was observed by DI between February 20 and April 9 2012, while the comet moved from 1.7 to 2.1 AU from the Sun. Among other results, the DI observations show rotational variability and coma morphology at levels undetected from the Earth (Farnham et al. 2013, in prep). We will present results from the analysis of the ISON and Garradd observations, including cometary variability, coma morphology, and production rates, and will discuss how the analysis fits in to the broader context for understanding the comet's development and evolution.

407.09 – The evolving activity of the Dynamically Young Comet C/2009 P1 (Garradd)

Dennis Bodewits[1], Tony L. Farnham[1], Mike F. A'Hearn[1], Lori M. Feaga[1], Adam McKay[2], Dave G. Schleicher[3], Jessica Sunshine[1]
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Comet C/2009 P1 (Garradd) was a dynamically young comet that was bright and well-observable from a heliocentric distance of 3.5 AU pre-perihelion until 4.5 AU outbound. The development of its activity was observed by many different observatories and instruments, both on the ground and in space (Deep Impact, Swift, SOHO-SWAN, VLT-UVES, IRTF, and many more). Because of this observing campaign, Garradd is the first comet for which production rates of all three main volatiles (H_2O, CO, and CO_2) were measured during a significant part of its passage through the inner solar system. These observations provide an invaluable key to how comets work. At -3.5 AU, Garradd had one of the highest dust-to-gas ratios ever observed, matched only by Hale-Bopp. Comparing slit-based measurements and observations acquired with larger fields of view indicated that between -3 AU and -2 AU a significant extended source started producing water in the coma (Combi et al. 2013, Paganini et al. 2012, Villanueva et al. 2012). This source, likely icy grains, disappeared quickly around perihelion (Bodewits et al. in prep.). The other volatiles observed in Garradd's coma indicate an even more complex story. Relative abundances measured with large apertures were lowered significantly by the extended water source, indicating that these icy grains were depleted of ices more volatile than water. Differences in the volatility of cometary ices may further explain the observed trends in the abundances of CN and CO_2 (mostly observed through [OI]; Decock et al. 2013). These effects do not explain the strange behavior of CO, whose production rate increased monotonically from -2 AU to +2AU (Feaga et al. submitted, and references therein). The activity of Garradd was complex and changed significantly during the time it was observed. We will discuss how these different sublimation processes fit into our understanding of cometary activity and evolution in general.

408 – JWST Town Hall: Observations in the Solar System

409 – Masursky Award (R. Greeley); Eberhart Award (R. Kerr)

410 – Mars Science Laboratory: Findings and Highlights of the First year, S.K. Atreya (Univ. Michigan)

410.01 – Mars Science Laboratory: Findings and Highlights of the First year

Sushil K. Atreya[1]
1. Univ. of Michigan, Ann Arbor, MI, United States.
Contributing teams: MSL Science Team

The overarching scientific goal of the Mars Science Laboratory, named Curiosity, is to quantitatively assess whether Mars has or ever had the environment for sustaining microbial life. The ten investigations of the Curiosity Rover are designed to synergistically address this goal by studying the geology and mineralogy, surface radiation, and atmospheric composition and characteristics in a suitably chosen local region of Mars, Gale crater and the layered terrain of Mount Sharp at its center. This talk will present key findings from the first year of exploration by the Curiosity rover in Gale crater, and discuss the progress made so far toward the mission goals.

411 – Voyager at the Edge of Interstellar Space, E.C. Stone (Caltech)

411.01 – Voyager at the Edge of Interstellar Space

Edward C. Stone[1]
1. California Institute of Technology, Pasadena, CA, United States.

Following encounters with Jupiter, Saturn, Uranus, and Neptune, the two Voyager spacecraft continued exploring the outer heliosphere as they searched for the heliopause, the boundary between the solar wind and the local interstellar medium. On August 25, 2012, Voyager 1 entered an unexpected region near the boundary in which the spiral solar magnetic field lines appear to be well connected to interstellar space, allowing the escape of energetic ions from inside the heliosphere and the entry of low energy galactic cosmic rays from outside. These observations have revealed new aspects of the boundary region of the heliosphere and provide a first view of what is outside.

412 – The Kuiper Belt after 20 years: Past, Present & Future, H. Schlichting (MIT)

412.01 – The Kuiper Belt after 20 years: Past, Present & Future

Hilke Schlichting[1]
1. MIT, Cambridge, MA, United States.

I will present an overview of what we have learned about the Kuiper Belt, starting with its discovery 20 years ago to its current state and will speculate about what new discoveries the future may hold.

413 – Comets Posters

413.01 – Rosetta – an update

Matt Taylor[1], Nicolas Altobelli[2], Fred Jansen[1, 2], Michael Kueppers[2], Gerhard Schwehm[1], Claudia Alexander[3], Maud Barthelemy[2], Bernhard Geiger[2], Richard Moissl[2], Claire Vallat[2], Bjoern Grieger[2], Albrecht Schmidt[2]
1. European Space Agency, ESTEC, Noordwijk, Netherlands. 2. European Space Agency, ESAC, Madrid, Spain. 3. NASA/JPL, Pasedena, CA, United States.

The Rosetta Mission is the third cornerstone mission (after XMM and Cluster/SOHO) of the ESA programme Horizon 2000. The aim of the mission is to map the comet 67-P/Churyumov-Gerasimenko by remote sensing, to examine its environment insitu and its evolution in the inner solar system. The lander Philae will be the first device to land on a comet and perform in-situ science on the surface. Launched in March 2004 and after a number of gravity assists and various asteroid fly –bys, the spacecraft entered deep space hibernation in June 2011. Nearly 10 years after launch on 20th January 2014 at 10:00 UTC the spacecraft will wake up for comet rendez-vous preparation. This presentation will provide a brief overview of the mission up to date and provide an insight into the exciting years we have ahead of us as Rosetta reaches and studies its target.

413.02 – A radiative transfer model for simulating VIRTIS/Rosetta molecular spectra

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The 2-5 micron VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) instrument on board the ESA's Rosetta probe will measure the infrared spectrum of 67P/Churyumov-Gerasimenko in nadir and limb geometry. From these measurements, the spatial distribution, production rate, and rotational temperature of several species will be obtained. We have developed a radiative transfer model which simulates the excitation of the vibrational bands of H2O, CO2 and CO in optically thick regions of the coma. The model is axisymmetric, and thus permits us to represent properly the effect of a non-isotropic excitation source (solar radiation). The model uses a spatial discretization for the gas parameters and the population distribution, which is uncoupled with the directional discretization used to treat the ray propagation. Our algorithm allows us to use a small number of rays. This makes the model computationaly efficient, which is necessary to compute the excitation of a large (50-100) number of ro-vibrational levels. We simulate VIRTIS observations of 67P/Churyumov-Gerasimenko in 2014-2015 and present the results. The rotational population distribution in the vibrational ground state is assumed to be at thermal equilibrium. The distribution of density, velocity and temperature of the gas is described by isentropic spherical expansion.

413.03 – The VIS-IR mapping of 67P/Churyumov-Gerasimenko comet nucleus: the observation strategy of VIRTIS-M onboard Rosetta

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Starting from the beginning of August 2014, ESA's Rosetta mission will begin the characterization of 67P/Churyumov-Gerasimenko comet nucleus from an heliocentric distance of 3.2 AU. In about one month, the Visible InfraRed Thermal Imaging Spectrometer (VIRTIS-M) shall acquire, in the 0.25-5.2 micron range, the entire nucleus' illuminated hemisphere. The data shall be used to derive compositional maps (ice vs carbon-rich, CO or CO2 source areas, organic material) and temperature/thermal inertia maps necessary for the proper selection of the Philae lander landing site. During the early "comet characterization" phase the Rosetta spacecraft will reach a minimum distance of about 100 km with solar phase <30°. In the subsequent period the S/C shall be at 50 km minimum distance and minimum phase of 35°. During these periods VIRTIS-M resolution is about 25-12 m/pixel. A Global Mapping Phase will follow where the orbiter shall be at a distance of 30-20 km allowing a more detailed observation of some pre-selected Philae landing sites, although in worse observing conditions. From the 30 km orbital arcs in fact VIRTIS-M will accomplish regional coverage at <8m/pixel resolution, but with a solar phase between 65° and The implemented observation strategy is optimized to maximize the scientific return given the observation conditions (distance, dwell time) and operative constraints (spacecraft pointings, data volume, power profile). Each observation has been simulated using syntethic spectra fed to a signal to noise simulator to define the instrument performances in the various cases, while the coverage has been optimised using pushbroom or scanning modes. In addition, to mitigate the effects of the expected compositional disuniformity, of the surface roughness and of the irregular shape of the comet's nucleus, we have planned to observe each surface's point more than one time with different illumination conditions. Moreover, to properly study the surface thermal response, we shall need to sample the diurnal temperature variation of a given area at different local times. During the entire pre-landing phase it is expected that VIRTIS-M shall acquire a total of about 4.2 million spectra of the nucleus in about one month.

413.04 – Simulation of the radiance from a cometary nucleus coma. Application to Rosetta-VIRTIS observations of 67P Churyumov-Gerasimenko.

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Abstract With the scope to support scientific investigation of VIRTIS (Visible and Infrared Thermal Imaging Spectrometer), a 0.25-5 μm imaging spectrometer onboard of the Rosetta spacecraft, simulations of the radiance coming from the coma of 67/P Churyumov-Gerasimenko, containing dusty and icy grains and gas, are necessary. During the observation plan phase such simulations drive the selection of the integration times and spacecraft's pointing while during the post-processing phase the same model shall be used to retrieve abundances of grains and gases from the measured radiance. Cometary coma spectra are strongly affected by the dynamical processes involving dust and ice grains present in the coma and by their physical properties. The solar light illuminates the grains that can scatter, absorb and emit radiation. The reflected and the emitted radiation has been modeled with a Monte-Carlo method using the SCATRD 06.10 code (Vasilyev et al., 2006). This code calculates the multiple scattered solar radiation for each wavelength in the VIRTIS spectral range. Moreover, the atmosphere is modeled in spherical geometry allowing us to simulate both limb and nadir (for various zenith angles) viewing geometries. The simulations have been performed at different heliocentric distances and using different dust grains models in which size distribution, composition and vertical distribution are changed. The gases composition, spatial distribution and coma properties have been retrieved from the Inner Coma Environment Simulation tools (ICES) (http://ices.engin.umich.edu/). The synthetic spectra derived are presently used to predict the VIRTIS expected signal to noise and to correctly plan the comet's observations during the different phases of the Rosetta mission.

413.05 – Sensitivity of MIRO continuum channels to thermophysical and dielectric properties in preparation of the Rosetta observations of 67P/Churyumov-Gerasimenko

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The Microwave Instrument for the Rosetta Orbiter (MIRO) is equipped with two channels at 0.5 and 1.6 mm (564 and 190 GHz), which provide continuum measurements of the thermal radiation at these frequencies. These measurements are sensitive to the thermophysical properties of the observed object, as the measured antenna temperatures correspond to two different emission depths, thereby allowing to constrain thermal inertia and its variability with location and time. However, the dielectric properties (loss tangent, dielectric constant) and viewing geometry come into play as the emission depth is dependent on the composition and porosity of the observed location and varies with emission angle. In preparation for the upcoming Rosetta observations of 67P/Churyumov-Gerasimenko, we use a cometary nucleus thermal model and a radiative transfer model to investigate the influence of dielectric properties of cometary materials and viewing geometry on the predicted antenna temperatures for a range of thermophysical properties.

413.06 – Calibration of the Dust Impact Monitor DIM onboard Rosetta/Philae

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The Rosetta lander spacecraft Philae will land on the nucleus surface of comet 67P/Churyumov-Gerasimenko in November 2014. Philae is equipped with the Dust Impact Monitor (DIM). DIM is part of the SESAME instrument package onboard Philae (Seidensticker et al., 2007) and employs piezoelectric PZT sensors to detect dust particle impacts. The PZT sensors are mounted on the outer side of a cube, facing in orthogonal directions, this way allowing for the detection of grains approaching normal to the nucleus surface and from two horizontal directions. DIM's total sensitive area is approximately 70 cm^2. It will measure impacts of sub-millimeter and millimeter sized ice and dust particles that are emitted from the nucleus and transported into the cometary coma by the escaping gas flow. A grain-size dependent fraction of the emitted grains is expected to fall back to the nucleus surface due to gravity. DIM will be able to detect both these components, the backfalling particles as well as the grains hitting the detector on direct trajectories from the surface. With DIM we will be able to measure fluxes, impact directions as well as the speed and size of the impacting cometary particles. We studied the performance of DIM based on impact experiments and compared the measurements with the sensor's expected theoretical behaviour as derived from Hertz' theory of elastic impact. We simulated impacts onto the DIM sensor with spherical particles of different materials (steel, glass, ruby, polyethylene), particle radii of 0.5 mm and impact speeds up to 2 m s^-1 (Flandes et al., 2013). Cometary grains on ballistic trajectories will have impact speeds below the escape speed from the nucleus surface (approximately 1.5 m s^-1), thus the impact speeds achievable by our experiments cover the range expected at the comet. Our results show that the signal strength and the contact durations measured with the DIM PZT sensors can be well approximated by Hertz' contact mechanics. In a dedicated liquid nitrogen-cooled experiment chamber we performed drop experiments with 0.5 mm water ice balls. We also present first results from these drop experiments.

413.07 – Dust observations of comet 67P/Churyumov-Gerasimenko and comparison with ICES model.

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The comet 67P/Churyumov-Gerasimenko, the target of Rosetta mission, was observed from the ground during its last approach at the 2009 perihelion. The observations, obtained in 4 epochs with the heliocentric distance varying from about 3 to 1.4 AU, consisted in images in the visible and near-IR spectral ranges. The analysis of the images in the visible have been already published (Tozzi et al. 2011) and it has been shown that the dust density increases exponentially with the decrease of the nucleocentric distance. A possible scenario to explain that finding is a slowly evolving coma, with very low velocities of the grains. Here we present an updated analysis of those data together with the analysis of the near-IR observations. In addition, we compare the results obtained from the spectral observations in terms of dust density Vs nucleus distance, with those predicted by the models available in the Inner Coma Environment Simulator (http://ices.engin.umich.edu/), a repository of models of the nucleus and coma used by ESA to predict the environment close to the comet nucleus.

413.08 – Dust Properties of Three Oort Cloud Comets and Comet 67P/Churyumov-Gerasimenko

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The composition of comet dust has been largely preserved since comet nuclei coalesced from the proto-planetary disk, more than 4 Gyr ago. Mid-infrared spectra of comet comae reveal emission from silicate dust species, the most prominent features being a wide band of emission from amorphous silicates at 8 to 12 µm, and, occasionally, narrow peaks from crystalline silicates distributed throughout the mid-IR wavelength range. The term 'amorphous silicate' refers to grains with non-stoichiometric compositions similar to olivine and pyroxene, and may be inherited from the interstellar medium. Contrary to amorphous silicates, the crystalline silicates in comets likely formed within the Sun's proto-planetary disk. Thus, the silicate species in comets may provide a measure of dust formation and mixing in the early solar system. We present mid-IR spectra, images, and models of Comets 67P/Churyumov-Gerasimenko, C/2009 P1 (Garradd), C/2011 L4 (Pan-STARRS), and C/2012 F6 (Lemmon), taken with the BASS spectrograph at the NASA IRTF, the IRS and IRAC instruments on the Spitzer Space Telescope, or the T-ReCS instrument at Gemini South. Crystalline silicates are clearly present in the spectra of all three Oort cloud comets, but are more difficult to discern in the spectrum of Comet 67P, despite the high signal-to-noise ratio. A preliminary dust model for Comet Pan-STARRS yields a crystalline silicate fraction of approximately 50%, for grains <1 µm in size. Photometry based on our IRAC images of Comet 67P yield a CO_2-to-H_2O coma mixing ratio upper limit of 10%, consistent with a ratio of 7% found by Ootsubo et al. (2012, ApJ 752, 15). Given the recent results on CO_2 in comets from Akari and Spitzer, and the potential to constrain CO_2 in several more comets with Deep Impact and Warm Mission Spitzer, we discuss our attempts to find correlations between the primary volatiles in the gas coma and coma dust properties. This work is supported by NASA PAST awards NNX09AF10G and NNX13AH67G, and is supported at The Aerospace Corporation by the Independent Research and Development program.

413.09 – Ultraviolet Observations Of C/2012 S1 (ISON) By MAVEN

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On its journey to Mars, MAVEN has been serendipitously positioned to study the anticipated sungrazing comet C/2012 S1(ISON) and offers important scientific observations. The MAVEN mission is the first to attempt to understand the evolution of the Martian atmosphere by determining the effects of atmospheric loss to space. The IUVS instrument has two large field of regard(55x11 and 24x11 degrees) and observes in the mid and far ultraviolet (115-340 nm). It was designed to be able to map the atmosphere in several neutral and some ionized species. These performance characteristics make IUVS ideal to study ISON, as it can take both two dimensional spatial scans as well as spectral data. Tentative plans indicate the comet can be acquired on Dec 8th, assuming that the comet survives the near sun encounter. If observations prove possible, IUVS will be able to study ISON shortly after perihelion, and from a different vantage point from Earth. Science goals include UV observations of D/H, morphology & time evolution of the hydrogen coma and UV spectroscopy of the inner coma. IUVS can potentially make a major contribution to the international community by measuring D/H, thus contributing to our understanding of the origin of Earth's water. IUVS will also make MUV and FUV observations of molecular species in the inner coma, valuable for understanding the chemical evolution of cometary molecular gases. The poster will present provisional observation plans as well as simulated spectra and spatial profiles. We welcome input from the community on these plans, in the spirit of maximizing the scientific return of the international campaign. The work has been supported by the MAVEN project and NASA Planetary Atmospheres grant NNX09AB59G.

413.10 – Hubble Space Telescope Pre-Perihelion ACS/WFC Imaging Polarimetry of Comet ISON (C/2012 S1) at 3.81 AU

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We present the first polarization images of Comet ISON (C/2012 S1) taken with the Hubble Space Telescope (HST) on UTC 2013 May 8 (r = 3.81 AU, delta = 4.34 AU), when the phase angle was $\alpha \approx 12.25$ degrees. Although this phase angle is approximately centered in the negative polarization branch, there is no evidence of a negative polarization circumnucleus halo region that has been observed in previous polarimetric images of Kuiper-belt comets. Instead, the central region (~ 0.32 arcseconds ≈ 1000 km) of the image shows a polarization p ~ 2.0 – 2.5% that is approximately perpendicular to the scattering plane. Such positive polarization has been observed previously as a characteristic feature of cometary jets. The region beyond 1000 km, with sufficient signal-to-noise to make a polarization measurement (≤ 5000 km), shows a negative polarization p ~ 1.8% that varies only slightly.

413.11 – A cometary update from the WISE mission

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Contributing teams: WISE Team

The Wide-Field Infrared Survey Explorer (WISE) mission conducted an all-sky survey in 2010 at infrared wavelengths of 3.4, 4.6, 12, and 22 microns. Over 150 comets were detected during the survey including 21 previously unknown comets, and 27 comets were detected at multiple epochs. As part of the NEOWISE project, we are characterizing the nuclei, comae, tails, and trails of these comets with the goal of better understanding the ensemble properties of long period and Jupiter family comets. One third of the comets detected were long period comets while two-thirds were Jupiter family comets. These two populations have likely undergone different amounts of thermal and collisional processing since formation. We use the WISE data to search for systematic differences

between the two populations and present the most recent results on nucleus size distributions, coma temperatures, and activity profiles. In addition we present interesting results obtained for individual comets, including 17P/Holmes. This comet underwent a massive outburst in 2007, expelling a dust trail of > mm-sized grains that WISE observed 3 years later. The largest dust grains are on the order of cm and can be compared to large-grain ejecta observed in 2007 shortly after the outburst. This publication makes use of data products from (1) WISE, which is a joint project of UCLA and JPL/Caltech, funded by NASA; and (2) NEOWISE, which is a project of JPL/Caltech funded by the Planetary Science Division of NASA.

413.12 – WISE/NEOWISE Observations of WISE/NEOWISE-discovered Cometary Dust Tails

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Contributing teams: The WISE Team

The Wide-field Infrared Survey Explorer (WISE) mission serendipitously observed over 150 comets during its all-sky survey, including 21 objects discovered by the mission. Of the 21 WISE-discovered objects, 10 were long-period comets and 11 were short-period (Jupiter-family and Halley-type) comets. WISE simultaneously imaged four infrared wavelength bands (3.4, 4.6, 12, and 22 μm), allowing for multi-wavelength analysis of each object. About half of the WISE-discovered comets (as well as about half of the comets in the entire data set) displayed a significant dust tail in the 12 and 22 μm (thermal emission) bands. We present here updated dynamical models based on the Finson-Probstein method for those comets with a significant dust tail, focusing on the objects discovered by WISE. These models make use of a novel tail fitting method that allows the best-fit model to be chosen analytically rather than subjectively. We highlight the interesting case of Halley-type comet C/2010 L5 (WISE), which was visited once pre-perihelion (January 2010, 1.67 AU), and twice post-perihelion (June and July 2010, 1.21 and 1.59 AU, respectively), and was observed to be active in the two post-perihelion observations. The tail morphology suggests that the dust was released as a single event within a few days of the comet's perihelion passage. We will present constraints on C/2010 L5's nucleus size, dust production rate and gas production rate. This publication makes use of data products from (1) WISE, which is a joint project of UCLA and JPL/Caltech, funded by NASA; and (2) NEOWISE, which is a project of JPL/Caltech, funded by the Planetary Science Division of NASA.

413.13 – Where are the small Kreutz-family members?

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The Kreutz sungrazer family is one of the best-known comet families and contains some of the most spectacular comets in history. However, due to its extreme orbit geometry, most members in this family are either too faint or too close to the sun to be observed from the ground. Space-based coronagraphs launched in recent decades, notably the Solar and Heliospheric Observatory (SOHO), have detected over 2000 Kreutz members that come very close to the sun. The observations are limited to a very short time period (~1-2 d) from the perihelion of these objects, and suffer from low astrometric/photometric precision; the states of these objects when they are away from the sun are still unconstrained. In this study, we use the 3.6-m Canada-France-Hawaii Telescope (CFHT) to search for small Kreutz comets at low solar elongation (~50 deg) on several nights from September 2012 to January 2013. We are able to cover ~10 sq. deg per night to g~22.5, a limiting magnitude that should be able to reveal small SOHO-size Kreutz members, according to the brightening rate proposed by Knight et al. (2010, AJ, 139, 926). Preliminary result will be presented in this talk.

413.14 – Manifestations of Cometary Activity

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Cometary activity can leave its imprints on nuclear parameters as well as on the coma structure. The investigation of such processes will allow us to learn about the activity itself as well as about the nucleus and coma processes and properties. We will discuss two such examples. (a) Investigation of rotational changes of four comets shows an interesting empirical relationship between cometary activity and rotational changes (Samarasinha and Mueller, 2013, submitted for publication). We will discuss the implications of this relationship. (b) The brightness profiles of gas jets in the coma of comets help us understand the nature of activity that generates these features. We will present the results for CN jets of comet 103P/Hartley 2 and discuss the ramifications. This work is supported by the NASA Planetary Atmospheres grant NNX12AG56G.

413.15 – Repeatability of the Dust and Gas Morphological Structures in the Coma of Comet

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Comet 1P/Halley is the most famous comet in history and has been observed for over two millennia, making it one of the most extensively studied comets. The morphology in the coma of comet 1P/Halley originates due to the activity at the nucleus and could be used as a probe of the nuclear rotation and the activity. We will present the results from a study summarizing the evolution of coma morphology of comet 1P/Halley observed from ground between October 1985 and June 1986. The results to be presented include analysis of dust features as well as gas (CN) features in the coma and comparisons will be made between their spatial and temporal evolution. About 80 CN images and 300 continuum images from the Small Bodies Node of the NASA Planetary Data System were analyzed using image enhancement techniques that were not available in the 1980s. This enables us to see coma structure never observed before in comet 1P/Halley. Because of the comet's proximity to Earth, most of our best signal-to-noise images were taken in the March-April interval of 1986. Despite the limited coverage of preceding and following months, there is a sufficient number of images to monitor morphological evolution over many months. The initial synodic periods as a function of time used to phase the images together were extrapolated from the lightcurves of the active coma (Schleicher et al. 1990, AJ, 100, 896-912). We will present the periods of repeatability of individual coma features measured using the position angle at different spatial distances from the nucleus in adjacent cycles. Separate features appear to have slightly different periods of repeatability, perhaps depending on the corresponding source regions on the nucleus and/or projection effects. The periods of repeatability of coma morphologies will be presented as a function of time from the perihelion. These results will ultimately be used in detailed modeling of the coma morphologies of comet 1P/Halley over the 1985-1986 apparition in order to characterize the activity of the comet. This work is supported by NASA Planetary Atmospheres grant NNX11AD85G and C.L.'s participation at the meeting is supported by a gift to the Lunar and Planetary Laboratory at the University of Arizona.

413.16 – PRE- AND POST-PERIHELION OBSERVATIONS OF C/2009 P1 (GARRADD): EVIDENCE FOR AN OXYGEN-RICH HERITAGE?

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We present pre- and post-perihelion observations of Comet C/2009 P1 (Garradd), on UT 2011 October 13 (heliocentric distance Rh = 1.83 AU) and 2012 January 8 (Rh = 1.57 AU), respectively, using the high-resolution infrared spectrometer (NIRSPEC) on the Keck II 10-m telescope on Mauna Kea, HI. On October 13, we obtained production rates for nine primary volatiles (native ices): H2O, CO, CH3OH, CH4, C2H6, HCN, C2H2, H2CO, and NH3. On January 8, we obtained production rates for three of these (H2O, CH4, and HCN) and sensitive upper limits for three others (C2H2, H2CO, and NH3). CO was enriched and C2H2 was depleted, yet C2H6 and CH3OH were close to their current mean values as measured in a dominant group of Oort cloud comets. We compare the composition of Garradd with other CO-rich comets C/1999 T1 (McNaught-Hartley), C/1996 B2 (Hyakutake), and C/1995 O1 (Hale-Bopp), and with other comets in our database. We discuss possible implications regarding the processing history of its pre-cometary

ices. Our measurements of C/2009 P1 indicate consistent pre- and post-perihelion abundance ratios for trace species relative to H2O, suggesting we were measuring a homogeneous composition to the depths sampled in the nucleus. The overall gas production was lower post-perihelion despite its smaller heliocentric distance on January 8. This is qualitatively consistent with other studies of C/2009 P1. On October 13, the water profile showed a pronounced excess towards the Sun-facing hemisphere that was not seen in other molecules nor in the dust continuum. Inter-comparison of profiles from October 13 permitted us to estimate the fraction of all H2O released in the coma and contained within our slit. We attribute this excess H2O to release from relatively pure, water-rich icy grains. Similar evidence for extended release was not observed on January 8 and this, together with its overall lower gas production post-perihelion, suggests loss of one or more active regions on the nucleus, perhaps resulting from depletion of volatiles and/or a seasonal change in pole orientation affecting the degree of insolation received locally on the nucleus.

413.17 – Revealing the Volatile Abundances in Comet C/2012 F6 (Lemmon) From Ground-based Observations

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Comets are comprised of molecular ices that may be pristine interstellar remnants of Solar System formation, along with high-temperature crystalline silicate dust that is indicative of a more thermally varied history in the protosolar nebula [1]. Comparing abundances of cometary parent volatiles and isotopic fractionation ratios to those found in the interstellar medium, in disks around young stars, and between cometary families, is vital to understanding planetary system formation and the processing history experienced by organic matter in the so-called interstellar-comet connection. Recently, there have been complimentary observations from multiple facilities to try to unravel the chemical complexity of comets. We report spectral observations of C/2012 F6 (Lemmon) from the Arizona Radio Observatory's Submillimeter Telescope and the Atacama Pathfinder Experiment. Multiple parent volatiles (e.g. HCN, CH3OH, CO) as well as a number of daughter products (e.g. CS) have been detected at multiple transitions from these facilities. Previous work has revealed a range of abundances of parent species (from "organics-poor" to "organics-rich") with respect to water among comets [2,3,4], however the statistics are still poorly constrained and interpretations of the observed compositional diversity are uncertain. We will compare the molecular abundances of F6 to a broad range of comets from diverse dynamical families and chemical compositions, supporting our long-term effort of building a comet taxonomy based on composition. [1] Wooden 2008, SpSciRev., 138, 75. [2] DiSanti, M. A., & Mumma, M. J. (2008), Space Sci. Rev., 138, 127. [3] Mumma, M. J. and Charnley, S.B. (2011), ARA&A, 49, 471. [4] Crovisier, J. et al. (2009) Earth, Moon Planet, 105, 267.

413.18 – Ethane (C2H6), Methane (CH4), and Carbon Monoxide (CO) in the Coma of Comet C/2006 W3 (Christensen) Beyond 3.2 AU from the Sun

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We applied a new generation of fluorescence models developed for CH4 (this work), C2H6 (Villanueva et al. 2011, JGR 116:E08012), and CO (Paganini et al. 2013, ApJ 766:100) to emission spectra from comet C/2006 W3 (Christensen) observed at 3.25 AU from the Sun, acquired with the Cryogenic Infrared Echelle Spectrograph (CRIRES) at the Very Large Telescope (VLT) Observatory (Paranal, Chile). The infrared detections of CH4 and C2H6 are unique since these species have no permanent dipole moments and therefore have no allowed pure rotational transitions. The infrared detections of CO provide the capability for rotational temperature extraction from multiple rovibrational lines, measured simultaneously. We present spatial intensity distributions along with updated production rates and mixing ratios for the detected volatiles. Although their column abundances are substantially smaller than for CO, emission lines for CH4 and C2H6 are very strong owing to their high fluorescence efficiencies and very low rotational temperatures. The new CO model revealed that significant optical depth affected the CO line intensities, so we also developed and applied models for radiative transfer in an optically thick coma. The retrieved CO production rate is an order of magnitude higher than values measured in a number of comets observed when much closer to the Sun. We compare our results with those from space (Herschel) and ground-based radio studies (Bockelee-Morvan et al. 2010, A&A, 518:L149), and with the CO2 and CO production rates from AKARI (Ootsubo et al. 2012, ApJ 752:15). Together, these studies provide a synergistic overview of volatile production in this comet. We gratefully acknowledge support by NSF's Astronomy and Astrophysics Research Grants Program (Bonev/Gibb), by NASA's Planetary Astronomy (Mumma; DiSanti), Planetary Atmospheres (DiSanti; Villanueva), and Astrobiology (Mumma) Programs, by the NASA Postdoctoral Program (Paganini), and by the German-Israel Foundation for Scientific Research and Development (Böhnhardt).

413.19 – Radio OH observations of Comet C/2011 L4 PANSTARRS

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We obtained 18cm OH spectra of comet C/2011 L4 PANSTARRS between 15 February and 10 May 2013, using the Arecibo Observatory 305m Gordon Telescope and the National Radio Astronomy Observatory 100m Green Bank Telescope (GBT). Spectra were obtained at 1667 and 1665 MHz (18cm wavelength) with a beam resolution of 2.9 arcminutes at Arecibo and 7.4 arcminutes at GBT, which, at geocentric distances of 1.1 to 1.6 AU corresponds to over 140,000 km at the comet. Heliocentric distances ranged between 0.4 and 1.5 AU, so that the OH coma generally filled no more than 20% of the observed beam and permitted snapshots of the gas production. At the same time, velocity resolution of 69 m/s for Arecibo or 219 m/s for GBT provide a closer look at the line-of-sight gas dynamics. Due to the low heliocentric distances, the OH coma was unusually variable over short timescales, and outflow velocities were generally more than 1 km/s. We will present the 1667 MHz spectra compared to Monte Carlo simulations for all observed dates, along with the derived best-fit outflow velocities and gas production rates.

413.20 – The Puzzle of Hydrogen Cyanide in Comets: Is HCN a Product or is it a Primary Species?

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Hydrogen cyanide has long been regarded as a primary volatile in comets, stemming from its supposed storage in the cometary nucleus. Here, we examine the evidence for that hypothesis, and argue that HCN may instead result from near-nucleus chemical reactions in the coma. The distinction (product vs. primary species) is important for multiple reasons: 1. HCN is often used as a proxy for water when the dominant species (H2O) is not available for simultaneous measurement, as at radio wavelengths. If a product species, the adoption of HCN as a water proxy could introduce unwanted bias to taxonomies based on composition. 2. HCN is important as one of the few volatile carriers of nitrogen accessible to remote sensing, NH3 being the dominant nitrile. If a product species, the precursor of HCN becomes the more important metric, for a taxonomic classification based on nitrogen chemistry. 3. The stereoisomer HNC is regarded as a product species, suggested to result from coma chemistry involving HCN. But, could another reaction of a primary precursor (XCN) with a hydrocarbon co-produce both HNC and HCN? 4. The production rate for CN greatly exceeds the possible production from HCN in some comets, demonstrating the presence of another (more important) precursor of CN radical. 5. The production rates of HCN measured through rotational (radio) and vibrational (infrared) spectroscopy agree in some comets, but in others the infrared rate exceeds the radio rate substantially. 6. With its strong dipole moment and H-bonding character, HCN should be linked more strongly in the nuclear ice to other molecules with similar properties (H2O, CH3OH), but instead its spatial release in some comets seems strongly coupled to volatiles that lack a dipole moment and do not form H-bonds (methane, ethane). We will present the evidence for these and other points, and suggest ways to test the primary and product origins of cometary HCN. This work was supported by NASA's Planetary Astronomy, Planetary Atmospheres, and Astrobiology Programs.

413.21 – Global 3D kinetic model of cometary rarefied atmosphere toward a description of the coma of Comet 103P/Hartley 2

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The recent images from the Deep Impact spacecraft at Comet 9P/Tempel 1 and from its extended mission EPOXI at Comet 103P/Hartley 2 showed heterogeneous gas release from the nucleus with multiple jets and complex active areas. The coma structure of a comet with such active areas differs from typical models where gas is often produced more uniformly from the surface of the nucleus. While 2D kinetic models are already able to describe relatively complex gas production and can give some critical insights of the physics of the coma, most of them assume cylindrical symmetry around the Sun-Nucleus axis preventing to model small active areas and solar orientations not aligned with the symmetry axis. With constantly increasing computer capacities, 3D kinetic models can now be implemented to give a complete insight from the near nucleus region of the coma where collisions drive its thermodynamics to larger distances where the atmosphere becomes rarefied. We describe a fully 3D kinetic Direct Simulation of Monte Carlo approach to modeling the coma, and a first application to enable progress toward a general tridimensional description of the rarefied atmosphere of Comet Hartley 2 from Fougere et al. (2013) with realistic day-night illumination not only with respect to the EPOXI geometry at closest approach but for other observations. [This work was supported by grant NNX09AB58G from the NASA Planetary Atmosphere program.]

413.22 – The volatile composition of comet 103P/Hartley 2 from ground-based radio observations

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103P/Hartley 2 (103P) is a Jupiter-family comet which has a short orbital period (6.5 years) and perihelion at 1.06 AU. 103P was discovered on 4 June 1984 by Malcolm Hartley at the Siding Spring Observatory and has been frequently observed over the 20 years following its discovery, both by ground-based and space telescopes. Observation from 1991 and 1997 indicated a maximum water production rate of 3 x 10^28 molecules/s. 103P passed perihelion on 28 October 2010 at q = 1.059 AU. It made an exceptional close approach to the Earth just before perihelion on 21 October 2010 at Δ = 0.12 AU. On UT 2010 November 4.58, the comet was visited by NASA's EPOXI spacecraft with a flyby at 700 km. As part of an ongoing investigation to establish the contribution of the natal molecular cloud from which the solar system was formed to primitive materials and comets, we have been conducting observations toward the comet 103P to determine taxonomy and cosmogonic quantities, such as the ortho:para ratio and isotope ratios. Here we report detections of HCN, H2CO, CS, and OH and upper limits on HNC and DCN toward comet 103P, using the Arizona Radio Observatory Kitt Peak 12m (12m) and submillimeter telescopes (SMT), the James Clerk Maxwell Telescope (JCMT) and the Greenbank Telescope (GBT). From these data physical parameters such as temperature, column densities, and production rates have been determined toward comet 103P. The ortho:para ratio has been derived from H2CO. We used the JCMT data to compute the D/H ratio from DCN and HCN. Here we present our analysis and discuss the origin of volatiles in cometary material.

413.23 – CO DETECTIONS IN 29P/SCHWASSMANN-WACHMANN 1 AT 6.21 AU USING NIRSPEC

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We obtained observations of Comet 29P/Schwassmann-Wachmann 1 on UT 2013 June 20 (heliocentric distance 6.21 AU) using the high resolution spectrometer (NIRSPEC) on the Keck II 10-m telescope on Mauna Kea. At this time, 29P had been in outburst and had displayed a significantly expanded coma for more than one week (since UT 2013 June 12). We have clear detections of five CO lines, obtained simultaneously. We present the production rate and rotational temperature for CO, and compare them with previous high resolution spectroscopic observations obtained at 6.26 AU (Paganini et al. 2013). Additionally, we compare CO production with recent sublimation models of 29P that predict CO-driven activity.

413.24 – A New Analysis of Spitzer Thermal Images of Comet 29P/Schwassmann-Wachmann 1

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29P/Schwassmann-Wachmann 1 (SW1) is a unique comet or Centaur circling the Sun just outside the orbit of Jupiter, with one of the lowest eccentricity of all known comets. Knowledge of cometary nuclear properties and the nuclear behavior are crucial in the effort to improve modeling of coma morphology, thermal evolution, and nuclear structure, providing a link to the nuclear properties of other observed comets. We present a reanalysis of Spitzer Space Telescope thermal observations of SW1 taken on UT 2003 November 21 and 24. The comet was not in CO-outburst during the time of observations. The analysis is similar to that done by Stansberry et al. [1,2], but with data products generated from the latest Spitzer pipeline. Photometry of the nucleus was performed for each image after a variety of coma removal processes were implemented to extract the nuclear point-source contribution to each image. SW1 has been identified in Spitzer's IRAC (5.8 μm, 8.0 μm) and MIPS (24 μm, 70 μm) images; the 5.8 μm detection has not been reported earlier. We will present the measured flux densities and present the results from applying the Near Earth Asteroid Thermal Model (NEATM, [3]), yielding the nuclear effective radius and constraints on the thermal inertia. We will also compare our results to previously published estimates of the nuclear properties. References: [1] J. A. Stansberry et al. 2004, Ap. J. Supp. 154, 436. [2] J. A. Stansberry et al. 2008, In 'The Solar System Beyond Jupiter' (M. A. Barucci et al., eds.), 161-179. [3] A. W. Harris, 1998, Icarus 131, 291. We acknowledge funding support from NASA's Outer Planets Research program (grant NNX12AK50G). This work is based on observations made with the Spitzer Space Telescope, which is operated by JPL/Caltech under contract with NASA.

413.25 – Observations of Comet 2P/Encke During the Fall 2013 Apparition

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We will present preliminary results from our observational campaign of Comet 2P/Encke during its 2013 perihelion passage. At optical wavelengths Encke is an extremely dust poor comet that has in past perihelion passages emitted a gas jet in the form a sunward fan. We expect to characterize both the morphology and lightcurve of the comet. The low optical dust means that even near perihelion the nuclear signature can be obtained in lightcurve data taken with narrowband continuum filters which cut out the gas emission. The campaign will consist of both narrowband and broadband imaging as well as infrared spectroscopy. Imaging will be obtained from 8 nights on the KPNO 2.1m between Sept. 7 and 14 UT. Additionally, the Murillo Family Observatory, a 0.5m telescope on the CSUSB campus which is equipped with both broadband filters and a narrowband Hale-Bopp set of filters will be used to observe the comet every clear night the moon allows between late August and early October to obtain extensive lightcurve data. These data will overlap both the Kitt Peak observations and the infrared spectroscopy which will be obtained with the SpeX instrument at the IRTF on four nights between September 26 UT and October 2 UT.

413.26 – Hydrogen addition reactions of aliphatic hydrocarbons in comets

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Comets are thought as remnants of early solar nebula. Their chemical compositions are precious clue to chemical and physical

evolution of the proto-planetary disk. Some hydrocarbons such as C2H6, C2H2 and CH4 in comets have been observed by using near-infrared spectroscopy. Although the compositions of C2H6 were about 1% relative to the water in normal comets, there are few reports on the detection of C2H6 in ISM. Some formation mechanisms of C2H6 in ISM have been proposed, and there are two leading hypotheses; one is the dimerizations of CH3 and another is the hydrogen addition reactions of C2H2 on cold icy grains. To evaluate these formation mechanisms for cometary C2H6 quantitatively, it is important to search the C2H4 in comets, which is the intermediate product of the hydrogen addition reactions toward C2H6. However, it is very difficult to detect the C2H4 in comets in NIR (3 microns) regions because of observing circumstances. The hydrogen addition reactions of C2H2 at low temperature conditions are not well characterized both theoretically and experimentally. For example, there are no reports on the reaction rate coefficients of those reaction system. To determine the production rates of those hydrogen addition reactions, we performed the laboratory experiments of the hydrogenation of C2H2 and C2H4. We used four types of the initial composition of the ices: pure C2H4, pure C2H2, C2H2 on amorphous solid water (ASW) and C2H4 on ASW at three different temperatures of 10, 20, and 30K. We found 1) reactions are more efficient when there are ASW in the initial compositions of the ice; 2) hydrogenation of C2H4 occur more rapid than that of C2H2.

413.27 – Hyper-volatiles in Comet C/2010 G2 (Hill)

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We performed high-dispersion near-infrared spectroscopic observations of comet C/2010 G2 (Hill) at 2.5 AU from the Sun using NIRSPEC (R ~ 2.5x10^4) at the Keck II telescope on UT 2012 Jan 9 and 10. The comet had been in outburst. Over the two nights of our observations, prominent emission lines of CH4 and C2H6 along with weaker emission lines of H2O, HCN, CH3OH and CO were detected. The gas production rate of CO was comparable to that of H2O. The mixing ratios of CO, HCN, CH4, C2H6, and CH3OH with respect to H2O are higher than those for normal comets by a factor of five or more. Hyper-volatile species such as CO and CH4 were enriched in the coma of comet Hill suggesting that the sublimation of these hyper-volatiles could sustain the outburst of the comet. Based on a comparison with optical observations, some fraction of water in the inner coma existed as icy grains. Those icy ice grains were likely ejected from nucleus by the sublimation of hyper-volatiles.

413.28 – Insights into Collisional between Small Bodies: Comparison of Impacted Magnesium-rich Minerals

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Impacts are sustained by comets and asteroids throughout their lives, especially early in the Solar system's history, as described by the Nice model. Identifying observable properties that may be altered due to impacts can lead to a better understanding their collisional histories. Here, we investigate spectral effects and physical shock features observed in infrared spectra and Transmission Electron Microscope (TEM) images, respectively, of magnesium-rich minerals subjected to shock through impact experiments. Samples of magnesium-rich forsterite (Mg_2SiO_4, olivine), orthoenstatite (Mg_2SiO_3, pyroxene), diopside ($MgCaSi_2O_6$, monoclinic pyroxene), and magnesite ($MgCO_3$, carbonate) were impacted at speeds of 2.4 km/s, 2.6 km/s and 2.8 km/s. Impact experiments were conducted in the Johnson Space Center Experimental Impact Laboratory using the vertical gun. Clear signatures are observed in both the mid-IR spectra (shift in wavelengths of the spectral peaks and relative amplitude changes) of all minerals except magnesite, and in TEM images (planar dislocations) of both the forsterite and orthoenstatite samples. Further discussion on forsterite and enstatite analyses can be found in Jensen et al., this meeting. Funding was provided by the NASA PG&G grant 09-PGG09-0115, NSF grant AST-1010012, and a Cottrell College Scholarship through the Research Corporation.

413.29 – Micrometeorite Impact Effects on Comets and Asteroids: Peak Pressure versus Spectral Variation

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At the Experimental Impact Laboratory at NASA Johnson Space Center, we have investigated the surface properties of asteroids caused by collisions in the mid-infrared (2.5 to 16 microns) by impacting forsterite and enstatite across a range of velocities (as predicted by the Nice Model) and at varying temperatures. The crystal structure in these minerals can be deformed by the shock wave from the impact as well as sheared into smaller particle sizes. Our current focus is on the differing effects between 2.3 and 2.6 km/sec, as well as the differences between a cold sample at -20C and a room temperature sample at 25C. We find that the spectral variation and crystal deformation varies non-linearly with the peak theoretical shock pressure. Funding was provided by the NASA PG&G grant 09-PGG09-0115, NSF grant AST-1010012, and a Cottrell College Scholarship through the Research Corporation.

413.30 – Search for the Return of Activity in Active Asteroid 176P/LINEAR

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We report the results of an optical search for the return of activity in Comet 176P/LINEAR during its 2011 perihelion passage using the University of Hawaii 2.2m, Gemini North, Subaru, and Keck I telescopes on Mauna Kea, Pan-STARRS1 on Haleakala, and ESO's NTT and VLT at La Silla and Paranal. Discovered to be active in 2005, 176P was recognized at the time as the third-known main-belt comet, which are objects which exhibit comet-like dust emission indicative of the presence of sublimating ice, yet occupy stable orbits in the main asteroid belt. Recent discoveries of asteroids which appear comet-like due to impact-generated ejecta clouds (or disrupted asteroids) have complicated the classification of observationally comet-like asteroids (or active asteroids) as main-belt comets, since it is now apparent that apparent comet-like activity alone is not a sufficient indicator of the presence of volatile material. Repeated cometary activity after a period of inactivity is currently considered to be one of the strongest indicators that activity is sublimation-driven. However, despite covering the same orbital arc over which the object was observed to be active in 2005, our 2011 observations of 176P reveal no indication that the object was active during this time. Detailed one-dimensional surface brightness profile analyses show no evidence of coma down to an approximate upper limit mass loss rate of 0.02 kg/s, lower than its estimated mass loss rate of approximately 0.07 kg/s when it was active in 2005. We also find no evidence of a photometric excess during the 2011 perihelion passage, measuring an average absolute R-band magnitude of 15.11 for the nucleus between June and September 2011, compared to average absolute R-band magnitudes of 14.80 between November and December 2005 during which visible activity was present, and 15.09 during our entire set of observations between 2006 and 2013 during which no visible activity was present. We will discuss the implications of these observations and consider whether active asteroid 176P is best characterized as a likely main-belt comet or disrupted asteroid.

413.31 – 3200 PHAETHON: IMPLICATIONS OF A UNIQUE POLE SOLUTION AND THERMAL MODELING

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3200 Phaethon is the parent body of the Geminid meteor stream, yet its activity mechanism remains debated. A pole solution is an important physical parameter used in thermal modeling for assessing the survival of volatiles and thus potential activity mechanisms forming the Geminids. We will present time-series photometry of 3200 Phaethon obtained on 15 nights from 1994 to 2004 primarily using the Tek2K CCD camera on the University of Hawaii 2.2m telescope. The data were obtained at four distinct ecliptic longitudes, allowing us to derive a pole solution of λ=98.4° and β= -15.7° with a refined rotation period of P=3.60277+/-0.00001 hours using the light-curve inversion software convexin. We applied the criteria presented in Durech et al. 2009 for using convexin to derive unique and accurate pole solutions with limited photometry datasets. Additionally, we input our pole solution

into a semi-implicit, one-dimensional thermal model to create maximum, minimum, and mean surface temperature maps as a function of latitude on the surface of 3200 Phaethon. We will discuss the implications of these surface temperature variations and also present results form deep searches for faint residual dust in the orbit of 3200 Phaethon.

413.32 – A Physical Model of Phaethon, a Near-Sun Object

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Physico-chemical modeling is central to understand the important physical processes that occur in small solar system bodies. We have developed a computer code, SUSEI, that includes the physico-chemical processes relevant to comets within a global modeling framework to better understand observations and in situ measurements and to provide valuable insights into the intrinsic properties of their nuclei. SUISEI includes a 3D model of gas and heat transport in porous sub-surface layers in the interior of the nucleus. We have successfully used this model in our study of previous comets at normal heliocentric distances [e.g., 46P/Wirtanen, D/1993 F2 (Shoemaker–Levy 9)]. We have adapted SUISEI to model near-Sun objects to reveal significant differences in the chemistry and dynamics of their comae (atmosphere) with comets that don't closely approach the Sun. At small heliocentric distances, temperatures are high enough to vaporize surface materials and dust, forming a source of gas. Another important question concerns the energy balance at the body's surface, namely what fraction of incident energy will be conducted into the interior versus that used for sublimation. This is important to understand if the interior stays cold and is relatively unaltered during each perihelion passage or is significantly devolatilized. This also bears upon the regimes where sublimation and ablation due to ram pressure dominate in the erosion or eventual destruction of sun-grazers. The resulting model will be an important tool for studying sungrazing comets and other near-Sun objects. We will present results on the application of SUISEI to the near-Sun object, Phaethon. Acknowledgements: We appreciate support from the SwRI IR&D and the NSF Planetary Astronomy Programs.

413.33 – Up a Cliff: Further Evidence of Scarp as Jet Source Area on Comet 9P/Tempel 1

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We measured the radial near-surface centerline radiance profiles of three well-defined dust jets in the Stardust-NExT dataset of Comet 9P/Tempel 1. The three chosen jets are the most prominent of the seven jets suspected of originating from a long scarp on the surface of the comet based on stereoimaging and limb crossing [1]. We estimated background radiance by averaging three radial near-surface radiance profiles distributed about the illuminated hemisphere of the comet in areas not known to source a jet according to [1], which we subtracted from the radiance profiles of the three chosen jets to estimate the intrinsic radiance of each jet. These background radiance profiles closely follow a logarithmic function: rad = 0.2716 – 0.035 ln (h), where rad is the calibrated radiance and h is height above the surface, with $R^2 = 0.99$. In contrast, the three jets' radiance follows power laws: rad = 1.5329 $h^{-0.644}$, rad = 1.3592 $h^{-0.641}$, and rad = 0.6327 $h^{-0.625}$ with R^2 values of 0.97, 0.98, and 0.89 respectively. The similarity in the exponents of the power laws suggests that these three jets have similar source regions, material, driving gases, and fragmentation mechanics, which strongly suggests that these jets originate from a common surface feature, such as the suspected scarp. Furthermore, the fundamentally different behavior exhibited by the background and the jets (power law vs. logarithm), suggests that the jets are formed by processes distinct from that of the global background emission. This indicates that jets originate from distinct active areas, and are not merely a result of topography or orography as described in [2]. Lastly, we measured three radial profiles in the noisy region between the seven suspected scarp jets, but did not find compelling evidence that this background emission behaves as either purely background (logarithm) or purely jet (power law). Further investigation may clarify the nature of this emission. References: [1] Farnham, T.L. et al. (2013) Icarus 222, 540-549 [2] Crifo, J.F. et al. (2002) Earth, Moon, and Planets 90, 227-238

414 – TNOs and Centaurs Posters

414.01 – Ordering Mean Motion Resonances with the Farey Tree: Application to the Kuiper Belt

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Mean motion resonances play an important role in sculpting the orbital structure of small body populations within planetary systems and in determining the dynamical interactions of planets in multi-planet systems. A p:q mean motion resonance occurs when the orbital period of one body in the resonant system is p/q times the orbital period of another body. In perturbation theory for small planet masses and low eccentricities and inclinations, the 'order' of a mean motion resonance is |p-q|, with small values of |p-q| corresponding to stronger resonances than large values of |p-q|. However, we find that |p-q| is a poor predictor of resonance occupation in the Kuiper belt. Instead we find that the Farey tree, an ordering of the rational fractions on the interval (0,1) first described by British geologist John Farey in 1816, provides a more useful ordering of Neptune's mean motion resonances. This is likely because the Farey tree orders the resonances in terms of their relative isolation from neighboring mean motion resonances. We present a description of the Farey tree and show its usefulness in predicting which of Neptune's mean motion resonances are occupied by observed objects.

414.02 – A Divot in the Size Distribution of the Kuiper Belt's Scattering Objects?

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The scattering objects are a small-body population of the Kuiper Belt undergoing strong (scattering) interactions with the giant planets. The scattering objects can come to pericentre in the giant planet region. This close-in pericentre passage allows for the observation of smaller objects, and thus for the constraint of the small-size end of the size distribution. Our recent analysis of the Canada France Ecliptic Plane Survey's scattering objects revealed an exciting potential form for the scattering object size distribution – a divot. Our divot (a sharp drop in the number of objects that then recovers) matches our observations well and can simultaneously explain observed features in other inclined (so-called "hot") Kuiper Belt populations. In this scenario all of the hot populations would share the same source and have been implanted in the outer solar system through scattering processes. If confirmed, our divot would represent a new exciting paradigm for the formation history of the Kuiper Belt. Here we present the early results of an extension of our previous work to include two new Kuiper Belt surveys. We expect an additional few scattering objects from these surveys which, in tandem with the full characterizations of their biases (which can act like non-detections limits), will allow us to better constrain the form of the scattering object size distribution.

414.03 – Color Distribution of excited TNOs in HST's Frontier Fields

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We are carrying out a study of small excited TNOs in HST's Frontier Fields. We will coadd light from two-orbit visits accounting for TNOs' motion, increasing our sensitivity. We expect colors for 10-50 very faint TNOs. Comparison of this population's color distribution and the distribution of larger objects will indicate whether the break in the size distribution is collisional or primordial. In this poster we will present the software development and preliminary results.

414.04 – Rotational variability in medium and large sized TNOs.

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Trans-Neptunian objects (TNOs) are considered some of the most pristine objects in the Solar System. Their surfaces display a wide range of compositions, going from surfaces covered by dark irradiation mantels, to surfaces totally covered by ices. According to models of the retention of volatiles, only TNOs with a diameter d $\gtrsim$ 1000 km are expected to retain any of their original complement of volatile ices on their surface. However, surface refreshing processes on smaller bodies (e.g., collisions, transient atmospheres and cometary activity) could bring to the surface some amount of ices that are stable at depth. When these processes affect only part of the surface they cause surface heterogeneity. The study of rotational variability of medium and large sized TNOs is important to better understand the physical processes affecting their surfaces, and if these processes are local in scale or, on the contrary, extend across the whole surface. We present rotationally resolved spectroscopy of two TNOs, (20000) Varuna and (136472) Makemake. Varuna is a medium sized TNO (d~621 km). We observed Varuna with NICS@TNG telescope, in the NIR, covering two entire rotations of the object. The analysis of the data shows a homogeneous surface composed of a mixture of complex organics, silicates and water ice. Our data also indicate an upper limit of 10% of methane ice on the surface. The Dwarf Planet Makemake is also studied in this work. The surface of this large TNO shows that, similar to Pluto and Eris, it clearly retains large amounts of volatile ices. Moreover, thermal observations indicate that Makemake has a heterogeneous surface that could be the result of volatile migration. We present new visible spectra of Makemake, obtained with ISIS@WHT telescope, covering 80% of the surface. We present a detailed study of the differences in the absorption bands across the surface that are indicative of changes in the relative abundances of ices, temperature, and/or particle size. Moreover, we collect all data available from literature, after 8 year from the discovery of Makemake, and compare with our data to investigate possible rotational and secular variations.

414.05 – Preliminary Results On The Surface Composition Of Centaurs From IRAC/Spitzer Photometry

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Centaurs are a population of icy bodies with probable origin in the trans-Neptunian region. They move in orbits with semimajor axes and perihelia between the orbits of Neptune and Jupiter. The visible colors of the Centaurs show a clear bimodality that divides them into the gray and the red groups. The origin of this peculiar distribution is under debate. It is not yet clear whether the color bimodality is related to their origin or if it is a result of the surface processes that affect the Centaurs. In both cases, these colors are directly related to the surface composition of these bodies, and it is suggested that is a result of variations in the ratio between silicate and organic abundances. Our hypothesis is that the color bimodality extends at wavelengths (λ) longer than 2.5 μm. The aim of this work is to test if the gray group corresponds to objects covered by mantles of silicates, while the red objects are covered, at least in part, by complex organics. The organic materials are typically characterized by an absorption at λ~3 μm that lies within the bandpass of the IRAC 3.6 μm filter. We observed 40 Centaurs with Spitzer/IRAC, at 3.6 and 4.5 μm, in cycles GO2, 4, 6 and GO8. Here, we compare these colors with reflectance values derived from synthetic models. Models of the reflectance from surfaces composed by mixtures of ices, organics and silicates show a wide range of colors at these wavelengths. Thus, measurements of colors of icy bodies beyond 2.5 μm are a very effective tool to study their surface. Of particular note, silicates and organics have very different reflectance at $\lambda > 3$ μm. We also correlate the colors in the visible and the new colors in the IR to test our hypothesis of the existence of color bimodality also in this wavelength range.

414.06 – New Scattered Disk Object and Centaur Colors

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We report B, V, and R magnitudes for scattered disk objects and centaurs from observations taken in December 2011 and August 2013 using the Lowell Observatory Perkins Telescope with PRISM and observations taken in March 2012 at the Vatican Advanced Technology Telescope (VATT) on Mt. Graham, Arizona. Targeted scattered disk objects include 2002 CY224, 2003 UY117, 2006 QJ181, 2008 CT190, 2009 YG19, 2010 FD49, 2010 VZ98. Targeted centaurs include 2002 QX47, 2005 UJ438, 2006 UX184, and 2007 RH283. We will determine if the resultant centaur colors follow the bimodal distribution (B-R either red or gray) previously detected. We will also compare the resultant scattered disk object colors to those published for other scattered disk objects. This work is based on observations with the Perkins Telescope at Lowell Observatory, and with the VATT: The Alice P. Lennon Telescope and the Thomas J. Bannan Astrophysics Facility.

414.07 – 29 November 2011 Stellar Occultation by 2060 Chiron: Symmetric Jet-like Features

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On 29 November 2011 UT, 2060 Chiron occulted a R=14.93 star; data were successfully obtained at the 3-m NASA Infrared Telescope Facility (IRTF) on Mauna Kea and 2-m Faulkes North Telescope at Haleakala. The IRTF lightcurve shows a solid-body detection of Chiron's nucleus with a chord duration of 16.0 ± 1.4 seconds, corresponding to a chord length of 158 ± 14 km. Symmetric, dual extinction features in the Faulkes light curve indicate the presence of optically thick material roughly 300 km from the body midpoint. The duration of the features indicates a 3 ± 2 km feature separated by 10-14 km from a second 7 ± 2 km feature. The symmetry, optical thickness, and narrow size of these features allow for the intriguing possibility of a near-circular arc or shell of material.

414.08 – Status of the Transneptunian Automated Occultation Survey (TAOS II)

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The Transneptunian Automated Occultation Survey (TAOS II) will aim to detect occultations of stars by small (~1 km diameter) objects in the Transneptunian region and beyond. Such events are very rare (< 10^{-3} events per star per year) and short in duration (~200 ms), so many stars must be monitored at a high readout cadence. TAOS II will operate three 1.3 meter telescopes at the Observatorio Astronómico Nacional at San Pedro Mártir in Baja California, México. With a 2.3 square degree field of view and high speed cameras comprising CMOS imagers, the survey will monitor 10,000 stars simultaneously with all three telescopes at a readout cadence of 20 Hz. In this presentation, we will describe the project in detail and discuss the progress on the development of the survey infrastructure.

414.09 – Probing The Outer Solar System Small Bodies With Stellar Occultations

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MIOSOTYS (Multi-object Instrument for Occultations in the SOlar system and TransitorY Systems) is a multi-fiber positioner coupled with a fast photometry camera. This is a visitor instrument mounted on the 193 cm telescope at the Observatoire de Haute-Provence, France. Our immediate goal is to characterize the spatial distribution and extension of the Kuiper Belt, and the physical size distribution of TNOs. We present the observation campaigns during 2010-2013, objectives and observing strategy. We report the detection of potential candidates for occultation events of TNOs. We will discuss more specifically the method used to process the data and the modelling of diffraction patterns.

414.10 – OSSOS: The New Era of Precision Planetary Cosmogony

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Contributing teams: the OSSOS Collaboration
The last two decades of discovery in the Kuiper belt have shown the essential need for surveys of the outer Solar System to have full characterisation of their biases, and to be attentive to the recovery and quality of the orbits of their discoveries. The known well-characterised trans-Neptunian objects (TNOs) inadequately challenge the current models of how giant planet formation and migration sculpted the small-body populations of the outer Solar System. We have designed OSSOS, a survey that will use 560 hours of CFHT time over four years to provide on the order of a thousand new TNOs with exquisitely characterised, high-precision orbits. This will double the known population of TNOs that are usable for testing models. Our first semester of observing confirms that our expected rate of discoveries are being found in our initial two survey areas. Each 21 square degrees, these survey areas were placed to sample the dynamically cold and the dynamically hot populations, and imaged to our survey depth of m_r ~ 24.5. We will discuss the implications of these initial results for the TNO populations.

414.11 – An Unusually Shaped Haumea Family Member

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2013 EL61 Haumea is a 2000 km-scale, fast-spinning Kuiper belt object covered in water ice, but with a bulk density near 2.5 g/cc implying a rocky interior. Approximately a dozen Kuiper belt objects (KBOs) have been identified as possibly related to Haumea in that they share similar orbital properties and have unusually fresh, icy surfaces similar to the water-ice mantle covering the latter. These KBOs are usually referred to as the Haumea family. Sparse photometry of one of the family members, 2003 SQ317, revealed an interesting high photometric variability. We followed up on those observations and used the NTT in La Silla to obtain dense, time-resolved photometry of SQ317 over two semesters. Analysis of the lightcurve indicates a spin period P=7.2 hr and a photometric range equal to 0.9 mag. We will present implications of this lightcurve to the object's shape and bulk density.

414.12 – Involving Citizen Scientists to Measure Trans-Neptunian Objects

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The Research and Education Cooperative Occultation Network (RECON) is an innovative citizen science project that will involve over 40 communities from Arizona to Washington to collect occultation data to determine the sizes of trans-Neptunian objects (TNOs). In particular, the network will measure sizes of both isolated and binary cold classical Kuiper Belt Objects (KBOs). Current uncertainties in TNO positions and stellar astrometry limit accurate occultation predictions for TNOs. To address this challenge, RECON will establish a "picket-fence" of observers every 50 km spread over a 2,000-km baseline. A pilot network of fourteen communities north and south of Reno, Nevada (from Tulelake, CA to Tonopah, NV) has been established as a proof-of-concept study for this project. Teachers, amateur astronomers, and community members from these the region were recruited via emails, phone, and face-to-face visits during two road-trips in Fall 2012. The strong response from these rural communities traditionally lacking in STEM resources has allowed us to enhance the number of participating sites from ten to fourteen. Telescope and camera equipment was tested and delivered to each community in Winter 2013. In April, representatives from each community brought this equipment to a 4-day intensive training workshop in Carson City. To demonstrate the effectiveness and integrity of the network, RECON will have conducted five coordinated occultation campaigns by the end of August involving Pluto as well as several main belt asteroids. Our presentation will describe challenges and successes associated with recruiting, preparing, and retaining citizen scientists from rural communities to conduct authentic astronomy research. We will also highlight efforts to engage both teachers and students in the scientific and engineering practices outlined in the Next Generation Science Standards. Finally, we will report on the initial results from initial occultation campaigns and next steps. The project is funded by the National Science Foundation through an Astronomy and Astrophysics Research Grant (AST-1212159). Visit http://tnorecon.net for more information.

415 – Origins Posters

415.01 – Regional Source of the Earth-Moon Progenitors

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Many studies have been performed with regards to the formation of the Moon via the Giant Impact theory. However, few of these studies have probed where the giant impactor likely originated and fewer have investigated variations upon the initial orbital state of such an impactor. E. J. Rivera [PhD thesis Stony Brook Univ. 2002] began an investigation assuming the Solar System to consist of 5 inner planets, initially, where 2 experienced an encounter to produce the Earth-Moon system. We extend this investigation using updated numerical techniques along with a more general parameter space. We delineate the regions where the Earth-Moon progenitors likely originated in a Solar System-like initial configuration of giant planets. Future extensions of this work will also be discussed, including consideration of a debris rich environment and an alternate initial configuration of giant planets akin to the Nice model.

415.02 – Formation of multiple-satellite systems from circumplanetary particle disks

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In the solar system, most of the planets have satellite systems around them. In systems with a single satellite such as Earth-Moon system, satellite mass is relatively high compared to the host planet's mass. On the other hand, giant planets such as Jupiter, Saturn have multiple-satellite systems. Generally, their inner major satellites called regular satellites exist outside their Roche limit with relatively small mass ratio to the host planet. Those inner satellites are on nearly circular prograde orbits with low inclination. Formation of large regular satellites of Jupiter and Saturn has been explained by accretion in a circumplanetary gas disk (Canup & Ward 2009). On the other hand, it has been recently shown that regular satellites of Saturn, Uranus and Neptune can be formed from a circumplanetary particle disks within the Roche limit (Crida & Charnoz 2012). Formation of satellites from those particle disks was first studied in the context of lunar formation (Ida, S., et al., 1997). Initially, particles are distributed within the Roche limit and their accretion is prohibited. Then, the disk spreads with time. As the disk spreads and the disk materials diffuse beyond the Roche limit, the materials start to form gravitationally bound aggregates. In the case of relatively massive disk, a large single satellite is its outcome (Ida, S., et al., 1997). However, if the initial disk is less massive, the viscosity of the disk is low and the time scale of disk diffusion is much longer. These aspects expect to lead to the different outcomes. Crida and Charnoz (2012) developed an analytic model for the formation of multiple satellites from a circumplanetary particle disk, with the assumption that the mass flow through the Roche limit is constant. Their model successfully explains the characteristics of the masses and orbits in the satellite systems of Saturn, Uranus and Neptune. However, the details of the evolution of less massive disk are still unclear. In the present work, we perform N-body simulations in order to see the evolution of less massive circumplanetary particle disks, and show that another satellite is secondly formed from a residual disk after the formation of the first satellite.

415.03 – The Evolution and Survival of Gaseous Protoplanets Embedded in a Disk

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We model the pre-collapse evolution of newly-formed protoplanets at various radial distances when the presence of the protoplanetary disk, and gas accretion are included. Using three different disk models, it is found that a Jupiter-mass protoplanet at radial distance less than 5-10 AU cannot undergo a dynamical collapse and evolve further to become a gravitational bound giant planet. As a result, we conclude that giant planets, if formed by disk instability mechanism, must form and remain at large radial distances during the first ~10^5-10^6 years of their evolution. The minimum radial distances in which protoplanets of 1 Saturn-mass, 3 and 5 Jupiter-mass protoplanets can evolve using a disk model with M_dot=10^-6 M_Sun/yr and alpha=10^-2 are found to be 12, 9, and 7 AU, respectively. While the exact radial distance for which contraction is no longer possible depends on the assumed disk model, it is clear from the models that the presence of the surrounding disk has an important effect on the planetary evolution, and that the pre-collapse timescale can be significantly longer at smaller radial distances. We next investigate the effect

of gas accretion on the planetary evolution assuming three different accretion rates. It is found that gas accretion can shorten the pre-collapse timescale substantially. Our study suggests that the timescale of the pre-collapse stage does not only depend on the planetary mass, but is greatly affected by the presence of the disk and on the efficiency of gas accretion. Our findings are in good agreement with previous research, but for the first time, are based on planetary evolution considerations. Finally, this study demonstrates the importance of including the presence of the disk and gas accretion when modeling the evolution of young gaseous protoplanets.

415.04 – Transport of C- and O-bearing volatiles in protoplanetary disks: implications for the formation of carbon-rich planets

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We explore the possibility of forming a giant planet with an atmospheric C/O ratio higher than that of its parent star. To do so, we use a transport model of major gaseous and solid C- and O-bearing volatiles that is based on the simultaneous dynamical evolution of their snowlines. The model takes into account the effects of aerodynamics of solid particles in presence of turbulence, in addition to the processes of sublimation, condensation, accretion and coagulation. The coupling of this transport model to a turbulent accretion disk model allows tracking of the solid particles and gases of major C- and O-bearing volatiles and the evolution of their respective snowlines. This allows us to compute the C/O ratios in planetesimals formed under various disk and gas phase conditions.

415.05 – Effect of a gaseous transition disc on planetesimal driven migration

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The latter stages of the formation of the solar system are believed to involve the migration of planets as a result of the gravitational interaction between these and a massive, remnant, outer planetesimal disc. In this paper we present a series of numerical simulations aimed at understanding the effect of a transition, gaseous, protoplanetary disk, on the dynamics of planets and planetesimals in this period and on the resulting solar system architecture. Starting from an initial compact configuration of the outer planets, as that used in the so-called Nice model, we find that gas drag leads to very efficient, and relatively fast, planetesimal capture in low order resonances with the outermost ice giant. We discuss the implications of our results and argue that, if the solar nebula passed through a transition disc phase lasting a few million years, our results suggest the need to revise current planetesimal driven migration and planet formation scenarios.

415.06 – Vortex Formation in Vertically Stratified Protoplanetary Disks

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A central problem of planet formation is how to form large planetesimals in a turbulent protoplanetary disk. Recent work suggests that MRI turbulence would excite such large velocities that the planetesimals would collisionally fragment rather than grow. The structure of chondritic meteorites indicates a gentle nebular environment where chondrules are sorted by size and cemented together rapidly. Although it is well established that anticyclones can concentrate particles that are weakly coupled to the gas in protoplanetary disks, the conditions required for the formation and long-time stability of anticyclones in a vertically stratified disk are still highly uncertain. Fully three dimensional fluid dynamic simulations of protoplanetary disks are computationally expensive when one requires a computational domain that is large compared to the vertical scale height of the disk. An alternative simulation approach is to use potential temperature as the vertical coordinate so that the equations of motion resemble the shallow water equations (Dowling et al. 1998). We have therefore modified a multilayer shallow water simulation code to model the formation of vortices in a vertically stratified protoplanetary disk with a radial entropy gradient. Vertical stratification of the disk is modeled by using multiple layers, where each layer has a different constant value of the entropy. By forcing a slope in the interfaces between the layers, we impose a radial entropy gradient in the disk. Radiative heating and cooling causes vertical mass exchange between adjacent constant entropy layers according to a Newton cooling formula. We find that the formation of anticyclones is robust, and that these vortices actively excite density waves, which in turn, transport angular momentum through the disk. Our simulations therefore yield new insights on how the dusty dead zones of protoplanetary disks can transport angular momentum through the disk by purely hydrodynamic processes. Support from NASA's Origins of Solar Systems program is gratefully acknowledged.

415.07 – Primary Accretion and Turbulent Cascades: Scale-Dependence of Particle Concentration Multiplier Probability Distribution Functions

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Primitive bodies with 10s-100s of km diameter (or even larger) may form directly from small nebula constituents, bypassing the step-by-step "incremental growth" that faces a variety of barriers at cm, m, and even 1-10km sizes. In the scenario of Cuzzi et al (Icarus 2010 and LPSC 2012; see also Chambers Icarus 2010) the immediate precursors of 10-100km diameter asteroid formation are dense clumps of chondrule-(mm-) size objects. These predictions utilize a so-called cascade model, which is popular in turbulence studies. One of its usual assumptions is that certain statistical properties of the process (the so-called multiplier pdfs p(m)) are scale-independent within a cascade of energy from large eddy scales to smaller scales. In similar analyses, Pan et al (2011 ApJ) found discrepancies with results of Cuzzi and coworkers; one possibility was that p(m) for particle concentration is not scale-independent. To assess the situation we have analyzed recent 3D direct numerical simulations of particles in turbulence covering a much wider range of scales than analyzed by either Cuzzi and coworkers or by Pan and coworkers (see Bec et al 2010, J. Flu. Mech 646, 527). We calculated p(m) at scales ranging from 45-1024 η where η is the Kolmogorov scale, for both particles with a range of stopping times spanning the optimum value, and for energy dissipation in the fluid. For comparison, the p(m) for dissipation have been observed to be scale-independent in atmospheric flows (at much larger Reynolds number) for scales of at least 30-3000η. We found that, in the numerical simulations, the multiplier distributions for both particle concentration and fluid dissipation are as expected at scales of tens of η, but both become narrower and less intermittent at larger scales. This is consistent with observations of atmospheric flows showing scale independence to >3000η if scale-free behavior is established only after some number N~10 of large-scale bifurcations (at scales perhaps 10x smaller than the largest scales in the flow), but become scale-free at smaller scales. Predictions of primitive body initial mass functions can now be redone using a slightly modified cascade.

415.08 – Building a Planetesimal: low-velocity collisions between centimeter sized proto-planetesimals

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Planetesimals grow through either collisional aggregation from smaller bodies or local gravitational instabilities. Collisional growth must be rapid enough for planetesimals to form before the smaller constituent pieces spiral into the central star due to gas drag. Furthermore, the impact velocities in the collisions can be high enough to disrupt the accreting aggregates. We model colliding rubble-piles using a collisional N-body simulation to determine the collisional parameters in the binary pair-wise accretion between proto-planetesimals. The model includes inter-particle gravitational attraction and electrostatic adhesion. This surface adhesion can be many orders of magnitude stronger than gravity. We wish to understand and characterize the effects of collisions on silicate rubble-piles and determine under what conditions adhesion allows small particles to grow through collisional aggregation. We use laboratory data to constrain the physical properties of the silicate aggregates, allowing for a more realistic study of the collisional variables involved in the outcomes of accreting 1 – 100 cm aggregates at impact speeds of 1 – 100 cm/s. We show that binary accretion of silicate aggregates through a meter in size is possible provided collision velocities are sufficiently low. We present the first results from this study showing the outcomes of collisions between 1 – 100 cm aggregates made up of 1 mm sized or larger spherical particles. We use the prescription for adhesion forces between spheres in JKR theory (Johnson et al. 1971, Proc. R. Soc. Lond. 304.301), and present the results of an initial exploration of collision parameter space to identify those collisions that can lead to growth of meter-sized objects. We will extend this work to the growth of km-sized planetesimals from meter-sized objects including both adhesion and gravity.

415.09 – Dynamics of Colliding Clusters of Millimeter Sized Adhesive Particles

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There are still many questions associated with the process of building planets from the dust of protoplanetary disks. We present the results of simulations of small patches of clusters of millimeter sized spheres. The clusters are on the order of a centimeter in radius. Some simulations use clusters formed as regular lattices of uniform spheres while others use clusters formed by letting a cold distribution naturally accrete. Separate work by Whizin et al. looks at how two clusters behave when they collide given different impact velocities, magnitudes of the adhesive force, and coefficients of restitution. In this work, we scale up to thousands of these clusters to explore how effective the adhesive force is at causing the clusters to accrete into larger structures. For numerical purposes, the initial clusters all start in the orbital plane because simulation times don't allow following the system for multiple orbits to allow particles to pass through the plane repeatedly. A single order of magnitude in either the impact velocities or the adhesive force leads to dramatic changes in the outcome of the simulations. A discussion of the building efficiency of occasional low velocity impacts in a distribution where most impacts are destructive is included.

415.10 – Fast Formation of Giant Planets by Photophoresis

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Giant planets consist of a solid core with a large gaseous envelope. Their formation can be divided into three phases. In the first phase a planetary core of about 5 earth masses forms. The last phase is runaway accretion of gas from the protoplanetary disk. In the second phase the core accretes gas from the surrounding environment together with planetesimals. Accretion of material heats the planetary atmosphere, while thermal radiation cools it down. The planetary atmosphere is in a hydrostatic equilibrium, which determines the accretion rate for the gas. Inward drifting planetesimals are subject to erosion and entrain large amounts of dust into the planetary atmosphere, together with primordial dust, which is accreted together with the gas. This strongly increases the opacity of the atmosphere, which prevents efficient cooling via thermal radiation. The atmosphere therefore heats up severely, which directly leads to a strong pressure increase. The larger pressure reduces significantly the possible accretion rate for the gas. The lifetime of gaseous protoplanetary disks is about 10 million years, so all gas giants have to form within this timescale. Such timescales are not reached, if the accretion rate is reduced by the opacity of the atmosphere. Within this work we present photophoresis as a mechanism, which is capable of clearing the inner part of the planetary atmosphere from dust. Photophoresis is based on the interaction between gas and particles. Dust particles are heated on one side by thermal radiation from the inner part and the induced temperature gradient leads to an outward directed net-force. We find that the drift timescales from the inner part to the outer atmosphere are much shorter than the formation timescales of giant planets. As the inner part of the atmosphere is cleared from dust, the opacity drops and thermal radiation cools down the system. This can lead to a strong increase of the accretion rate and therefore shorten the timescales for gas accretion significantly.

415.11 – Promises and Problems of Pebble Accretion

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Despite the large number of exoplanets indicating that giant planets are a common outcome of the star formation process, theoretical models still struggle to explain how ~10 Earth mass rocky/icy embryos can form within the lifetimes of gaseous circumstellar disks. In recent years, aerodynamic-aided accretion of ``pebbles,'' particles ranging from millimeters to decimeters in size, has been suggested as a potential solution to this long-standing problem. Local simulations, simulations which look at the detailed behavior of these pebbles in the vicinity of a planetary embryo, have shown that the potential planetary growth rates can be surprisingly fast. If one assumes that most of the mass in a protoplanetary disk resides in these pebble-sized particles, a Mars mass core could grow to 10 Earth masses in only a few thousand years. However, these local studies cannot investigate how this accretion process behaves in the more complicated, multi-planet environment. We have incorporated the local accretion physics into LIPAD, a Lagrangian code which can follow the collisional / accretional / dynamical evolution of a planetary system, to investigate the how this pebble accretion will manifest itself in the larger planet formation picture. We present how these more comprehensive models raise challenges to using pebble accretion to form observed planetary systems.

415.12 – Water and OH in Protoplanetary Disks Irradiated by FUV and X-rays

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We present an integrated thermal-chemical model for the atmosphere of the inner region of a protoplanetary disk that includes irradiation by both far ultraviolet (FUV) and X-ray radiation. The focus is on how the photodissociation of water and OH affects the abundances of these and related species and on how it contributes to the heating of the atmosphere. The dust in the atmosphere plays several important roles, primarily as the site of H2 formation and by absorbing the FUV. Large amounts of water are synthesized within the inner 4 AU for a standard model of the disk around a classical T Tauri star, in which the dust surface area is 20 times smaller than interstellar dust. In this case, OH is found primarily at the top of a warm region where the gas temperature is 650 - 2000K and water below it where the temperature is lower, 250 - 650K. The amounts of water and OH and their temperatures are in agreement with recent Spitzer measurements and support the notion of it in situ production of water in the inner regions of protoplanetary disks. The synthesized water is effective in shielding the disk midplane from stellar FUV radiation. Reducing the grain surface area by another factor of 10 significantly reduces the amount of water due to decreases in both the attenuation of the FUV and in the production of H2. Diversity in the extent of grain growth and settling among disks may thereby lead to diversity in their emission properties.

415.13 – N-Body Simulations of Low-Velocity Impact Experiments

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During the early stages of planet formation, collisions in the protoplanetary disk were dominated by small particles with collision velocities extending from 10's of m/s down to a fraction of a m/s. Similar collisions occur at the present epoch in planetary ring systems at the slow end of the velocity range. In order to simulate these collisions numerically we use a hard sphere N-body collisional integrator. Here we report on the testing, calibration, and validation of this collisional model through comparison with experiment. We have carried out a series of low-velocity impact experiments into a bed of spherical 2-mm diameter beads and a series of numerical simulations that replicate the experimental conditions. We have tried several different models for the coefficient of restitution in order to match the experimental results with the N-body simulator. We find that a simple analytic prescription for the coefficient of restitution cannot reproduce the observed distribution of ejecta launch angles, launch positions, and launch velocities. However, introducing a normal distribution in the values of the coefficient of restitution around a velocity-dependent mean value produces good agreement between simulation and experiment. We suggest that this distribution helps capture the variations introduced by small-scale surface roughness on the particles that is otherwise unresolvable by the simulation. Such stochastic models of the coefficient of restitution may be used in other collisional N-body simulations of planetary ring systems. The results of this work will also allow us to simulate planetismal aggregation through collisional growth.

415.14 – Formation of regular satellites from the spreading of massive rings : Why some planets have one moon and other have many ?

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Around giant planets, the regular satellites pile-up at a distance of a few planetary radii, their masses increasing with the distance to the pile-up. In contrast, terrestrial bodies are dominated by one large satellite (the Moon for the Earth, Charon for Pluto). Here we show that both cases can be understood in the frame of a new paradigm for satellite formation : the spreading of a debris disk initialy confined inside the Roche radius of the planet (a « tidal disk »). By definition, beyond the Roche radius, solids aggregate and accrete, forming new moons. Those moons then migrate outward, repelled by the disk. We find that if the life-time of the disk is short (the spreading is fast), then accretion is faster than migration and all the material gathers into one large satellite. If the life-time of the disk is long, many satellites form and migrate away ; merging events take place during the migration, so that the mass should be proportional to the distance to the Roche radius to the power 9/5 . This is in good agreement with the distribution of the inner satellites of Saturn, Uranus, and Neptune. Relating the life-time of the disk to its mass ratio to the planet, we find that a debris disk around a giant planet should give birth to many satellites, while the Moon forming disk should give birth to one large satellite of about one lunar mass, possibly with a smaller companion as recently suggested to explain the lunar highlands5.

416 – Enceladus Posters

416.01 – Enceladus Near-Fissure Surface Temperatures

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Recently reported Cassini VIMS observations of thermal emission from the Enceladus south-pole fissures (Goguen et al. 2013) when combined with previous longer wavelength Cassini CIRS observations (Spencer et al. 2006) allow us to better constrain the highest temperatures present, but also require more detailed modeling of the processes which control those highest temperatures. The simplest interpretation of the VIMS observations is that the 3-5 μm thermal radiation comes from the walls within a fissure, rather than the adjacent surface. But as part of investigating that latter alternative it became clear that very high sublimation rates are implied by some predicted surface temperatures. Abramov and Spencer (2009) produced models of the expected surface temperature distribution, assuming conduction of heat through the ice, balanced by thermal radiation at the surface. However as temperature is raised, at 186K sublimation cooling equals radiation, and because it depends exponentially on temperature, it quickly dominates. We have found that including the surface sublimation cooling suppresses the higher temperatures. Regardless of the fissure temperature, surface temperatures above 200K can only be maintained by conduction within a few tens of centimeters of the assumed fissure wall. The high sublimation erosion rates (0.25 m/yr at 180K, rising to over 100 m/yr at 220K) imply that the fixed boundaries we have previously assumed are unrealistic. If these surface temperatures are maintained then either a sublimation lag of non-ice components will accumulate, inhibiting sublimation, or the geometry of the fissure vent will rapidly change. However the rate of change will be limited by the available heat provided by conduction. We are now developing numerical models with moving boundary conditions to explore the time evolution. The simplest result may be that the lip of the fissure erodes back till it no longer remains in thermal contact with the rising vapor which maintains the high fissure temperatures. Ingersoll and Pankine (2010) have explored the importance of vapor/ice equilibrium within the fissure. Those same physical principles will also control the surface temperature near the fissures.

416.02 – Direct Monte Carlo Simulations of Gas Flow from Enceladus' Nozzle-like Vents

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Collective observations by the Cassini spacecraft indicate that the gas plumes emanating from Enceladus' south pole contain micrometer sized ice grains that travel at speeds 50-80% lower than the bulk gas speed (Kempf et al., 2008, Hedman et al., 2009, Teolis et al., 2010). Previous studies indicate the difference in velocity originates below the surface, and the gas flow to the surface occurs supersonically suggestive of nozzle like vents (Schmidt et al., 2008, Hansen et al., 2011). Here we use a 2D Direct Monte Carlo Simulation (DSMC) technique (Bird, 1994) to model gas flow and grain acceleration in nozzle like fissures for Enceladus' vent geometries. First, we use the DSMC technique to model the transition of the gas flow from inside the highly collisional vent to a couple of meters above the surface where the gas flow becomes essentially collisionless. Then the DSMC results for gas density, temperature and velocity are used with an equation of motion for the drag force on a grain entrenched in a gas. The flow is tracked in both the vertical direction from the vent opening, and the radial direction from the vent axis. It is impossible to consider every type of vent geometry, but using Cassini data for grain sizes and velocities within the plumes we consider a few vent geometries of different width, length, and opening angle with respect to the surface. The Enceladus vents are not likely to be axially symmetric, but the simulations provide insight into possible vent geometries, and the effect of the vent wall geometry on gas flow and grain acceleration for suggested plume water production rates (0.5 – 1×10^{28} s^{-1}) inferred using Cassini data (Tenishev et al., 2010). We obtain density and velocity distributions at the vent exit for the gas and grains that can serve as parameters for plume models and be used as comparisons for interpretation of various Cassini measurements. Kempf, S., et al., 2008, Icarus 193, 2. Hedman, M.M., et al., 2009, AJ 693. Teolis, B.D., et al., 2010, JGR 115. Schmidt, J., et al., 2008, nature 451. Hansen, C.J., et al., 2011, GRL 38. Bird, G.A., 1994, Oxford University Press. Tenishev, V., et al., 2010, JGR 115.

416.03 – The Source of CO_2 Ice on Enceladus' Surface

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Traces of CO_2 ice have been found on Enceladus' surface (Brown et al., 2006 p. 1427 [1]). We suggest that the CO_2 came from subsurface pockets of gas. Such pockets are a natural consequence of the hydrothermal circulation of Enceladus' gas-rich ocean water [2]. Ocean water rises through fissures in the icy crust and brings heat and chemicals to the surface. Near the surface the water flows horizontally below the relatively thin cap ice before returning to the ocean. The horizontal flow allows some of the CO_2 bubbles in the seawater to raise and collect as gas pockets in irregularities along the bottom of the cap ice. Subsequent fissuring (e.g., as suggested by Hurford et al. [3]) at irregular intervals allows the gas to escape to the surface where it can condense as CO_2 ice and is seen by Cassini VIMS. This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. [1] Brown R. H. et al., Science 311, 1425-1428, 2006. [2] Matson D. L. et al., Icarus 221, 53–62, 2012. (also see Matson et al. LPS 44 Abstract 1371, 2013). [3] Hurford T. A. et al., Nature 447, 292-294, 2007.

416.04 – Silica nanoparticles as an evidence of hydrothermal activities at Enceladus

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Silica serves as a unique indicator of hydrothermal activities on Earth as well as on Mars. Here we report the Cassini Cosmic Dust Analyser (CDA) observation of nanosilica particles from the Saturnian system. Based on their interaction with the solar wind electromagnetic fields, these charged nanosilica particles, so-called stream particles, are found to be dynamically associated with Saturn's E ring, indicating Enceladus being their ultimate source. Their metal-free composition as well as the derived confined size range (2-8 nm in radius) indicate a hydrothermal synthesis origin. The observation of Saturnian nanosilica particles thus serves as a strong evidence of hydrothermal activities at the subsurface water reservoir in the geologically active moon Enceladus. Considering plasma erosion as the major mechanism of releasing embedded nanosilica particles from the E ring grains, our dynamical model and the CDA observation provide a lower limit on the average nanosilica concentration in E ring icy grains. This can be translated into constraints on the hydrothermal activities on Enceladus. In light of the latest hydrothermal experiments, the derived silica concentration of the water reservoir indicates that the hydrothermal reactions most likely take place with a pristine, chondritic rock composition at temperature higher than 150 degree C. The inferred pH range is consistent with colloid silica formation conditions as well as the results derived from the E ring ice grain composition. The presence of the nanosilica particles indicates the existence of a warm, slightly basic, and saline water reservoir at the interior of Encleadus.

416.05 – Enceladus Close Up: New Details Recovered from Cassini ISS Boresight-Drag Images

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Among the many Cassini ISS (Imaging Science Subsystem) images of Enceladus are a few severely-underexposed, motion-blurred images that were acquired on "boresight-drag" events on the closest flybys. During boresight-drags, ISS is statically aimed at a point that intercepts the predicted path of Enceladus' across the sky. The ISS Narrow angle (NAC) and Wide Angle (WAC) cameras are repeatedly triggered together in hope of serendipitously capturing a close-up "BOTSIM" image-pair of the body as it passes.

Because the events are so fast, the surface footprints and lighting geometry cannot be predicted in advance – a cascade of images are just quickly shuttered at the minimum 5 msec exposure. On each of four boresight-drags, surface images were captured. However, the two most recent (image-pair W/N1669812043 in November 2010 and W/N1713106405 in April 2012, respectively) were poorly illuminated – three of four images only in Saturnshine. Despite their poor signal quality, they are rare images of Enceladus' surface obtained with spatial resolutions better than a few meters/pixel. Careful use of Fourier filtering and spatial reconstruction techniques was needed to eliminate image noise and residual electronic banding that was not removed during routine radiometric calibration of the images. Fourier motion debluring techniques were then applied to correct for significant motion smear. Images W/N1669812043 (55.1°N, 20.2°W) are in old cratered terrain, inside a prominent 23 km sized impact crater along the rise of its updomed floor. They show a system of parallel ~250m wide mesas trending around the dome's circumference. Smooth detritus inundates mesas and valleys near the dome summit and the mesa surfaces are otherwise mantled with regolith that is finely cratered down to the ~2 m/pixel NAC resolution limit. W/N1713106405 (66.9°S, 29.5°W) show the chaotically fractured margin of the active South Polar Terrain – an area divided by parallel ridges and troughs with relatively smooth flanks and valley floors. Quasi-linear arrangements of ice-blocks, each block tens of meters or smaller, are found mostly near ridge-tops.

416.06 – Modeling a close-up observation of Enceladus by Cassin/VIIMS with layered water ice

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We have been working on layered water ice models that fit the measured spectra of Enceladus by the Cassini Visual and Infrared Mapping Spectrometer (VIMS). Our original inspection using two observations (equatorial and South Pole) showed that good fits could be made using fractional monolayers of 2-μm frost over 20 μm for the polar ice and about 1 monolayer of 1-μm frost over 7 μm for the equatorial ice. We then ran ~200 general models that could be used for any analysis. We found that with small misfits around 1.5 and 2.5 μm, that the whole infrared spectrum 0.8-5.2 μm could be adequately fit by single layer models. The mosaic studied was observed on 14 July 2006, and extended from just above the equator to the sunlit south pole, and from 140-150 W to 230 W longitudes, crossing the leading-trailing boundary. The observations are all in high resolution mode, with a finest resolution of 4 by 8 km, but more typically 6 by 12 km. The modeling shows that the trailing side observed is uniformly r=5-7 μm base grain size with ~one monolayer of r=1 μm ice. This grades gradually to r=20 or more μm and a fractional (~0.1) monolayer of r=2 μm ice. The south polar terrains are similar to the leading side pattern, except in the center of the tiger stripes where there is no layering and unresolved (requiring mixing of two grain sizes) grain radii close to 500 μm. This layering is due to Enceladus orbit in the E-ring of micron sized water ice particles whose source is the geysers on Enceladus' south pole. The low latitude grain size patterns do not agree well with band-depth studies, which find the grain size related to geology (Jaumann et al., 2008, Icarus 193, 407). We do not observe the whole globe here, so the patterns could be semi-hemispherical similar to ring dynamics models show (Kempf et al., 2010, Icarus 206, 446).

417 – Other Icy Satellites Posters

417.01 – Interpreting the Thermal Lightcurve of Iapetus at 1.3mm

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Saturn's moon Iapetus is distinguished by a clearly defined hemispherical difference in geometric albedo, ranging from 0.03-0.4 over its disk [1,2]. The resulting expected large temperature (and hence thermal flux) variations with longitude make it interesting to study the object's thermal light curve. By using continuum data obtained in 2011 with the Submillimeter Array (SMA) at 1.3 mm (230 GHz), flux measurements of 0.069+/-0.004 Jy (bright side) and 0.089+/-0.011 Jy (dark side) were obtained. By converting the flux to brightness temperature and assuming a standard emissivity value of 0.9, disk-averaged surface temperatures were derived. The optically darker hemisphere has a temperature of 91.9 +/- 11.7 K, while the bright hemisphere has a temperature of 63.939 +/- 3.4 K. This temperature difference at 1.3 mm confirms the presence of a thermal dichotomy in the subsurface (~1 cm depth) of Iapetus, which has already been observed on the surface by mid-IR thermal measurements [2]. We will demonstrate how the measured temperature variation can be related to the hemispheric albedo difference and other geographical variations of surface properties. [1] Morrison et al., 1975, Icarus 24, p. 157-171 [2] Blackburn et al., 2011, Icarus 212, p. 329-338

417.02 – Photometric Properties of Thermally Anomalous Terrain on Icy Saturnian Satellites

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Spectral maps of thermal emission from Mimas obtained by Cassini's Composite InfraRed Spectrometer (CIRS) show that a V-shaped boundary, centered at 0° N and 180° W, divides relatively warm daytime temperatures from an anomalously cooler region at low to mid-latitudes on the leading hemisphere (Howett et al. 2011 Icarus 216, 211). This cooler region is also warmer at night, indicating that it has high thermal inertia, and also coincides in shape and location with that of high-energy electron deposition from Saturn's magnetosphere (Roussos et al. 2007 JGR 112, A06214; Schenk et al. 2011 Icarus 211, 740). Global IR/UV color ratio maps assembled from Cassini Imaging Science Subsystem (ISS) images revealed a lens-shaped region of relatively blue terrain centered on the leading hemisphere (Schenk et al. 2011, Icarus). The area with low IR/UV ratio also coincides in shape and location with the region of high thermal inertia. A preliminary photometric analysis of Cassini ISS CL1 CL2 filter (centered at 611 nm) images using the Hapke (2008) model suggests that the high thermal inertia region on Mimas is rougher and more strongly backscattering than terrain with lower thermal inertia. Particles on the surface of the thermally anomalous terrain may have a more complex microtexture due to the high-energy electron bombardment. This work is supported by the NASA Cassini Data Analysis Program.

417.03 – Cassini CIRS characterization of icy moon surface composition

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Compositional studies of Saturn's icy moons were one of the original science goals for Cassini's Composite Infrared Spectrometer (CIRS) [1], but to date they have received less attention than measurements of atmospheres, surface temperatures and thermophysical properties across the Saturn system. Recent Cassini Visual and Infrared Mapping Spectrometer (VIMS) data have shown tantalizing evidence of possible organic molecules and metals on several Saturnian moon surfaces [e.g., 2,3], but the stronger fundamental absorptions in the mid-IR would allow confirmation of these constituents and more specific identifications. The spectral region covered by CIRS focal planes 3 and 4 is rich in emissivity features due to both simple and complex molecules [4], but the study of emissivity variations in this region is often challenged by low signal to noise ratios for individual spectra. We present an approach to average CIRS spectra from the full icy moon dataset on the Planetary Data System to increase signal-to-noise and use emissivity spectra to constrain surface compositions. A first look at CIRS spectra averaged over the dark terrain of Iapetus is presented. Preliminary results show that averaging greatly reduces noise in radiance and emissivity spectra, revealing a potential spectral feature that does not correspond to any known instrument artifact. We are working to identify it as a possible non-ice contribution to Iapetus' surface composition. [1] Flasar, F.M., et al. (2004), Exploring the Saturn system in the thermal infrared: The Composite Infrared Spectrometer, Space Sci. Rev., 115, 169–297. [2] Brown, R.H., et al. (2006), Composition and physical properties of Enceladus' surface, Science, 311, 1425–1428. [3] Clark, R.N., et al. (2012), The surface composition of Iapetus: Mapping results from Cassini VIMS, Icarus, 218, 831–860. [4] Hand, K.P., Chyba, C.F., Priscu, J.C., Carlson, R.W. & K.H. Nealson (2009), Astrobiology and the Potential for Life on Europa. In Europa. Eds. R. Pappalardo, W. McKinnon, & K. Khurana. Univ. of AZ Press.

417.04 – Hydrocarbons and other organic materials on Iapetus: Revised analysis

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We present a revised quantitative analysis of the hydrocarbon and other organic molecular inventory in the low-albedo material of Saturn's satellite Iapetus, based on a revision of the calibration of the Cassini VIMS instrument. Our study uses hyperspectral data from a mosaic of Iapetus' surface (Pinilla-Alonso et al. 2012, Icarus 215, 75-82) constructed from VIMS data on close fly-bys of the satellite. We extracted >2000 individual spectra of the low-albedo regions, and with a clustering analysis tool (Dalle Ore et al. 2012, Icarus 221, 735-743) separated them into two spectrally distinct groups, one concentrated on the leading hemisphere of Iapetus, and the other on the trailing. This distribution is broadly consistent with that found from Cassini ISS data analyzed by Denk et al. (2010, Science 327, 435-439). We modeled the average spectra of the two geographic regions using the materials and techniques described by Clark et al. (2012, Icarus 218, 831-860), and extracted the residual (Iapetus/model) in the interval 2.7-4.0 μm for analysis of the organic molecular bands that occur in this spectral region. These bands are the C-H stretching modes of aromatic hydrocarbons at ~3.28 μm (~3050 cm-1), plus four blended bands of aliphatic -CH2- and -CH3 in the range ~3.36-3.52 μm (~2980-2840 cm-1). In these data, the aromatic band, probably indicating the presence of polycyclic aromatic hydrocarbons (PAH), is unusually strong in comparison to the aliphatic bands, as was found for Hyperion (Dalton et al. 2012, Icarus 220, 752-776; Dalle Ore et al. 2012 op. cit.) and Phoebe (Dalle Ore et al. 2012 op. cit.). Our Gaussian decomposition of the organic band region suggests the presence of molecular bands in addition to those noted above, specifically bands attributable to cycloalkanes, olefinic compounds, CH3OH, and N-substituted PAHs. Insofar as the superficial layer of low-albedo material on Iapetus originated in the interior of Phoebe and was transported to Iapetus (and Hyperion) via the Phoebe dust ring (Tamayo et al. 2011, Icarus 215, 260-278), the organic inventory we observe is likely representative of a body that formed in the transneptunian region prior to its capture by Saturn.

417.05 – Looking for Dione's Volatiles with Cassini's Ultraviolet Imaging Spectrograph

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The Cassini UltraViolet Imaging Spectrograph (UVIS) has been used successfully to detect Europa's oxygen atmosphere, and the water vapor plume jetting from Enceladus. We have used the same observational techniques to search for volatiles emanating from Dione. The first report that Dione has a molecular exosphere signature came from the Cassini magnetometer team [1] who reported the detection of mass-loading in Saturn's magnetosphere in the vicinity of Dione. Does Dione have water vapor jets similar to those of Enceladus? With UVIS we have observed a series of stellar occultations as is being done to investigate Enceladus' plume. Detecting a jet at Dione is more difficult – Dione's larger size means the gravitational pull is >2x Enceladus. It is less likely that the molecules will be on escape trajectories. That means that we are looking for a plume that will only be found relatively close to the surface. We roughly estimate that to detect a jet the star must intersect the surface somewhere within a 300 km radius of the source. So far we have observed 6 stellar occultations and have not found a definitive signature of a jet. There are 8 stellar occultations remaining in the Cassini Solstice Mission. The presence of a tenuous oxygen exosphere has been reported by the Cassini Plasma Spectrometer (CAPS) team [2]. The CAPS team estimates the minimum column density for Dione's O2 exosphere to be at least 0.9 to 7 x 10^11 cm^-2. We were able to detect the O2 atmosphere at Europa by looking for emission features at 130.4 nm and 135.6 nm. Using long integration observations of Dione we are unable to detect these emissions in the expected ratio, thus the O2 exosphere, so we can put an upper bound of 1.5 x 10^13 cm^-2 on the column density. With a range of 10^11 to <10^13, and in the absence of a jet detection, the O2 is most likely sputtered from the surface and not produced by endogenic processes similar to Enceladus. References: [1] Krishan, K. et al., (2007) AGUSM.P43A..03K; [2] Tokar, R. L. et al., (2012) GRL 39, L03105.

417.06 – Geologic Evolution of Saturn's Icy Moon Tethys

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Tethys, 1072 km in diameter, is a mid-sized icy moon of Saturn imaged for the first time in two Voyager flybys [1][2][3]. Since July 2004, its surface has been imaged by the Cassini ISS cameras at resolutions between 200 and 500 m/pxl. We present results from our ongoing work to define and map geologic units in camera images obtained preferentially during Cassini's Equinox and Solstice mission phases. In the majority of Tethys' surface area a densely cratered plains unit [1][2][3][this work] is abundant. The prominent graben system of Ithaca Chasma is mapped as fractured cratered plains. Impact crater and basin materials can be subdivided into three degradational classes. Odysseus is a fresh large impact basin younger than Ithaca Chasma according to crater counts [4]. Heavily degraded craters and basins occur in the densely cratered plains unit. A smooth, less densely cratered plains unit in the trailing hemisphere was previously identified by [2] but mapping of its boundaries is difficult due to varying viewing geometries of ISS images. To the south of Odysseus, we identified a cratered plains unit not seen in Voyager data, characterized by remnants of highly degraded large craters superimposed by younger fresher craters with a lower crater density compared to the densely cratered plains unit. Its distinct linear northern contact with the densely cratered plains suggests a tectonic origin. Sets of minor fractures can be distinguished in the densely cratered plains, and locally, features of mass wasting can be observed. References: [1] Smith B. A. et al. (1981), Science 212, 163-191. [2] Smith B. A. et al. (1982), Science 215, 504-537. [3] Moore J. M. and Ahern J. L. (1983), JGR 88 (suppl.), A577-A584. [4] Giese B. et al. (2007), GRL 34, doi:10.1029/2007GL031467.

417.07 – Comparison between Dione' and Enceladus' terrain units

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Dione has a diameter of 1122 km and a density of ϱ = 1.475 g/cm3. Most of Dione' surface is covered by the heavily cratered terrains, located mainly in the trailing hemisphere and crossed by high-albedo wispy streaks that are likely tectonic features. Enceladus has a mean diameter of 504 km and its surface appears to be completely made up of pure water ice. Form data acquired by Cassini spacecraft it was observed a present-day geologic activity coming from the South polar region. Plumes of micron-sized particles of water ice erupting from this region represent the major source of the E-ring. The VIMS spectrometer is able to acquire hyperspectral cubes in the overall spectral range from 0.3 to 5.1 μm. We select VIMS cubes of Dione and Enceladus in the IR range between 0.8 and 5.1 μm and we normalize all spectra at λ=2.232 μm in different illumination conditions effects. We apply a clustering technique to the spectra of each cube based on the supervised method Spectral Angle Mapper (SAM) to emphasize the presence of spectral units. The endmembers used by the SAM for the classification of each terrain type, were selected applying the unsupervised clustering technique k-means to the cubes with the highest spatial resolution. In particular, k-means technique identified nine endmembers for Dione. To summarize the result of the SAM classification, we projected classified cube's pixels on a Dione's cylindrical map. For both satellites, the infrared spectrum is dominated by the prominent signatures of H2O ice /OH bands at 1.5, 2.0 and 3.0 μm. We conclude that a classification method applied to VIMS hyperspectral data is crucial to understand geochemical processes taking place on the surface of the icy satellites. From our analysis we find that several spectral units on the two satellites are characterized by different values of the spectral indices, such as the water ice bands' depths, which are indicators of the water ice grain size and abundance. Particles of water ice coming from the E-ring, deposits on Dione's leading hemisphere, making this side of brighter than the trailing hemisphere. Therefore, a comparison between Dione and Enceladus spectra is crucial to quantify the effectiveness of this mechanism.

417.08 – Can Spatial Statistics Provide Another Approach to Understanding Impact Crater Saturation Equilibrium?

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For several decades there has been a debate whether heavily cratered surfaces in our solar system are in "saturation equilibrium" [e.g., 1-3; a state where crater density reaches an (quasi-) equilibrium]. Saturation equilibrium is critical to understand because otherwise the crater size-frequency distribution (SFD) shape and/or impact flux may be misinterpreted. This work explores if spatial statistics (quantitative measures of objects' distributions in space) could be a complementary approach to crater SFDs [e.g., 1-3] in determining if a heavily cratered surface is saturated. The use of spatial statistics was introduced by Lissauer et al. [4]

and Squyres et al. [5]. They proposed that a crater distribution would become more spatially uniform (more evenly spaced than expected for a random distribution) as it reached saturation equilibrium. Squyres et al. [5] combined a numerical simulation of a steeply-sloped SFD (cumulative slope = -2.7) with observations of heavily cratered terrains on Rhea and Callisto to empirically show this hypothesis could be valid for these cases. However, it is still uncertain whether populations with other slopes will also become more spatially uniform as they reach saturation equilibrium. My work continues the approach of Squyres et al. [5] by combining a new numerical simulation with new observations of cratered terrains throughout the solar system. The simulation is developed in IDL and varies the input SFD slope, importance of very small craters in erasing craters ("sandblasting"), and effectiveness of ejecta in erasing craters. I report preliminary results of this modeling and observations. MRK acknowledges the support of NASA PGG grant NNX12AO51G. References: [1] Woronow, A. (1977) JGR 82, 2447-56. [2] Hartmann, W. K. & Gaskell, R. W. (1997) MAPS 32, 109-21. [3] Marchi S., et al. (2012) EPSL 325-6, 27-38. [4] Lissauer, J. J., et al. (1988) JGR 93, 13776-804. [5] Squyres, S. W., et al. (1997) Icarus 125, 67-82.

417.09 – Catastrophic Collisions of Icy Satellites

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We will present results from simulations of the collisions of ice impactors and targets where the targets cover the size range of Saturnian satellites (diameters from 100 to 2000 km), and velocities ranging from sub-km per second to tens of km per sec. For these calculations we make use of SPHERAL++, developed by M. Owen and others at LLNL. SPHERAL++ is an open-source environment for N-body smoothed-particle hydrodynamics calculations. Our goal in these calculations is twofold: 1) to establish criteria for catastrophic disruption by impacts and characterize the criteria in terms of parameters such as impact velocity, impact angle, and mass ratio, and 2) to determine the extent to which water vapor generated during the impact is retained or escapes from the system. We will also compare our results with those from previous simulations done with other SPH codes.

418 – Galilean Satellites Posters

418.01 – Io during the New Horizons era: Insights from spacecraft and ground-based data

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We used NASA's Infrared Telescope Facility (IRTF) to observe Io's active volcanoes during the New Horizons spacecraft encounter with the Jupiter system. We also used data from three of the instruments on the New Horizons spacecraft. The Long-Range Reconnaissance Imager (LORRI), a high-resolution black and white camera, obtained 190 images in a wideband filter covering 0.3-1.1 microns, including 89 of an eclipsed Io. The Multicolor Visible Imaging Camera (MVIC), a four-color (visible to near infrared) camera, obtained 17 sets of images. The Linear Etalon Imaging Spectral Array (LEISA), a near-infrared imaging spectrometer covering 1.25 – 2.5 microns, obtained 9 image cubes. The IRTF observations complement the New Horizons data in terms of wavelength and temporal coverage. Our observations took place between August 2006 and June 2007 enabling us to put the New Horizons observations from late February 2007 in context. During seven partial nights, we imaged Io at 3 wavelengths (2.2, 3.5, and 4.8 microns) and obtained a series of short exposures for shift-and-add processing to increase spatial resolution. During an additional nine partial nights we observed Io in eclipse (to avoid reflected sunlight) and during Jupiter occultations (to isolate individual volcanoes). The occultations allow us to accurately determine the 1-D location of any active volcanoes visible. Furthermore, the IRTF occultation lightcurves cover only the Jupiter-facing hemisphere (longitudes 270 – 90 W) of Io and the NH LORRI observations are missing longitudes 30 to 170 W. The IRTF sunlit images and the NH LEISA data cover all longitudes of Io equally. We compare the data from both the IRTF and the NH spacecraft to determine how active each volcano was at the time of the flyby and how long the activity lasted. We found that the Tvashtar volcano was active for over a month before the NH flyby.

418.02 – Constraining Diameters of Ash Particles in Io's Pele Plume by DSMC Simulation

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The black "butterfly wings" seen at Pele are produced by silicate ash which is to some extent entrained in the gas flow from very low altitudes. These particles are key to understanding the volcanism at Pele. However, the Pele plume is not nearly as dusty as Prometheus, and these are not the only particles in the plume, as the SO2 in the plume will also condense as it cools. It is therefore difficult to estimate a size distribution for the ash particles by observation, and the drag on ash particles from the plume flow is significant enough that ballistic models are also of limited use. Using Direct Simulation Monte Carlo, we can simulate a gas plume at Pele which demonstrates very good agreement with observations. By extending this model down to nearly the surface of the lava lake, ash particles can be included in the simulation by assuming that they are initially entrained in the very dense (for Io) gas immediately above the magma. Particles are seen to fall to the ground to the east and west of the vent, agreeing with the orientation of the "butterfly wings", and particles with larger diameters fall to the ground closer to the lava lake. We present a model for mapping simulated deposition density to the coloration of the surface and we use it to estimate the size distribution of ash particles in the plume.

418.03 – Simulations of Global Flows in Io's Rarefied Atmosphere

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The sulfur-rich Ionian atmosphere is populated through a number of mechanisms, the most notable of which include sublimation from insolated surface frost deposits, material sputtering due to the impact of energetic ions from the Jovian plasma torus, and plume emission related to volcanic activity. While local flows are collisional at low altitudes on portions of the moon's dayside, densities rapidly tend toward the free-molecular limit with altitude, necessitating non-continuum (rarefied gas dynamic) modeling and analysis. While recent work has modestly constrained the relative contributions of sputtering, sublimation, and volcanism to Io's atmosphere, dynamic wind patterns driven by dayside sublimation and nightside condensation remain poorly understood. This work moves toward the explanation of mid-infrared observations that indicate an apparent super-rotating wind in Io's atmosphere. In the present work, the Direct Simulation Monte Carlo method is employed in the modeling of Io's rarefied atmosphere; simulations are computed in parallel, on a three-dimensional domain that spans the moon's entire surface and extends hundreds of kilometers vertically, into the exobase. A wide range of physical phenomena have been incorporated into the atmospheric model, including: [1] the effects of planetary rotation; [2] surface temperature, surface frost inhomogeneity, and thermal inertia; [3] plasma heating and sputtering; [4] gas plumes from superimposed volcanic hot spots; and [5] multi-species chemistry. Furthermore, this work improves upon previous efforts by correcting for non-inertial effects in a moon-fixed reference frame. The influence of such effects on the development of global flow patterns and cyclonic wind is analyzed. The case in which Io transits Jupiter is considered, with the anti-Jovian hemisphere as the dayside. We predict that a circumlunar flow develops that is asymmetric about the subsolar point, and drives atmosphere from the warmer, dayside hemisphere toward the colder nightside. The resultant flow patterns, column densities, species concentrations, and temperatures are discussed in relation to previous simulations of Io in a pre-eclipse configuration. This research is supported via NASA-PATM.

418.04 – Europa's Atmosphere: Production & Loss

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Europa is embedded not only in the ionized material of the Io plasma torus, but is also surrounded by the material (both ionized and neutral) produced by the interaction of this plasma with the moon's surface and atmosphere – as illustrated in the schematic below. Moreover, there are energetic ions and electrons that diffuse inwards from the outer magnetosphere and interact with the moon and surrounding neutral clouds. The multiple components of Europa's environment are thought to vary on timescales of hours to weeks and to be strongly coupled. Europa's O2 atmosphere is created by ion bombardment of the surface. Earlier studies assumed that the energetic (10s keV) ions were responsible (see review in Smyth and Marconi, 2006). New research (Cassidy et al. 2013) suggests that the "thermal" ion population of the Io plasma torus produces most of Europa's O2. But this cooler population is easily diverted by currents induced in Europa's ionosphere and prevented from reaching the surface. This feedback has not been adequately explored. Modelers have historically focused on a single piece of the puzzle; plasma modelers assume a static atmosphere and atmosphere modelers assume static plasma. We are now in a position to consider these new sources of atmosphere and determine how the observed system comes about as well as quantify the timescales and causes of its evolution. This begs the question is Europa's atmosphere-magnetosphere interaction self-regulating? We are specifically interested in how the system responds to changes – for example, how does Europa's atmosphere change when the inflowing plasma flux increases or decreases? What is the corresponding change in the electrodynamics and diversion of plasma flow around Europa? How much and on what time scale does the extended neutral cloud respond? And what are the consequences for the influx of energetic particles? We model this coupled system to address how each component responds to changes in the other components.

418.05 – VUV spectroscopy and photochemistry of ices relevant to outer solar system icy bodies

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Vacuum ultraviolet (VUV) spectral region that includes far ultraviolet (FUV) from 200 - 120 nm and extreme ultraviolet (EUV) at shorter wavelengths below 120 nm has been used to determine gas-phase atomic and molecular composition. Many outer solar system ices also show characteristic absorption features in the FUV region, recently measured by the UVIS instrument on the Cassini spacecraft. However, optical constants of many of these ices in the VUV region are not available under these conditions (temperatures <120 K) and continuous spectral coverage has been difficult in laboratory conditions. We have used continuously tunable synchrotron radiation in the wavelength region between 250 nm and 120 nm and measured quantitatively transmission spectra of several pure and mixed ices containing H2O, NH3, CH4, CH3OH, O2, etc. The talk will present these results and the methods we are developing to derive optical constants of these ices.

418.06 – The Gravitational Fields of the Galilean Satellites – Revisited

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One of the major scientific results from the Galileo mission to the Jovian system was the determination of the gravitational fields of the Galilean satellites. Schubert et al. summarize those results in chapter 13 of Jupiter: The planet, satellites and magnetosphere (Bagenal, Dowling, and McKinnon, eds., Cambridge U. Press, 2004). As a part of our recent update of the ephemerides of the Galilean satellites, we redetermined the satellite gravitational fields from the Galileo data. Our reprocessing of the data included, for the first time, calibrations for the effects of Io's plasma torus. We also removed some close encounter data at Europa and Callisto which was corrupted by the encountered satellite ionosphere. In fitting the data we employed a data whitening algorithm, developed for Cassini gravity science data processing, which takes into account the effect of the solar plasma on the Doppler data. Our new results confirm the previous ones for Io and Europa; the Io torus has a negligible effect on the fit to the Io encounter data. However, for Ganymede we found that the data whitening removes the data signature which was previous attributed to mass anomalies (Palguta et al. 2006, Icarus 180), and for Callisto we found that removing the ionosphere corruption significantly reduced the J2. Our overall conclusion is that a quadrupole field in hydrostatic equilibrium is sufficient to fit the data for all four satellites.

418.07 – Science of the Europa Clipper Mission Concept

Robert T. Pappalardo[1], David Senske[1], Louise Prockter[2], Brian Paczkowski[1], Steve Vance[1], Wes Patterson[2], Barry Goldstein[1], Tom Magner[2], Brian Cooke[1]
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Contributing teams: Europa Study Team

The Europa Clipper mission concept would place a spacecraft in orbit around Jupiter in order to perform a detailed investigation of Europa, a world that shows strong evidence for a liquid water ocean beneath its icy crust and which could host conditions favorable for life. As envisioned, the mission would send a highly capable, radiation-tolerant spacecraft into orbit around Jupiter to perform repeated close flybys of Europa. The Europa Clipper science objectives are: (1) Ocean and Ice Shell: Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange; (2) Composition: Understand the habitability of Europa's ocean through composition and chemistry; (3) Geology: Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities. To maximize success of a potential future landed mission, the Europa Clipper mission would include a reconnaissance capability. Reconnaissance objectives are: (1) Landing Safety: Assess the distribution of surface hazards, the load-bearing capacity of the surface, the structure of the subsurface, and the regolith thickness; (2) Scientific Value: Assess the composition of surface materials, the geologic context of the surface, the potential for geologic activity, the proximity of near surface water, and the potential for active upwelling of ocean material. Updates on the mission concept, the planning encounter trajectory, and science and reconnaissance objectives will be presented.

418.08 – Studying the Formation, Evolution, and Habitability of the Galilean Satellites

J. H. Waite[1], Tim Brockwell[1], Melissa A. McGrath[2], William B. McKinnon[3], Danielle Wyrick[1], Olivier Mousis[4], Brian Magee[1]
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Highly sensitive, high-mass resolution mass spectrometry is an important in situ tool for the study of solar system bodies. In this talk we detail the science objectives, develop the rationale for the measurement requirements, and describe potential instrument/mission methodologies for studying the formation, evolution, and habitability of the Galilean satellites. We emphasize our studies of Ganymede and Europa as described in our instrument proposals for the recently selected JUICE mission and the proposed Europa Clipper mission.

500 – Mars 3: Atmosphere

500.01 – Cloudy Greenhouse on Noachian Mars

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Urata and Toon (Icarus, Simulations of the martian hydrologic cycle with a general circulation model: Implications for the ancient martian climate 226, 229-250, 2013) show that a cloudy greenhouse, which likely needs to be induced by a large impact, can create a stable Martian climate during the Noachian with global average temperatures just below the freezing point. We also find, if frozen seas or extensive snowfields were present at mid-latitudes, that precipitation rates can be around 10 cm/yr, which is 10% of current terrestrial values, in certain regions. The regions favored with high precipitation rates vary with obliquity, and so they will sweep across the regions observed to have river valley networks over time. More than 200 mbar of CO2 must be present to maintain the greenhouse, mainly because efficient heat transport to the poles is required to prevent the water from being cold trapped at the poles. The era with extensive precipitation thus ended with the lowering of CO2 pressures below 200 mbar. In this talk we discuss the results of this modeling work for Mars and contrast it with similar work for the Archaen Earth, where we are not able to create a cloudy greenhouse, and instead water clouds cool the planet.

500.02 – The Energetics of a Collapsing Martian Atmosphere

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Throughout Mars' history, the Martian atmosphere has been affected by both the gradual increase in insolation from the Sun and the constantly varying insolation due to changes in orbital parameters (e.g. obliquity changes). For some combinations of insolation and orbital parameters, the Martian atmosphere likely underwent large scale condensation of its carbon dioxide

atmosphere, a process that is often called 'atmospheric collapse'. Here we present general circulation model (GCM) simulations of the Martian atmosphere for both an early Mars under a faint young Sun and current Mars under the current solar luminosity in order to investigate the conditions that control the onset of atmospheric collapse. The solar insolation and obliquity are the two primary parameters that we simulated in order to understand the physical processes that control the possible stable and collapsed states of the Martian atmosphere. We also present an analysis of the partitioning of energy transport into a mean circulation, an eddy circulation, and a condensation flow. The partitioning of energy into these three categories provides insight into the physical processes that control the Martian atmospheric collapse.

500.03 – The icy highlands scenario for early Mars: modeling of transient melting events and comparison with the geological evidence

Robin Wordsworth[1], Laura Kerber[2], François Forget[2], James W. Head[3], Jean-Baptiste Madeleine[3, 2], Ehouarn Millour[2], Kathleen Scanlon[3]
1. UChicago, Chicago, IL, United States. 2. Laboratoire de Meteorologie Dynamique, Paris, France. 3. Brown University, Brown, RI, United States.

Explaining the geological evidence for fluvial erosion on Mars' most ancient terrain remains a key challenge to planetary science despite decades of research. Previously, we performed 3D simulations of the global climate and water cycle in the Noachian under a thicker (0.1-2 bar) primitive atmosphere and faint young Sun (75% of present flux). These simulations revealed a possible mechanism for replenishing valley network sources: because of altitude-dependent adiabatic surface cooling, net transport of ice to the equatorial and southern Noachian highlands occurs via precipitation (snowfall) over long timescales. Here we investigate potential mechanisms for episodic melting of the highland ice deposits once they have formed. We present simulations of the melting and runoff rates induced by volcanic SO_2/H_2S emissions and the resulting formation of sulphate aerosols. Through modeling and basic theory, we evaluate recent suggestions that early Mars could have been warmed above freezing by water ice clouds or forced into a long-lived runaway greenhouse state by impacts. Finally, we discuss how large-scale variations in the VN distribution may inform us about the varying state of the atmosphere during the Noachian era.

500.04 – Atmospheric Structure and Diurnal Variations at Low Altitudes in the Martian Tropics

David P. Hinson[1, 2], Aymeric Spiga[3], Stephen Lewis[4], Silvia Tellmann[5], Martin Pätzold[5], Sami Asmar[6], Bernd Häusler[7]
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We are using radio occultation measurements from Mars Express, Mars Reconnaissance Orbiter, and Mars Global Surveyor to characterize the diurnal cycle in the lowest scale height above the surface. We focus on northern spring and summer, using observations from 4 Martian years at local times of 4-5 and 15-17 h. We supplement the observations with results obtained from large-eddy simulations and through data assimilation by the UK spectral version of the LMD Mars Global Circulation Model. We previously investigated the depth of the daytime convective boundary layer (CBL) and its variations with surface elevation and surface properties. We are now examining unusual aspects of the temperature structure observed at night. Most important, predawn profiles in the Tharsis region contain an unexpected layer of neutral static stability at pressures of 200-300 Pa with a depth of 4-5 km. The mixed layer is bounded above by a midlevel temperature inversion and below by another strong inversion adjacent to the surface. The narrow temperature minimum at the base of the midlevel inversion suggests the presence of a water ice cloud layer, with the further implication that radiative cooling at cloud level can induce convective activity at lower altitudes. Conversely, nighttime profiles in Amazonis show no sign of a midlevel inversion or a detached mixed layer. These regional variations in the nighttime temperature structure appear to arise in part from large-scale variations in topography, which have several notable effects. First, the CBL is much deeper in the Tharsis region than in Amazonis, owing to a roughly 6-km difference in surface elevation. Second, large-eddy simulations show that daytime convection is not only deeper above Tharsis but also considerably more intense than it is in Amazonis. Finally, the daytime surface temperatures are comparable in the two regions, so that Tharsis acts as an elevated heat source throughout the CBL. These topographic effects are expected to enhance the vertical mixing of water vapor above elevated terrain, which might lead to the formation and regional confinement of nighttime clouds.

500.05 – Inter-Annual Similarities during the Martian Dusty Season

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Contributing teams: MCS Team

We investigated the occurrence of large (regional) dust storms during the martian dusty season—southern spring and summer (Ls 180° to 360°). We used a zonal mean climatology at 50 Pa (~25 km) from TES/MGS and MCS/MRO to identify the regional and global dust storms and then to characterize their extent and evolution. A 200 K contour outlines the season and latitudinal extend of the significant storms in the zonal mean climatology. We find that years without a global dust storm are quite similar. There are three regional storms each of the five years without a global dust storm covered by the two instruments (MY24, MY26, MY29, MY30 and MY31). The exact timing, duration and peak temperatures vary from year to year, but each of the three storms has distinct characteristics and behavior and overall the years follow a very similar pattern. In each year, there is an early storm ("A" storm) that starts between Ls 210° and 240° in the southern mid-latitudes. It lasts for 15° to 40° of Ls and has peak zonal mean temperatures between 210 K and 230 K. There is always noticeable northern dynamical heating associated with the "A" storm. The second storm ("B" storm) each year occurs as the "A" storm is decaying. It starts around the perihelion (3° before to 10° after) along the southern seasonal polar cap edge and lasts through the solstice until between Ls 285° and 295°. The resulting warming remains south of the tropics. The final storm each year ("C" storm) starts between Ls 305° and 320°. It lasts a relatively short 3° to 15° of Ls. The peak temperatures are quite variable for the "C" storm. The later the "C" storm starts, the larger its temperature perturbation. Only the strong "C" storms trigger a northern dynamical warming.

500.06 – Extending the NASA Ames Mars General Circulation Model to Explore Mars' Middle Atmosphere

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The NASA Ames Mars General Circulation Model (MGCM) upper boundary has been extended to ~120 km altitude (p ~10^{-5} mbar). The extension of the MGCM upper boundary initiates the ability to understand the connection between the lower and upper atmosphere of Mars through the middle atmosphere (~70 – 120 km). Moreover, it provides the opportunity to support future missions (i.e. the 2013 MAVEN mission). A major factor in this extension is the incorporation of the Non-Local Thermodynamic Equilibrium (NLTE) heating (visible) and cooling (infrared). This modification to the radiative transfer forcing (i.e., RT code) has been significantly tested in a 1D vertical column and now has been ported to the full 3D Mars GCM. Initial results clearly show the effects of NLTE in the upper middle atmosphere. Diagnostic of seasonal mean fields and large-scale wave activity will be shown with insight into circulation patterns in the middle atmosphere. Furthermore, sensitivity tests with the resolution of the pressure and temperature grids, in which the k-coefficients are calculated upon, have been performed in the 1D RT code. Our progress on this research will be presented. Brecht is supported by NASA's Postdoctoral Program at the Ames Research Center, administered by Oak Ridge Associated Universities through a contract with NASA.

500.07 – New nitric oxide (NO) nightglow measurements with SPICAM/MEX as a tracer of Mars upper atmosphere circulation

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In the upper atmosphere of Mars, CO_2 and N_2 are photo-dissociated by solar UV and EUV on the day side, producing O and N atoms. They are carried to the night side by planet rotation and general circulation in the thermosphere. When they recombine to form nitric oxide (NO), they emit light in the UV in the so-called delta and gamma bands, producing a UV nightglow that was discovered by SPICAM/Mars Express in 2005 during dedicated limb observations. Therefore, it provides an important tracer of thermospheric circulation, tracing mostly descending air. A new data set has been produced by using more frequent

star occultations (more than 2000), which in about 10% cases revealed the presence of the NO emission in addition to the star signal. We have developed a method allowing to retrieve the vertical profile of the NO emission intensity, after disentangling the star signal from the limb signal. We have made a first-order comparison with the LMD-MGCM model. The peak intensity (a few kilorayleigh) and the peak altitude (around 80 km) are in reasonable agreement with model predictions. There is a discernible seasonal pattern of the latitude location of the emission. The latitude of the emission as a function of season (solar longitude, Ls) can be approximated with a relationship of the form Lat=-80 sin(Ls). At solstices (Ls=90 and 270), there is agreement between the observations and the model, which predicts an emission in the depth of the winter polar night. At equinoxes (Ls=0 and 180), the emission is observed near the equator, in total contradiction with the model, which predicts on the contrary an emission simultaneously at both polar regions. The significance of this major discrepancy for the general circulation of the upper atmosphere of Mars will be discussed, and the observed NO and O2 nightglows will be compared.

500.08 – Mars Obstacle Distortions of the Draped Magnetosheath Fields -Insights from MHD Models of the Solar Wind Interaction

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One of the key measurements of the MAVEN mission is the strength and orientation of the interplanetary magnetic field (IMF). The IMF controls many processes involved in the Mars-solar wind interaction and associated atmospheric escape. However in addition to the usual challenges of measuring fields on spacecraft, MAVEN's mission is during a period of unusually weak IMFs related to the weak solar fields of cycle 24. Thus instead of the usual ~3-5 nT fields at ~1.5 AU, MAVEN is likely to frequently encounter fields ~1 nT. For the MGS mission data analyses, where other issues such as mapping orbit bias produced non-ideal IMF measurement opportunities, the investigators took advantage of the IMF compression in the subsolar magnetosheath to obtain an approximation to the field orientation and strength (Crider and Brain and coworkers, papers in JGR 2003-2006). However, Brain et al. (2006) found some still-unexplained departures from the ideal sheath draping picture that compromise the direct evaluation of the IMF from these data. One of the signatures of is systematic IMF-dependent rotations of the field from what would be expected. The authors suggested that the interaction of the IMF with the Mars remanent fields might be responsible. In this poster we use BATS-R-US models of the Mars-solar wind interaction to investigate the dayside interaction of the IMF and the Mars obstacle toward resolving this question. In particular we use sample runs with the strong remanent fields on either the dayside or nightside, together with IMFs of both polarities, to visualize how the planetary obstacle and IMF interact in the limit of the MHD treatment. The results show draping deviations similar to those observed- implying that other details of the interconnected internal and external field geometries are also reproduced by these models-and that the sheath fields can be used for IMF determinations if the appropriate adjustments are made for expected obstacle boundary field distortions.

500.09 – Plasma Temperatures at Mars

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Ion and electron temperatures in the ionosphere of Mars affect plasma densities. These quantities vary with altitude and time of day. Modeling results are used to interpret existing measurements and to support anticipated MAVEN measurements. A 1D fluid model of the Martian ionosphere has been coupled to a kinetic supra-thermal electron transport model in order to self-consistently calculate ion and electron densities and temperatures. The models include diurnal variations, revealing hundreds of Kelvin changes in dayside electron and ion temperatures at fixed altitude. The models treat each ion species separately, revealing hundreds of Kelvin differences between H+ and O2+ temperatures. Consistent with previous studies using single-ion plasma, solar EUV heating alone is insufficient to heat the thermal electrons and ion species to observed temperatures, indicating the presence of additional heating sources.

501 – Galilean Satellites 1

501.01 – Spatially Resolved HST/STIS Observations of io's Dayside Equatorial Atmosphere

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We present a detailed analysis of 2011/2012 HST/STIS near ultraviolet (NUV) observations of Io's dayside equatorial atmosphere. Our results indicate that i) Io's atmosphere is not in instantaneous equilibrium with the surface frosts; ii) that the level of SO_2 continuum emission on Io's dayside in regions free of any known persistent volcanic plume source is 50x greater than the volcano free disk average brightness of Io during eclipse; and iii) that Io's dayside SO_2 gas density is longitudinally variant, peaking near 167W. This latter result is also evident in previously obtained NUV and near infrared observations (c.f. Tsang et al. 2013); thus, supporting the idea that Io's dayside SO_2 longitudinal variability is static. At the same time, comparison of spatially resolved spectral observations of Io obtained in 2011 and 2001 indicates that Io's equatorial gas density was higher by a factor of 2 in 2011. This result is consistent with the gas density variation predicted by vapor pressure equilibrium, based on the frost temperature variation expected as a function of heliocentric distance and the relative difference in the heliocentric distance of Io on those dates. Thus, this result suggests that Io's atmosphere is sublimation dominated. Trends in Io's SO_2 gas density distribution map closely to the variability of Io's NUV surface reflectance levels. Because the NUV brightness does not map directly to the total SO_2 frost abundance (Doute et al. 2001), the reason for the close correlation between the SO_2 gas density and the NUV brightness is not fully understood. The NUV brightness seems to correlate with 200-400 µm SO_2 frost grains (McEwen et al. 1988, Calrson et al. 1997), but it may also represent the level of molecular contamination of the SO_2frost by other volcanic constituents (Doute et al. 2001). Since each of these properties uniquely impacts the rate of gas production for a sublimation supported atmosphere, these relationships must be thoroughly investigated before the specific physical processes that support the static pattern of longitudinal variation Io's atmospheric gas density can be fully defined.

501.02 – Io's Post-Eclipse Atmosphere: Evidence Against Atmospheric Collapse During Eclipse

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Io's atmosphere is supported by a combination of direct volcanic injection of SO2 and SO2 frost sublimation from its surface. To determine the relative contributions of these two components on the overall density of the atmosphere, observations of Io's transition into and out of Jupiter eclipse provide useful constraints on the degree of frost sublimation support, as sublimation is a strong function of surface temperature which is highly affected by insolation. Previous observations of Io's atmosphere during ingress and egress have focused on atomic species seen in the far-ultraviolet. However, these auroral emissions are a product of magnetospheric particle interactions and therefore probe atmospheric density changes less directly and more globally. Here, we present 2011 Hubble Space Telescope Cosmic Origins Spectrograph spectra of the 2100 – 2350 Å SO2 bands as Io exits eclipse. These SO2 bands directly probe Io's bulk atmosphere. Two separate orbits show no changes in the band depths from eclipse egress to 2 hours after egress. This is in contrast to previous observations of FUV atomic S and O line strengths decreasing in eclipse and increasing post-egress. Our observations might indicate the atmosphere facing Jupiter is dominated by volcanic emission rather than frost sublimation, although this is not easy to reconcile with the FUV results. We present a model of possible combinations of frost thermal inertia and albedo that might be consistent with a static atmosphere, and provide alternative explanations for the lack of response.

501.03 – HST/COS Detection of Atomic Oxygen Emissions from the Atmosphere of Callisto

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We report on the detection of O I 1304 Å and 1356 Å emission from Callisto, using the Cosmic Origins Spectrograph aboard the

Hubble Space Telescope. An O_2-dominated atmosphere on Callisto has been suspected for many years, but the only previously detected atmospheric components have been CO_2 and ionospheric electrons, both found by the Galileo orbiter in 1997-1999. The new, faint O I detections (~4 Rayleighs at 1356 Å, assuming uniform emission from Callisto's disk) include a component centered on or close to Callisto's disk that has a 1304/1356 Å ratio consistent with electron-impact dissociation of O_2. In addition, there is apparently a more extended component dominated by 1304 Å emission and apparently derived from atomic oxygen. The observed emission is consistent with upper limits from previous, less sensitive, observations. We present our observations, analysis to separate Callisto emission from geocoronal and reflected solar O I signals, and the implications for Callisto's atmosphere: that it is collisionally thick, as inferred from the Galileo radio occultation measurements of ionospheric electrons, and its column density of O_2 is probably comparable in magnitude to Io's SO_2 column density. This puts Callisto in competition with Io for the third-most-massive satellite atmosphere in the Solar System, after Triton and Titan.

501.04 – The Ultraviolet Albedo of Ganymede

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A large set of ultraviolet images of Ganymede have been acquired with the Hubble Space Telescope over the last 15 years. These images have been used almost exclusively to study Ganymede's stunning auroral emissions (Feldman et al. 2000; Eviatar et al. 2001; McGrath et al. 2004; Saur et al. 2011; McGrath et al. 2013), and even the most basic information about Ganymede's UV albedo has yet to be gleaned from these data. We will present a first-cut analysis of both disk-averaged and spatially-resolved UV albedos of Ganymede, with focus on the spatially-resolved Lyman-alpha albedo, which has never been considered previously for this satellite. Ganymede's visibly bright regions are known to be rich in water ice, while the visibly dark regions seem to be more carbonaceous (Carlson et al., 1996). At Lyman-alpha, these two species should also have very different albedo values. References Carlson, R. and 39 co-authors, Near-infrared spectroscopy and spectral mapping of Jupiter and the Galilean satellites: Results from Galileo's initial orbit, Science, 274, 385-388, 1996. Eviatar, A., D. F. Strobel, B. C. Wolven, P. D. Feldman, M. A. McGrath, and D. J. Williams, Excitation of the Ganymede ultraviolet aurora, Astrophys. J, 555, 1013-1019, 2001. Feldman, P. D., M. A. McGrath, D. F. Strobel, H. W. Moos, K. D. Retherford, and B. C. Wolven, HST/STIS imaging of ultraviolet aurora on Ganymede, Astrophys. J, 535, 1085-1090, 2000. McGrath M. A., Lellouch E., Strobel D. F., Feldman P. D., Johnson R. E., Satellite Atmospheres, Chapter 19 in Jupiter: The Planet, Satellites and Magnetosphere, ed. F. Bagenal, T. Dowling, W. McKinnon, Cambridge University Press, 2004. McGrath M. A., Jia, Xianzhe; Retherford, Kurt; Feldman, Paul D.; Strobel, Darrell F.; Saur, Joachim, Aurora on Ganymede, J. Geophys. Res., doi: 10.1002/jgra.50122, 2013. Saur, J., S. Duling, S., L. Roth, P. D. Feldman, D. F. Strobel, K. D. Retherford, M. A. McGrath, A. Wennmacher, American Geophysical Union, Fall Meeting 2011, abstract #SM23D-08, 2011.

501.05 – Local Topographic Shielding and Radiation Shadows from Electron Irradiation on Europa

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A torus of magnetically trapped high-energy electrons and ions encompasses Jupitern and at Europa's orbital radius the density of these particles is especially high, yielding a continuous bombardment of its surface by these energetic particles. The high surface irradiation dosage makes it unlikely that chemical signature of simple organisms remain detectable and also drives chemical and physical processing of the surface. Energetic electrons with energies less than 25 MeV preferentially impact Europa on its trailing hemisphere, while higher energy but lower intensity electrons irradiate the leading hemisphere. This effect arises from the prograde motion of the Jovian magnetic field relative to Europa and the opposite motion of electrons due to gradient-curvature drift. Therefore, the total energy flux is greater on the trailing hemisphere and this bombardment has been linked to albedo variations on Europa's surface. In addition, energetic electrons gyrate about magnetic field lines. While energetic electrons are striking Europa's surface, the gyro-motion and surface interaction causes the directional surface irradiation flux to be anisotropic, even if the source electron flux in Jupiter's magnetosphere is isotropic Therefore, depending on the location, inclination, and orientation of the impact point, energetic electrons strike that point from limited local zenith and azimuth directions. We have computed the anisotropic flux of energetic electrons bombarding Europa's surface as a function of longitude along the equator. We identify the most likely scenarios for how a local topographic features may produce a radiation shadow such when the irradiation flux is sufficiently oblique to the surface. We find that local topography can shadow certain surface points from electron irradiation, such that these points could preserve the chemical signatures of the original pristine ice surface or emergent inorganic and organic material from the putative subsurface ocean for longer times. That is, the radiation age of these points could be much longer than elsewhere with potentially detectable effects on surface chemistry.

501.06 – Does Extension Play a Role in Ionian Tectonics? Potential Effects of Preexisting Bounding Faults, Local Brittle Failure, and Sulfur Pore Pressure on Crustal Stresses

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The majority of mountains observed on Io are tectonic, upthrusted blocks. Their formation is generally thought to be related to Io's heat-pipe volcanism, crustal subsidence, and accompanying lateral confinement. In previous work, we demonstrated that compressional thermal stresses from sustained local or regional shut down of Io's heat-pipe volcanism could also play a vital role in mountain formation, and help explain the anticorrelation between Io's mountains and volcanic centers [Kirchoff and McKinnon 2009, Formation of mountains on Io: Variable volcanism and thermal stresses, Icarus 201, 598-614; Kirchoff et al. 2011, Global distribution of volcanoes and mountains on Io: Control by asthenospheric heating and implications for mountain formation, Earth Planet. Sci. Lett. 301, 22–30]. Here we refine our previous model by using an "unconfined" horizontal boundary condition (zero average lateral stress), including brittle failure (crustal plasticity), and adding sulfur to our rheological model. The unconfined horizontal boundary condition accounts for stresses released on preexisting, more distant faults; including crustal plasticity allows us to more realistically represent stresses that would exceed the brittle failure limit otherwise, and addition of sulfur to the model composition of Io's crust further improves the rheological model of the crust. Heated and melted at depth, liquid sulfur creates pore pressure in the lower crust and profoundly reduces the brittle failure limit. Including these modifications when the volcanic eruption rate decreases introduces a region of tensional failure in the upper crust and increases the size of the region in compressional failure in the lower crust. Finite element models show that increasing compression at depth imparts substantial bending stresses, which can drive surface faulting and block rotation. Such conditions further facilitate mountain formation at the surface, and highlight the difference between Io's crustal/lithospheric stress regime and that of Mercury (compression throughout). These models, incorporating a greater degree of realism, further support the previous conclusion that mountain formation is more likely where volcanism is decreasing.

501.07 – A Chaos Conveyor Belt

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A critical question for the habitability of Europa remains: how does the ice shell work? The detection of shallow subsurface lenses below Europa's chaos implies that the ice shell is recycled rapidly and that Europa may be currently active. While this is not the first time liquid water has been implicated for Europa, the location of these features combined with new perspective on their dynamics frames the question in a new way. Melt lenses are intriguing potential habitats. Moreover, their formation requires the existence of impurities within the upper ice shell that may be sources of energy for microorganisms. Geomorphic evidence also exists for hydraulic redistribution of fluids both vertically and horizontally through pores and fractures. This process, observed in terrestrial ice shelves, may preserve liquid water within the ice matrix over many kilometers from the source. Horizontal transport of material may produce interconnectivity between distinct regions of Europa, thus preserving habitable conditions within the ice over a longer duration. At a surface age of 40-90 Myr, with 25-50% covered by chaos terrain, Europa's resurfacing rate is very high and water likely plays a significant role. Because of the vigor of overturn implied by this new work, it is likely that surface and subsurface materials are well-mixed within the largest and deepest lenses, providing a mechanism for bringing oxidants and other surface contaminants to the deeper ice shell where it can reach the ocean by convective or compositional effects. The timescales over which large lenses refreeze are large compared to the timescales for vertical transport, while the timescales for smaller lenses are comparable to or shorter than convective timescales. Moreover, marine ice accretion at the bottom of the ice shell may be contributing to a compositional buoyancy engine that would change the makeup of the ice shell. From this point of view, we evaluate the habitability of Europa's ice and ocean in light of active processes that may form a "chaos conveyor belt" that drives material exchange on Europa.

501.08 – Forming Ganymede's grooves at smaller strains: Toward a consistent local- and global-scale strain history for Ganymede

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Numerical simulations of the formation of Ganymede's grooved terrain (vast swaths of periodically spaced ridges and troughs) have long struggled to reproduce the observed amplitude of Ganymede's grooves (up to 500 m or more, peak-to-trough). Under ideal conditions, these simulations required >30% extension to form even moderate-amplitude deformation. Such large strains are at odds with Ganymede's global strain history, which likely included a 1-6% increase in surface area (though observations suggest it may have been as high as 8% [Collins 2006, 2008]) during either late-onset differentiation [Mueller and McKinnon 1988] or resonance passage [Showman et al. 1998; Bland et al. 2009]. Whereas limited regions of the surface may have undergone large amounts of extension (50-100%), the majority of Ganymede's grooves presumably formed at lower strains (~10%) [Collins 2006, 2008]. Thus, local-scale numerical models of groove formation are inconsistent with the regional and global constraints on Ganymede's surface strain history. Here we present numerical simulations of groove formation that reproduce the complete morphology of large-amplitude grooves (wavelengths of ~10 km, amplitudes up to 450 m, low slopes) with just 10% extensional strain. These simulations are more consistent with global strain constraints and are therefore a step toward linking a detailed mechanical understanding of groove terrain formation with the broader strain evolution of the satellite. The increased groove amplitudes result from implementing more realistic models of brittle failure in the lithosphere and, to a lesser extent, vertical temperature structure. These simulations utilize cold, polar-like surface temperatures [Dombard and McKinnon 2001]; warmer surface temperatures inhibit amplitude growth. For 10% extension, groove amplitudes decrease by ~50% at 100 K (relevant to ancient, high-albedo equatorial terrains), requiring greater extensional strains to produce grooves of equivalent amplitude. At 120 K (typical of ancient, low-albedo terrains), amplitude growth is much more limited, challenging the notion that grooves formed from dark terrain via tectonic resurfacing.

501.09 – The Pinnacles of Callisto

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Many regions of Callisto feature an unusual landscape consisting of rolling dark plains with interspersed bright knobs (pinnacles) and ridges. In earlier work we interpreted the dark plains as dusty, mass-wasted residue from sublimation from volatile-rich bedrock and the bright knobs (often crater rims) as water ice accumulations at locations sheltered from thermal reradiation from the dusty residue. We simulated evolution of Callisto's craters as a combination of bedrock volatile sublimation, mass wasting of the dark, non-coherent residue, and redeposition of ice, and concluded that the ice pinnacles and ridges might be underlain by tens to hundreds of meters of ice. Here we report the initial work of a new study of pinnacles addressing additional questions: 1) Is there an evolutionary sequence starting, e.g., from a cratered initial surface through growth and formation of a dust mantle and pinnacles, to eventual loss of ice to sublimation resulting in just a dark, dusty surface? 2) What determines the areal density and spatial scale of pinnacles – volatile content of bedrock, crater density, surface age, broad-scale topographic setting? 3) Are pinnacles still forming? Several observations address these questions. In a few places scattered high-albedo blocks ~25-60 m in diameter occur in the vicinity of large icy pinnacles. We interpret these blocks to be remnants from the collapse of tall pinnacles that were undermined by mass wasting. Some high-relief icy knobs have developed a skeletonized planform due to mass wasting by avalanching, or perhaps to seeding of new sites of ice deposition on mass-wasted ice blocks. Some areas nearly lack fresh craters with well-defined ejecta and ice-free rims. This may imply rapid transformation of fresh craters by sublimation, mass wasting, and ice reprecipitation. In other areas small sharp-rimmed craters occur which lack ice pinnacles, but the craters nonetheless lack visible ejecta sheets. Our preliminary interpretation is that mass wasting is very efficient on Callisto, or alternatively the dust cover is very thick and lacks competent coarse materials.

502 – Comets 2: Volatile Activity

502.01 – First Cometary Observations with ALMA: C/2012 F6 (Lemmon)

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Cometary ices contain material left over from the birth of the solar system, and studying their composition provides an important source of information regarding the physical and chemical conditions of the early Solar Nebula. Previous observations have been unable to ascertain the precise origin of fundamental coma species H2CO, HCN and HNC, and details regarding their possible formation in the coma are currently not well understood. In order to ascertain the chemical origin of these molecules and to place constraints on their coma release mechanisms, spatially and spectrally-resolved molecular emission maps of comets at mm and sub-mm wavelengths are required. In 2013, as part of our Director's Discretionary Time program, observations of the unusually-bright, gas-rich comet F6 (Lemmon) were executed using ALMA in the frequency range 339-362 GHz, covering emission lines from CH3OH, H2CO, HCN and HNC. We will present full details of these unique observations, and an analysis of the observed spectra.

502.02 – Pre- And Post-Perihelion Results On The "Unexpectedly-Bright" Comet C/2012 F6 (Lemmon) Using IR Spectroscopy

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Comet Lemmon has the potential to become the highlight of the 2013 calendar year. Indeed, this comet showed strong activity during its perihelion passage, and our high-resolution infrared spectroscopy revealed high production rates and a composition rich in volatiles, which even triggered follow-up observations at other wavelengths. The comet was observed on UT 2013 February 2–4 at pre-perihelion distances (Rh = 1.20 AU) with CRIRES at ESO's Very Large Telescope (VLT, Chile), and on 2013 March 31 and April 1 at Rh = 0.75 AU (post-perihelion) with CSHELL at NASA's Infrared Telescope Facility (IRTF, Hawaii). We present chemical abundances (relative to water), rotational temperatures and 1D spatial profiles for several primary volatiles. With CRIRES, we quantified the ortho-para ratio of H2O using ortho and para emission lines, and searched for HDO obtaining an upper limit for D/H in water even though the required Doppler velocity during our astronomical campaign was inadequate to completely separate the terrestrial HDO contribution. Along with our IR observations, we will discuss the implications of these results in the context of the IR taxonomy based on primary volatiles in comets. We gratefully acknowledge support by the NASA Postdoctoral Program (Paganini), by NASA's Planetary Astronomy (Paganini, Mumma, DiSanti, Villanueva) and Astrobiology (Mumma, DiSanti, Bonev) Programs, by NSF's Astronomy and Astrophysics Research Grants Program (Bonev, Gibb), by the Max Planck Gesellschaft (Böhnhardt), and by the European Southern Observatory (Käufl).

502.03 – IRAM-30m Molecular Submm Surveys of Two Very Different Comets: C/2011 L4 (PanSTARRS) and C/2012 F6 (Lemmon)

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The two bright comets of the spring of 2013, C/2011 L4 (Pan-STARRS) and C/2012 F6 (Lemmon) were observed on 14-18 March and 5-8 April with the IRAM-30m radiotelescope in Spain. Despite adverse observing conditions we conducted wide frequency surveys (85-93, 166-170, 210-272 GHz) of the two comets using the EMIR receivers and high resolution FTS spectrometer. The wide instantaneous frequency coverage (12-16 GHz dual polarization) enables the coverage of many lines of the same molecular species, making the detection faster. We detected HCN, HNC, CS, HCO+, CH3OH, HC3N, HNCO in comet PanSTARRS and HCN, HNC, HC3N, CH3CN, HNCO, CH3OH, H2CO, H2S, CS, C34S, SO, OCS, H2CS, HCO+ and HDO in comet Lemmon. We present derived production rates and their time evolution. Relative molecular abundances will be discussed in the context of our taxonomic study of Oort-cloud comets [1,2,3]. Comet Lemmon appears intrinsically much more gaseous than comet PanSTARRS and relatively rich in volatiles. [1] Biver et al. (2002), Earth, Moon and Planets 90, 32 [2] Crovisier et al. (2009), Earth, Moon Planet 105, 267 [3] Biver et al. (2011), A&A 528, A142

502.04 – Multi-Wavelength Observations of Comet C/2011 L4 (PanSTARRS)

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Comet C/2011 L4 (PanSTARRS), which reached a visual magnitude brighter than 0 mag near its perihelion in March 2013, is one of the brightest comets since the great comet C/1995 O1 (Hale-Bopp). Discovered at 8AU from the Sun, the apparition of comet C/2011 L4 (PanSTARRS) provided a rare opportunity to monitor the dynamically new comet over a significant time period as well as a wide range of heliocentric distances. We will present our multi-wavelength observations of this dynamically new comet during its first in-bound leg from the Oort Cloud. A strong absorption band of water ice was detected at 2.0 microns in the moderate- to low-resolution spectra taken with 8-m Gemini-North and 3-m IRTF telescopes atop Mauna Kea, Hawaii. However, the companion 1.5 micron band of water ice was not observed. Our spectral models show that the weakened or absent 1.5 micron band can be explained by submicron-sized fine ice grains. Hindered by the weakness of the 1.5 micron feature, we were not able to constrain the crystallinity of the water ice particles in the coma of C/2011 L4. No gas emission (i.e. CN, HCN and CO) was observed pre-perihelion both in the optical and in the sub-millimeter using the 8-m Gemini-N and the 15-m JCMT telescopes. An estimated upper limit for CO production rate is at a level of 10^27 mol/sec when the comet was 3.44-2.31 AU from the Sun. The comet showed a very strong continuum in the optical that became redder as the comet approaching the Sun. Based on the Gemini optical spectroscopy, we calculated the Afρ quantity of this comet and found the value to be ~120 m. We further estimated the pre-perihelion dust production rate of ~650 kg/s which yielded a lower limit of the dust-to-gas ratio of 4. Our observations show that C/2011 L4 is a dust-rich/gas-poor comet. We will discuss the comparison between C/2011 L4 and other Oort Cloud comets.

502.05 – Spatially Resolved Spectroscopic Observations of Na and K in the Tail of Comet C/2011 L4 (PanSTARRS)

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We used the Dunn Solar Telescope (DST) of The National Solar Observatory to obtain spectroscopic observations of comet C/2011 L4 (PanSTARRS) on 13 and 14 March 2013. The DST has the advantage for comet observations that one can observe the comet when it is close to the Sun. At the time of our observations, comet PanSTARRS was at 0.31 and 0.32 AU heliocentric distance. We used the Horizontal Spectrograph to observe five different spectral regions of the coma. The resolving power was 50,000 - 60,000. The slit was 0.3 arcsec wide and 171 arcsec long. At the comet's geocentric distance, the slit covered 1.43e5 km. The comet was approximately centered on the slit. We observed strong emissions from sodium (D1@589.592nm and D2@588.995nm) and potassium (D1@770.108nm and D2@671.701nm), along with a weak continuum. Lithium was not detected. The sodium was visible on the optocenter and the tailward side of the comet and extended to the edge of the slit (i.e. at least 70,000km tailward). It shifted redward at larger cometocentric distances, attributable to the acceleration of sodium by solar radiation pressure. The potassium was much weaker than the sodium and does not appear to extend as far from the optocenter. In this paper, we will show the distribution of these gases and compare their relative strengths. We will discuss the effects of the different photodissociative lifetimes of sodium and potassium and how they dictate what we observed.

502.06 – Spatial Distribution and Rotational Variations of Comet 103/P Hartley 2's Volatiles

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Deep Impact acquired a unique rotational data set during its close flyby of comet 103/P Hartley 2 (DIXI mission, November 4, 2010). The HRI-IR spectrometer (1.05-4.85 microns) monitored the coma throughout the encounter acquiring infrared scans every 2 hr over the 18 hr period prior to closest approach and every 30 min for 2 days after closest approach. Water vapor (2.7 microns), carbon dioxide (4.3 microns), and bulk organics (~3.4 microns) were the dominant emission bands detected in these spectra and their distribution was found to be highly asymmetric and variable. In particular, the distribution maps from the 8 hrs following closest approach (~half of the dominant 18.4 hr rotation period) are unique with spatial resolutions ranging from 0.2-3.5 km/pixel. These data allow us to explore correlations among the volatiles and the role of extended coma sources. These data will also help to quantify the heterogeneity of the outgassing and better locate specific source regions on the nucleus of Hartley 2.

502.07 – The Origin of Daughter Species in Cometary Comae: Results from Observations of Comets 103P/Hartley and C/2009 P1 Garradd

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The origin of daughter species in cometary comae has been a subject of much debate. Some cases, like that of OH and H_2O, are well understood, while most cases are not. In order for the origin of daughter species to be properly understood, coincident observations of both daughter species and their candidate parent molecules are needed to constrain the prevailing coma photochemistry. We present analysis of near simultaneous observations of candidate parent molecules and their daughters in comets 103P/Hartley and C/2009 P1 Garradd using a combination of infrared and optical spectroscopy with the goal of more firmly understanding the parentage of C_2 and CN and using the red-to-green line ratios in OI as a probe of the relative production rates of its dominant parents, H_2O, CO, and CO_2. We obtained optical observations with the ARCES echelle spectrometer mounted on the Astrophysical Research Consortium 3.5-meter telescope at Apache Point Observatory located in Sunspot, New Mexico, while we obtained IR observations for Garradd with the CSHELL IR spectrometer mounted on NASA's Infrared Telescope Facility in Hawaii. We also compare our results to measurements of candidate parent species reported in the literature. Observations in the optical were conducted with sufficient time resolution and time coverage to detect modulation in the production rates and mixing ratios from rotation (Hartley) and changing heliocentric distance (Garradd). We measure how the production rates and mixing ratios vary and discuss the implications for the progeny of C_2, CN, and OI in cometary comae.

502.08 – Study of the Forbidden Oxygen Lines in Comets at Different Heliocentric and Nucleocentric Distances

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Oxygen is an important element in the chemistry of the solar system objects given its abundance and its presence in many molecules including H2O (~80% of cometary ices). The analysis of oxygen atoms in comets can provide information not only on the comets themselves but also on the solar system. These atoms have been analyzed using the 3 forbidden oxygen lines [OI] observed in emission in the optical region at 5577.339 Å (the green line), 6300.304 Å and 6363.776 Å (the red lines) (Swings, 1962). Our analysis is based on a sample of 12 comets of various origins. The observing material is made of 53 high signal-to-noise spectra obtained with the high-resolution UVES spectrograph at the ESO VLT from 2002 to 2012 (Manfroid et al, 2009). After noticing that the green line is blended with one C2 line, we built synthetic spectra of C2 for each observing circumstances and we subtracted its contribution to the cometary spectra in order to ensure the decontamination of the 5577 Å line. Then, we measured the intensity of the 3 [OI] lines at different heliocentric distances. By comparing the green to red lines ratio (G/R) with the Bhardwaj & Raghuram (2012) effective excitation rates, we found that H2O is the main parent molecule when the comet is observed at r~1 au. When the comet is located beyond 2.5 au from the Sun, CO2 also contributes to the production of oxygen. Studying forbidden oxygen lines could be a new way to estimate the abundances of CO2 in comets, a very difficult task from the ground (Decock et al. 2013). In order to estimate the effect of the quenching on our results, we analyzed the evolution of the G/R ratio at different nucleocentric distances. For nearby comets, we divided the extended 2D spectrum into several zones in order to analyze the oxygen lines as close as possible to the nucleus (down to ~10 km for the closest comets). Their analysis will allow us to study the link of the oxygen lines with the nucleocentric distance. We found a clear variation of the G/R ratio close to the comet nucleus that is in agreement with a contribution from CO2 as predicted by Raghuram & Bhardwaj (2013).

503 – Origins 1: Solar System Shuffle and Outer Moons

503.01 – On the Behavior of the Galilean Satellites in the Jumping Jupiter Scenario

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The Nice model of the dynamical instability and migration of the giant planets can explain many properties of our present Solar System, and can be used to constrain its early architecture. In the jumping Jupiter version of the Nice model, required from the terrestrial planet constrains, Jupiter is involved in encounters with an ice giant. Here we study the survival of the Galilean satellites in the jumping Jupiter model. This is an important concern because the ice giant encounters, if deep enough, could dynamically interfere with the orbits of the Galilean satellites, and lead to implausible results. The jumping Jupiter models are taken from Nesvorný and Morbidelli 2012 (NM12). Our metodology in this study take into account the effects of the Sun, Jupiter's oblateness and obliquity, as well as the planetary close encounters tracked in NM12 upon the Galilean moons. We considered three instability cases that differed in the number and distribution of ice giant encounters with Jupiter. In each case, we considered 1000 realizations of the Galilean satellite system before the instability, and integrated the dynamical response of satellite orbits to ice giant encounters. We found that in one of the considered cases, where the number of close encounters was relatively small, the Galilean satellite orbits were not significantly disturbed. In the other two, the final orbital eccentricities were [0-0.2], and Callisto's semi-major axis ended within [22-30]Rj, while the other satellites kept their semi-major axis nearly constant. As Callisto's semi-major axis may vary as much, we also hint on the possibility that all four Galilean satellites were originally formed in a Laplace resonance, and Callisto was kicked out of it by encounters. These results: i) show that Galilean satellites are an important constrain on the planetary instability; ii) can check on the possibility to the Galilean system have been formed in a different configuration of seen today. Acknowledgement: FAPESP

503.02 – \`Getting down to brass tacks' in the Grand Tack scenario: matching important accretion and timing constraints

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The recently proposed Grand Tack model (Walsh et al., 2011) couples the gas-driven migration of giant planets to the accretion of terrestrial planets. In this model the first inward and then outward migration of Jupiter and Saturn creates a truncated disk of embryos and planetesimals, the subsequent evolution of which eventually broadly reproduces the orbital and mass distributions of the terrestrial planets, including a small Mars. Here we show that the Grand Tack model for the formation of the terrestrial planets can also match important accretion constraints including the time and mass of the last giant (i.e. Moon forming) impact on the Earth, the mass of the late veneer, and the rapid accretion of Mars. Expanding from Walsh et al. (2011), we explore a variety of oligarchic growth regime configurations. We adjust the individual mass of the initial embryos and the ratio of total masses in embryos and planetesimals. The individual embryo mass is diagnostic of the efficiency of the oligarchic growth process and/or its duration before being interrupted by the migration of Jupiter. We discover that more massive embryos can explain the rapid accretion timescale of Mars. The ratio of total masses in embryos and planetesimals is a reflection of the severity of collisional grinding during the oligarchic growth phase and its duration before interruption. An increased embryo to planetesimal total mass ratio creates Solar System analogs with evolution histories more similar to our own, including the timing of the last giant impact on Earth analogs and the small mass of the late veneer. Adjusting these parameters weakly effects on the final orbit and mass distributions of the simulated systems. After 150 million years of evolution, most are Solar System analogs with 4 or 5 planets that capture the mass-orbit relationship of the real terrestrial planets. The major drawback of these simulations is that the synthetic Mercury is typically too massive and too far from the Sun. To solve this problem, we will present results from simulations where the initial embryo mass increases with semi-major axis and we will explore the possibility that a small embryo was scattered inwards off the inner edge of the disk during early times.

503.03 – Terrestrial Planet Formation During the Migration and Resonance Crossings of the Giant Planets

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The newly formed giant planets may have migrated and crossed a number of mutual mean motion resonances (MMRs) when smaller objects (embryos) were accreting to form the terrestrial planets in the planetesimal disk. We investigated the effects of the planetesimal-driven migration of Jupiter and Saturn, and the influence of their mutual 1:2 MMR crossing on terrestrial planet formation for the first time, by performing N-body simulations. These simulations considered distinct timescales of MMR crossing and planet migration. In total, 68 high-resolution simulation runs using 2000 disk planetesimals were performed, which was a significant improvement on previously published results. Even when the effects of the 1:2 MMR crossing and planet migration were included in the system, Venus and Earth analogs (considering both orbits and masses) successfully formed in several runs. In addition, we found that the orbits of planetesimals beyond a ~1.5-2 AU were dynamically depleted by the strengthened sweeping secular resonances associated with Jupiter's and Saturn's more eccentric orbits (relative to present-day) during planet migration. However, this depletion did not prevent the formation of massive Mars analogs (planets with more than 1.5 times Mars' mass). Although late MMR crossings (at t > 30 Myr) could remove such planets, Mars-like small mass planets survived on overly excited orbits (high e and/or i), or were completely lost in these systems. We conclude that the orbital migration and crossing of the mutual 1:2 MMR of Jupiter and Saturn are unlikely to provide suitable orbital conditions for the formation of solar system terrestrial planets. This suggests that to explain Mars' small mass and the absence of other planets between Mars and Jupiter, the outer asteroid belt must have suffered a severe depletion due to interactions with Jupiter/Saturn, or by an alternative mechanism (e.g., rogue super-Earths).

503.04 – Dynamical Fate of Clumps Formed in Satellite Mergers

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The end result of a similar-sized collision (SSC) can be an effective accretion, an escaping 'hit and run', or chains of related bodies (Asphaug et al. 2006). Even in near-perfect accretion, several percent of the colliding material can escape, forming new planetary bodies. The diversity of the next-largest bodies (NLBs) increases with time in an accreting system (Asphaug 2010), offering a way of explaining planetary and satellite diversity – core-rich bodies stripped of their mantles, mantle-rich bodies shredded from accreted cores, and relics of partial accretion with larger bodies (e.g. planets in the asteroid belt; Chambers & Wetherill 2001) that have since disappeared. The Moon is an example. More speculative scenarios involve escaping NLBs to explain the origin of Mercury, diverse meteorite parent bodies, middle-sized icy satellites, KBOs, and possible newly identified planetary systems. Collisional models produce evocative outcomes, but lacking are N-body models to see what fraction of these interesting collisional byproducts survive the eons. For instance, Genda & Kokubo (2010) argue that the accretion of the largest bodies proceeds independently of hit and runs, because bodies that almost accrete, eventually accrete later since their orbits continue to cross. We present exploratory results of simulations of the hypothesized late origin of the Saturn system (Asphaug & Reufer 2013). In this model Titan forms from successive satellite mergers, out of an initially stable Galilean-like satellite system that was rendered chaotic in some way. The icy middle-sized moons are flung off. We create artificial collisions (forcing 2 satellites to collide), replacing the output with the largest merged satellite (M1) at the average orbit of the original satellites, plus its distribution of icy clumps (M2, M3, M4...) already identified in SPH simulations. The collision approach vector is a free parameter governing the e's and i's of the new-formed clumps, having a large parameter space even considering one collision in one evolution scenario. For each N-body simulation we report the fraction of clumps that survive evolution for thousands of orbits, which is their characteristic sweep up time by the accreted body M1.

503.05 – Forming the small satellites of Pluto

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The Pluto systems is one of extremes. In addition to Pluto, the system contains at least 5 satellites. Charon is the most massive, being more than 1/9 the mass of Pluto. This makes it the most massive satellite, relative to the primary, of any other planet or dwarf-planet in the Solar System. The other satellites are much smaller - having radii that are probably significantly less than 50 km. They are on nearly circular, co-planer orbits. Perhaps one of their most intriguing characteristics is that they are all close to n:1 mean motion resonances (MMRs) with Charon. In particular, Nix, P4, and Hydra are close to the 4:1, 5:1, and 6:1 MMR, respectively. (There is as yet no good orbit for P5). Observations are good enough for Nix and Hydra to conclude that while the are near their respective resonances, they do not appear to actually be librating in them. This has been a challenge for theories of their formation. We will present some new work exploring a heretofore unexplored dynamical mechanism that might help explain the puzzling orbits of the small satellites.

504 – Galilean Satellites 2

504.01 – Cycloid Formation in Europa's Viscoelastic Ice Shell

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Cycloids are linked arcuate segments that are thought to form as tensile fractures in response to daily-varying tidal stress on Europa (e.g. Hoppa et al., 2001). Good fits to observed cycloids have been achieved using formation models that assume the shell behaves elastically (e.g. Rhoden et al., 2010). However, computations for a rheologically-layered Europa have revealed that both the magnitude and the timing of diurnal tidal stress differ from the elastic shell model (Wahr et al., 2009; Jara-Orue and Vermeersen, 2011). The deviations are even more pronounced for long-term sources of stress such as non-synchronous rotation (NSR). In order to assess the influence of rheological layering on cycloid formation we have now incorporated the viscoelastic computations of tidal stress into our existing cycloid modeling software (see Rhoden et al., 2010). As in previous work, we attempt to fit the paths of six observed Europan cycloids, employing automated parameter searching techniques and quantitative measures of fit quality. We test two interior structure models, both of which assume a linear viscoelastic Maxwell rheology and include a 30-km ice shell. In one case, the whole shell is effectively elastic, and in the other, the lower part of the shell is highly dissipative. Using the viscoelastic diurnal stresses, we find little improvement in the quality of the fits over the thin, elastic shell model (Rhoden et al., 2010). In addition, the parameter values associated with the fits are similar enough to the previous values that our conclusions as to the cycloid formation mechanism and Europa's rotation state remain unchanged from previous work. Preliminary fits using a stress field that also includes stress from non-synchronous rotation indicate that NSR does not contribute significantly to the formation of cycloids. However, consistent with all previous cycloid modeling work, good fits can only be achieved if the cycloids have shifted in longitude since their formation, presumably due to NSR.

504.02 – Measurements of the spin states of Europa and Ganymede

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Measuring the spin states of the Galilean satellites holds the key to fundamental interior and surface properties. First, the spin state can reveal the presence of a subsurface ocean: a decoupling between the icy shell and the interior results in a different spin signature than that of a solid body. Second, the value of the obliquity combined with the known gravitational harmonics can provide a direct measurement of the polar moment of inertia, a crucial constraint on interior models. Finally, the obliquity may explain remarkable surface features, such as the distribution and shape of cycloids on Europa, and the direction of strike-slip faults. Here we present the first direct observations of the spin axis orientations of Europa and Ganymede. We use the same Earth-based radar technique that provided measurements of Mercury's obliquity at the sub-arcminute level, observational evidence that the core is molten, and core size estimates [1,2]. The measurements make simultaneous use of the Goldstone Solar System Radar and the Green Bank Telescope located ~3200 km away. It is the correlation of radar echoes received at these two stations that yields superb leverage on the spin state of the illuminated body. Because the Galilean satellites are further away than Mercury, and because they spin faster than Mercury, the signal-to-noise ratio of the observations is reduced by a factor of ~3000. Nevertheless, the telltale correlations are clearly detected in our data. Using measurements at 13 epochs in 2011 and 4 epochs in 2012, we are able to pinpoint Europa's spin axis orientation with a precision of ~0.1 deg, and our result is inconsistent with theoretical or model-based estimates [3,4,5]. For Ganymede, we secured measurements at 3 epochs in 2011 and 2 epochs in 2012, and the larger signal-to-noise ratio results in a comparable precision for the spin axis orientation. References [1] J. L. Margot et al. Science, 316:710, 2007. [2] J. L. Margot et al. JGR (Planets), 117(E16), 2012. [3] R.-M. Baland et al. Icarus, 220:435, 2012. [4] A. R. Rhoden et al. Icarus, 210:770, 2010. [5] A. R. Rhoden et al. Icarus, 211:636, 2011.

505 – Comets 3: Potpourri

505.01 – Rotation Analyses of Main-belt Comet P/2006 VW139

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Originally, the term main-belt comet (MBC) was coined to describe any asteroid within the main-belt that had a comet-like dust tail or coma as a result of sublimating ice [1]. Another term, disrupted asteroid, was introduced to further distinguish main-belt asteroids whose activity appears to be the result of processes other than sublimation [2]. The origin of activity in MBCs is not definitively known, but Jewitt [3] described a suite of possible mechanisms that could result in the comet-like activity observed on these asteroids. A true main-belt comet would be active as a result of ice sublimation driven dust ejection [2] and although no direct evidence of gas has been observed on these asteroids, recurrent activity is observed on several of these objects and is a strong indicator that sublimation is the driving force for activity [4]. Other potential mechanisms include rotational instability and impact ejection. We are interested in determining the rotation period of the recently discovered MBC P/2006 VW139 [2] to assess the possibility of rotational instability as a mechanism for activity in this MBC. We will present rotation period analyses of data collected in 2011 from the University of Hawai'i 2.2m, Lowell Perkins 1.8m, Himalayan Chandra 2.0m, Faulkes 2.0m and in 2012 from the University of Hawai'i 2.2m and Gemini North 8.1 meter telescopes. Due to the sparseness of the 2011 data as well as the effects of coma contamination, we are comparing the rotation periods derived from the 2011 to that of our 2012 data. Aside from attempting to clarify the true nature of the activity in MBCs, determining the nucleus properties of the known MBCs is also necessary to determine what distinguishes them from other non-active asteroids [2]. [1] Hsieh, H. H., & Jewitt, D. 2006, Science, 312, 561 [2] Hsieh, H. H., et al. 2012, ApJ, 748, L15 [3] Jewitt, D. 2012, AJ, 143, 66 [4] Hsieh, H. H., Yang, B., and Haghighipour, N. 2012, ApJ, 744, 9

505.02 – Properties of dust in inner cometary comae from polarimetric observations

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Evidence for changes in the properties of dust particles in cometary comae is provided by observations of the linear polarization of the solar light they scatter, which only depends upon the observational conditions and the dust properties. Local polarimetric changes in a coma under fixed observational conditions point out changes in the properties of the dust (e.g. size distribution, morphology, complex refractive indices and thus albedo). After evidence was obtained from local polarimetric observations of Halley's comet with Giotto spacecraft, techniques of remote polarimetric imaging have been developed, providing polarimetric images of the comae of some comets [e.g. 1]. Up to three different regions may be noticed: a background coma, jet-like features with a higher polarization, and a polarimetric halo extending on less than 2000 km around the photometric center. The possible presence of dust particles with different properties in the innermost coma is of major importance for the Rosetta mission, expected to rendezvous with comet 67P/Churyumov-Gerasimenko in 2014 and to approach its nucleus, while releasing the Philae lander from an altitude smaller than 10 km. Polarimetric observations, as interpreted through both experimental and numerical simulations [e.g., 2, 3], together with recent Stardust and Deep Impact in situ missions, provide clues to the following properties: the dust particles are quite small (0.1 micrometer to a few millimeters); they are very porous and irregular, possibly consisting of fluffy aggregates; they mostly consist of silicates and carbonaceous compounds, although the presence of icy grains cannot be ruled out in the innermost coma. We will discuss the origin of changes between the properties of dust particles present in the innermost coma and those of found further away from the nucleus, as mostly deduced from recent laboratory simulations of dust polarimetric properties. Support from CNES is acknowledged. [1] Hadamcik et al. JQSRT 79, 661, 2003. [2] Hadamcik et al. Icarus 190, 660, 2007. [3] Lasue et al. Icarus 199, 129, 2009.

505.03 – Characteristics of Deep Impact Ejecta Dust in the Immediate Aftermath of Collision

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The collision of an impactor released by the Deep Impact spacecraft with comet 9P/Tempel 1 produced an ejecta cloud composed of material excavated from the comet nucleus. This surprisingly thick cloud completely obscured the impact crater and cast a shadow on the surface of the nucleus. Analysis of the images taken by the Deep Impact Medium Resolution Instrument (MRI) showed that the shadow had a complex structure, revealing variations in optical thickness within the cloud. Even over the period a few seconds, the brightness distribution within the shadow changed with time, reflecting density and/or compositional variations of the dust in the ejecta cloud. We model the scattering of sun light by the ejecta cloud to reproduce the shadow structure and its change with time. The modeling is based on the 3D radiative transfer code HYPERION (Robitalle, A&A, 536, A79, 2011). Following Richardson et al. (Icarus, 191, 176, 2007), the ejecta cloud is presented as an oblique, hollow cone. The cone is populated with dust particles whose properties, primarily composition and number density, we adjust to get the best fit to the brightness of the ejecta and the shadow. We assume that the scattering by the ejecta dust follows the Henyey-Greenstein phase function and use Mie theory to determine single scattering albedo (SSA) and extinction cross-section, averaged over size distribution. The best fit (although still tentative) could reproduce the observed peak brightness of the ejecta cone (10 W/(m^2 sr μm)) and of the surface covered by the shadow (0.2 W/(m^2 sr μm)). It was obtained using number density of 10^{-3} particles/cm^3, power law size distribution with power -3, and particles composed of a mixture of equally represented amorphous carbon, silicates and organics (composition of measured comet Halley refractories) - 3.3%, ice - 29.7% and voids - 67%, that gave SSA of 0.641. Temporal and spatial variations in the properties of the dust most likely reflect variations of the structure and composition of the nucleus of Comet Tempel 1, thus providing an insight into the comet interior. The work is supported by NASA PMDAP grant #NNX10AP31G.

505.04 – Detailed Characterization of Low Activity Comet 49P/Arend-Rigaux

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Comet 49P/Arend-Rigaux is well known as a low-activity Jupiter Family comet. Previous observations suggest that 49P might become purely asteroidal in appearance so by studying it over several apparitions we can start to understand this process. However on March 27, 2012 (160 days after perihelion) we discovered that comet 49P had a prominent jet pointing at an approximate position angle of 180 degrees (south) and a tail at about 270 degrees (west). The projected extent of the jet was ~9.3 x10^4 km and the projected tail was ~2.3x10^5 km long. Searching amateur archives (at http://comet.observations.free.fr) showed that the jet appeared somewhere between March 16 and March 23. We obtained follow-up observations on six dates between March 31 and July 10 using the 1.2m telescope on Calar Alto and the UH 2.2m telescope on Mauna Kea. On March 31 the jet was still present but appeared more separated from the comet, on April 15 we observed minor remnants of activity near the surface of the comet in the same region, and by June 5 the nucleus appeared stellar. To understand this outgassing event, we used 26 nights of data over 4 apparitions between 1985 and 2012 to model the heliocentric light curve. Ice sublimation models were consistent with water-ice sublimation as the volatile driving activity on 49P. Our initial models show no evidence for a secular decrease in activity. Preliminary results on two consecutive apparitions suggest a grain size of ~20 μm and a fractional active area of about 0.6% which is consistent with the low activity. Finson-Probstein (FP) dust dynamical models (Farnham, 1992) show that the data from the 1992 apparition consisted of emission of large grains emitted (up to 2 mm) with very low emission velocities near 1 m s^{-1} (Farnham, 1996). We will present our results from running FP models for the 2012 apparition to determine a grain size distribution and emission velocity and compare this with the 1992 apparition. We will also show how these results constrain the ice sublimation models to get better estimates of grain sizes and fractional active area.

505.05 – Sub-millimeter Observation of Water Vapor at 557 GHz in Comet C/2002 T7 (LINEAR)

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We present sub-millimeter observations of the ground-state rotational transition (110–101) of water vapour from comet C/2002 T7 (LINEAR) obtained with the MIRO Instrument on the ESA Rosetta Spacecraft (s/c) Orbiter on April 30, 2004, which is about 7.5 days after its perihelion. The comet was at a distance of 0.63 AU from the Sun and 0.68 AU from the s/c at the time of the observations. The Doppler velocity of the comet relative to the s/c was -72.585 km/s. The ground state rotation transition of ortho-water at 556.936 GHz was observed and integrated for ~ 8 hours using a frequency switched radiometer to provide short and long term stability. MIRO beam size is 7.5 arcmin in terms of full width half maximum, corresponding to a width of 2.2x105 km at the location of the comet. The observed signal line area of the water line spectrum is 4.26 ± 1.17 K km/s, leading to the signal to noise ratio of 3.64. Using a molecular excitation and radiative transfer model and assuming the spherically symmetric and constant radial expansion of gas in the coma, we estimate that the production rate of water is (7.0 ± 0.2)x1E29 molecules/s and the expansion velocity is 1.0 ± 0.2 km/s at the time of the MIRO observation. The present estimation of the water outgassing rate of the comet is in good agreement with other observation-based estimations when the outgassing rates with respect to the time after perihelion are compared.

505.06 – A Search For $^{15}NH_2$ Emission Lines In Comets

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The determination of nitrogen isotopic ratios in solar system objects is important for a good understanding of their origin. The measurements of $^{14}N/^{15}N$ isotopic ratio done so far in various solar system objects and molecules have revealed a great diversity (from 50 to 441), all of them, except Jupiter, being enriched in ^{15}N compared to the protosolar nebula. Different explanations have been proposed to explain this enrichement. One of them suggests that these differences reflect the different interstellar N reservoirs from which N-bearing molecules are originating (Hily-Blant et al., 2013). These authors, from observations of $H^{13}CN$ and $HC^{15}N$ in two prestellar cores, suggest that the molecules carrying the nitrile- (-CN) functional group would be more enriched in ^{15}N than the molecules carrying the amine (-NH) functional group. Comets are interesting targets to test this theory because they contain both HCN and NH_3 molecules. So far the $^{14}N/^{15}N$ ratio has only been measured in CN (Arpigny et al., 2003; Manfroid et al., 2009) and HCN (Bockelée-Morvan et al., 2005, 2008) in comets, leading for both species to $^{14}N/^{15}N \approx 150$. Our work aimed at measuring the $^{14}N/^{15}N$ isotopic ratio in NH_2, which comes from NH_3. We have determined accurately the wavelengths of $^{15}NH_2$ emission lines with the AILES beamline spectrometer at synchrotron SOLEIL by Fourier transform spectroscopy. The analysis of this spectrum has permitted to extract the $^{15}NH_2$ emission lines wavelengths and to search for $^{15}NH_2$ cometary emission lines. Thanks to a collection of spectra of 12 different comets obtained from 2002 to 2011 with the UVES spectrometer at the VLT ESO 8-m telescope (Manfroid et al., 2009), it has been possible to search for $^{15}NH_2$ emission lines with a high sensitivity. We will present the results obtained from these data. Arpigny et al., Science, 301, 1522-1525, 2003 Bockelée-Morvan et al., in Comets II, ed. M. C. Festou, H. U. Keller, & H. A. Weaver (Tucson: Univ. Arizona Press), 391-423, 2005 Bockelée-Morvan et al., ApJ, 679, L49-L52, 2008 Hily-Blant et al., Icarus 223, 582-590, 2013 Manfroid et al., A&A, 503, 613-624, 2009

505.07 – FUV spectroscopy of the comet C/2001 Q4 (NEAT) with FIMS

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We present the results of far-ultraviolet (FUV) observations of comet C/2001 Q4 (NEAT) obtained with Far-ultraviolet Imaging Spectrograph (FIMS) on board the Korean microsatellite STSAT-1, which operated at an altitude of 700 km in a sun-synchronous orbit. FIMS is a dual-channel imaging spectrograph (S channel 900-1150 Å, L channel 1350-1750 Å,$\lambda/\Delta\lambda\sim$ 550) with large image fields of view (S: 4°.0×4′.6, L: 7°.5×4′.3, angular resolution 5′-10′) optimized for the observation of diffuse emission of astrophysical radiation. Comet C/2001 Q4 (NEAT) was observed with a scanning survey mode when it was located around the perihelion between 8 and 15 May 2004. Based on the scanning mode observations in the wavelength band of 1400 - 1700 Å, we have constructed the image of the comet for an angular size of 5° × 5°, corresponding to the central coma region around the nucleus. Several important fluorescence emission lines were detected such as S I triplets at 1429 and 1479 Å, C I lines at 1561, 1657 Å, and the CO $A^1\Pi$-$X^1\sigma^+$ Fourth Positive system, and we have estimated the production rates of the corresponding species from the fluxes of these emission lines. We estimated average production rates of CO, C by the photodissociation of CO, S by S I 1429 Å triplet, and S by S I 1479 Å triplet. We found existence of short-lived parent molecule of C atom in small cometocentric distances comparing the radial profiles of observing C I emission lines with the Haser model of CO molecule.

505.08 – Capabilities to measure isotopic ratios in water at comet 67P/Churyumov-Gerasimenko with ROSINA/DFMS

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Contributing teams: ROSINA-Team

The likelihood that comets may have delivered part of the water to Earth has been reinforced by the recent observation of the earth-like D/H ratio in Jupiter-family comet 103P/Hartley 2 by Hartogh et al. (2011). Prior to this observation, results from several Oort cloud comets indicated a factor of 2 enrichment of deuterium relative to the abundance at Earth. The European Space Agency's Rosetta spacecraft will encounter comet 67P/Churyumov-Gerasimenko, another Jupiter-family comet of likely Kuiper belt origin, in 2014 and accompany it from almost aphelion to and past perihelion. Onboard Rosetta is the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) which consists of two mass spectrometers and a pressure sensor [Balsiger et al. 2007]. With its unprecedented mass resolution, for a space-borne instrument, the Double Focusing Mass Spectrometer (DFMS), one of the major subsystems of ROSINA, will be able to obtain unambiguously the ratios of the isotopes in water from in situ measurements in the coma around the comet. We will discuss the performance of this sensor on the basis of measurements of the terrestrial hydrogen and oxygen isotopic ratios performed with the flight spare instrument in the lab. We also show that the instrument on Rosetta is capable of measuring the D/H even in the very low density water background released by the spacecraft. This capability demonstrates that ROSINA should obtain very sensitive measurements of these ratios in the cometary environment. These measurements will allow detection of fractionation as function of the distance from the nucleus as well as fractionation due to mechanisms that are correlated with heliocentric distance. References: H. Balsiger et al., Space Sci. Rev., 128, 745–801 P. Hartogh et al., Nature, 478, 218–220, 2011 M. Hässig et al., PSS, 84, 148–152, 2013

506 – Jovian Planets 1: Atmospheric Chemistry and Microphysics

506.01 – An Intense Red Jovian Cyclone: Another Key to Finding the Chromophores?

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An intense red cyclone was visible on Jupiter in 1995 and is visible in several Hubble Space Telescope datasets from 1994 through 1995. This cell has a distinctly different spectrum than the Great Red Spot, but is quite similar to the North Equatorial Belt. All three regions show spectral differences from a full-disk Jupiter spectrum, giving new clues to the composition of the color causing compounds, or chromophores, on Jupiter. Principal component analyses show several components and further highlight the differences between regions. Temporal analysis shows that the darkest regions of the NEB are relative constant in color, while the slope of the GRS core may vary slightly. The color difference between regions may be indicative of the same chromophore under different conditions (mixing with white clouds, or longer UV irradiation at higher altitude), although multiple compounds involving NH4SH and hydrocarbons may be needed to explain each spectrum.

506.02 – Spot-On: Ammonium Hydrogen Sulfide and Jupiter's Great Red Spot

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The color and composition of Jupiter's Great Red Spot (GRS) has been debated for more than a century. While there are numerous hypotheses for the origin of Jupiter's GRS, recent work suggests that the GRS's color could originate from multiple components (Carlson et al., 2012; Simon-Miller et al., submitted). In light of this, we have recently begun conducting in situ laboratory experiments that test whether ammonium hydrosulfide, NH_4SH, or its radiation decomposition products contribute to the GRS spectrum. In this presentation, we will discuss some of our most recent results, where we have monitored color and compositional changes in NH_4SH samples using infrared and ultraviolet-visible spectroscopy. Funding for this work has been provided by NASA's Planetary Atmospheres and Outer Planets Research programs. References Carlson, R. W., K. H. Baines, M. S. Anderson, G. Filacchione. Chromophores from photolyzed ammonia reacting with acetylene: Application to Jupiter's Great Red Spot, DPS, 44, 2012. Simon-Miller, A. A., R. W. Carlson, A. Sanchez-Lavega. An Intense Red Jovian Cyclone: Another Key to Finding the Chromophores? Icarus, submitted.

506.03 – The Deep Cloud Structure and Volatile Abundances in Jupiter's Great Red Spot

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Images of Jupiter at 5 microns reveal a dynamic range of about 20 in thermal emission between the hottest Hot Spots and the lowest flux regions on the planet. The Great Red Spot is dark at 5 microns due to thick clouds, but imaging alone does not reveal which cloud layers are responsible for attenuating this radiation. Initial expectations were that upper level clouds were sufficiently opaque that structure at the water cloud level would be completely hidden. Fortunately, this is not the case. We used NIRSPEC on the Keck telescope and CSHELL on the Infrared Telescope Facility to spectrally resolve line profiles of CH3D and other molecules on Jupiter in order to derive the pressure of the line formation region in the 5-micron window. Deuterated methane is a good choice for studying cloud structure because methane and its isotopologues do not condense on Jupiter. Variations in CH3D line shape with position on Jupiter are therefore ONLY due to cloud structure rather than due to changes in gas mole fraction. By aligning the slit east/west on Jupiter, we sampled the Great Red Spot and a Hot Spot 7 arcsec to the west. The profile of the CH3D lines is very broad in the Hot Spot due to collisions with up to 8 bars of H2, where unit optical depth due to collision induced H2 opacity occurs. The extreme width of these CH3D features implies that Hot Spots do not have significant cloud opacity where water is expected to condense. This is consistent with the Galileo probe results. Within the Great Red Spot, the line profiles are substantially narrower than in the Hot Spot, but they are broader than would be expected if they were formed in a column above an opaque cloud at 0.7 bars (NH3) or 2 bars (NH4SH). The best fit to the line shape of CH3D requires an opaque cloud at 5 bars, which we identify as being a water cloud. Gaseous H2O is clearly evident in the Great Red Spot, which provides independent evidence that we are sounding deep in Jupiter's atmosphere. A combination of Keck and IRTF data will allow us to retrieve NH3, PH3, and gaseous H2O inside the Hot Spot and within the Great Red Spot. This technique can be applied to study the deep cloud structure anywhere on Jupiter whether or not upper level clouds are present.

506.04 – Saturn Limb Hazes as Seen from Cassini

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The Cassini Orbiter has obtained images of Saturn's limb at solar phase angles greater than 150° and spatial resolutions ~10 km, with filter pairs covering the methane absorption bands at 727 nm and 890 nm and nearby continuum wavelengths. Images obtained in the Imaging Science Subsystem (ISS) MT2 filter (effective wavelength 727 nm) and MT3 filter (889 nm) show radial specific intensity (I/F) profiles quite different from those in the neighboring CB2 (750 nm) and CB3 (938 nm) filters. The difference is caused by variation with altitude in the relative amounts of scattering haze and absorbing methane gas. Radial I/F profiles across the limb in these images can be inverted to yield the detailed vertical structure and single scattering properties of absorbing/scattering particulates in Saturn's stratosphere (e.g. Rages et al. 1999, Icarus 139, 221), together with precise pressure levels for any discrete features seen. We will present results from our ongoing program to carry out such an analysis on the available Cassini high-phase-angle images of Saturn. This work was funded through the Cassini Data Analysis and Participating Scientist program.

506.05 – Microphysical Modeling of Saturn Limb Hazes

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Haze particles in Saturn's stratosphere can be seen in the visible limb images of Cassini's Imaging Science Subsystem (ISS). These hazes are likely a mix of particles, including solid organics formed as a result of methane photolysis and electron deposition, as well as the condensation of water and hydrocarbon ices. Quantifying the composition, size, and vertical structure of these stratospheric particulates is important to the understanding of gas giant atmospheric dynamics, energy deposition, and the composition of particles in the troposphere. In conjunction with our work in analyzing Cassini ISS data, we have developed a microphysics model for Saturn's stratosphere based on the Community Aerosol and Radiation Model for Atmospheres (CARMA). We will focus here on the ice component of these hazes and present a number of results following the nucleation and growth of compounds including water ice, butane, and diacetylene in order to quantify the likely size and altitude of these particles in Saturn's stratosphere. This work was funded by NASA's Cassini Data Analysis and Participating Scientist program and the Outer Planet Research program.

506.06 – Seasonal changes in Saturn's stratosphere from Cassini/CIRS data

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Saturn undergoes important seasonal variations in solar insolation because of its large obliquity (26.7°). Hence, we expect significant changes in the atmospheric temperature, photochemistry and possibly in large scale circulation. To measure the seasonal variations of the stratospheric thermal structure, we analyze limb spectra acquired by Cassini/CIRS (Composite InfrarRed Spectromer) in September 2010 and January 2012, during the spring in the northern hemisphere and we compare them to the previous observations of March 2005 and August 2006 during winter. The CIRS data of September 2010 span from 25°N to 80°N (before the large northern storm) whereas the data of January 2012 probe the latitudes from 30°S to 70°S. Their limb viewing geometry and the two wavelengths ranges used (from 7 μm to 9 μm and from 9 μm to 17 μm) allow us to measure the temperature from the lower to the upper stratosphere (i. e. from 20 hPa to 0.001 hPa) with a resolution of 1.5 times the scale height. We use a forward radiative transfer model coupled to a constrained linear inverse method to retrieve temperature profiles at the different observed latitudes. In the northern hemisphere, the temperatures increased by 10 K at 1 hPa consistent with the results of Fletcher et al. (2010) from CIRS nadir data. Nevertheless, in the upper stratosphere at 0.1 hPa, the temperature do not show any significant variation within 2 K. This was not predicted by radiative equilibrium models such as Greathouse et al. (2008). This suggests that the temperature is not simply governed by the radiative heating and cooling by the atmospheric minor constituents but that other processes such as large scale dynamics or wave breaking are at play. We also present seasonal variations of ethane abundance in the stratosphere. Guerlet et al. (2009) found that ethane displayed meridional variations not accounted for by the seasonal 1-D photochemical models of Moses et al. (2005), hence showing its sensitivity to atmospheric dynamics. Following this work, we will study its seasonal variations between 2005 and 2012 in order to provide constraints on Saturn's stratospheric seasonal circulation.

506.07 – Haze, Methane and Para-hydrogen on Uranus and Neptune, 2001-2007: Results from an Analysis of Near-IR Spectra

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Results form an investigation of spatially resolved near-IR spectra of Uranus and Neptune are presented. For reasons not yet understood, Neptune is one of the most meteorologically active planets in the solar system. Uranus, which appeared relatively featureless in Voyager 2 images, has shown increased activity in recent years [1], presumably revealing seasonal changes.
The advent of the HST and adaptive optics technology has allowed researchers to map clouds and retrieve chemical abundances [2,3], providing clues to the dynamics driving these worlds. For this study, latitude resolved H- and K-band spectra and images were obtained using adaptive optics on the 200" Hale telescope at the Palomar Observatory. Data was acquired nearly annually from 2001 to 2007, with several longitudes covered each year. We use a constrained inversion algorithm to minimize differences between observed and modeled spectra. Best fitting vertical profiles of aerosol and methane abundance are retrieved, along with the molecular hydrogen para-fraction. Most observations suggest two layers of aerosols, with a stratospheric depletion of methane, and roughly equilibrium para-fractions. These parameters are tracers of atmospheric motions and can provide insight into the atmospheric circulations. Variations with latitude and time suggesting dynamical motions and seasonal changes are investigated. This project was funded under the NASA Outer Planets Research program. [1] Rages, K.A., H.B. Hammel and A.J. Friedson, 2004. Evidence for temporal change at Uranus' south pole. Icarus, 172, 548-554. [2] Sromovsky, L.A. and P.M.Fry, 2008. The methane abundance and structure of Uranus' cloud bands inferred from spatially resolved 2006 Keck grism spectra. Icarus, 193, 252-266 [3] Karkoschka, E., 2011. Neptune's cloud and haze variations 1994-2008 from 500 HST-WFPC2 images. Icarus 215. 759-773.

507 – TNOs and Centaurs 1: Physical and Surface Properties

507.01 – Ultra-red TNOs: a peek into their compositional history

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We present the results of a systematic analysis of the surface composition of nine of the reddest trans-neptunian objects (TNOs) with a view to investigate their initial chemical compositions and the evolution of that composition since their formation. The objects are mostly in the Classical and Resonant dynamical groups, with the exception of three Centaurs. The Classical and Resonant objects are expected to be similar in composition, while the surfaces of the three Centaurs could have been significantly modified as their orbits evolved. The available data consist of broad-band photometric measurements in the wavelength range between 0.3 and 4.5 μm. The photometric measurements are scaled to the albedo at 0.55 μm to yield an approximation of the spectral continuum of each object that is then compared to a library of synthetic spectra of mixtures of materials known to be present on the surfaces of TNOs. For each object we obtain a range of compositions that match their spectral distribution. This yields the likelihood for the various materials to be present on the surface as well as a measure of the error of the estimate. Ices are grouped into 'stable' (H_2O), 'partially stable' (CH_3OH, CO_2), and 'volatile' (CH_4, CO, N_2). Our preliminary results show some difference in the amount of 'volatile' and 'partially volatile' ices among the Classical and Resonant objects. A trend in the sense of less ice present on closer and smaller objects is apparent, possibly related to the objects' ability to retain those ices and to the ices available in the solar nebula at those distances at the time of formation. On the other hand Pholus, one of the Centaurs, exhibits loss of 'volatile' ices and enhancement of organic material with respect to the Classical and Resonant objects. Since Centaurs are believed to originate from TNOs captured into fairly short-lived orbits closer to the Sun, our findings are consistent with the idea that Pholus has recently lost to sublimation some of its 'volatile' ice reservoir, exposing more of its native organic material.

507.02 – Atmospheres on Volatile-Bearing Kuiper Belt Objects

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Seven large bodies in the outer solar system have volatiles ices detected or inferred on their surfaces (Pluto, Triton, Eris, Makemake, 2007 OR10, Quaoar, and Sedna; Brown et al. 2011, ApJ 738, L26), which may lead to atmospheres over some or most of their orbits (Stern & Trafton 2008, Sol. Sys. Beyond Neptune, 365-380). We have investigated the role of internal heat (e.g., McKinnon et al. 1997, Pluto and Charon, 295-343) and thermal inertia on the seasonally varying surface temperatures and atmospheres. We quantify when atmospheres are global (Pluto-like, with similar pressures over the surface), local but collisional (Io-like, with large pressure gradients), or non-collisional. We conclude that four bodies (Pluto, Triton, Eris and Quaoar) should be global over some or all of their orbits, and that 2007 OR10 should be global near perihelion only for low thermal inertia. Five bodies (Pluto, Triton, Eris, Makemake and Quaoar) should be global or local-collisional over their entire orbits. 2007 OR10 reaches non-collisional pressures at aphelion for low thermal inertia. Sedna is non-collisional for most of its orbit, but may be collisional near perihelion for low thermal inertia. Long-lived radiogenic heat can be important for the atmospheres of larger and/or more distant Kuiper belt objects.

507.03 – IR Measurements of Icy Solids of the Outer Solar System: A New Spectral Database

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Icy surfaces in the outer Solar System are made not just of frozen H2O, but also hydrocarbons, carbon oxides, and solid nitrogen. Quantitative analyses of these ices by remote sensing require a suitable database of well-characterized spectra of such compounds. Our research group recently has initiated a new laboratory program to systematically measure IR spectra, optical constants (n, k), absorption coefficients, and absolute band strengths for amorphous and crystalline phases of selected hydrocarbons and other molecules in various icy matrices below about 70 K. Here we report new measurements on methane (CH4) and acetylene (C2H2) ices at temperatures applicable to the outer Solar System. Comparisons will be made to earlier work and a few surprises will be presented. Electronic versions of the data will be made available as will a computer routine to use our new n and k values to simulate the observed laboratory IR spectra. This work is funded by NASA's Outer Planets Research program.

507.04 – Short-term variability of binary and non-binary Trans-Neptunian Objects

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Since 1992, more than 1400 Trans-Neptunian Objects (TNOs) have been discovered. Our approach to understand such objects is to study their rotations by monitoring their brightness variations. By studying the rotational properties of the TNOs a wealth of information can be obtained on their physics. So, the study of the spins and shapes of TNOs is a powerful method of gaining information on the formation and evolution of our Solar System. We have observed most of the brightest TNOs and centaurs, and compiled one of the largest lightcurves samples. The main purpose was to increase the number of objects whose short-term variability has been studied and present a homogeneous dataset trying to avoid observational biases. A dataset composed of 54 TNOs/Centaurs is reported and analyzed. Amplitudes and rotational periods have been derived for 45 of them with different degrees of reliability. For 9 objects, only an estimation of the amplitude is reported. Because most of the TNOs/Centaurs have low amplitude lightcurves, it is difficult to distinguish between single- and double-peaked lightcurves. Based on our results and the literature, following Binzel et al. (1989) study about asteroids rotational frequency distribution, we studied the TNOs spin rate distributions. We performed several Maxwellian fits to various histograms obtained considering that the lightcurves are single- or double-peaked. We tested lightcurve amplitude limits to distinguish if the lightcurve is albedo- or shape-dominated. Such a consideration introduces important changes in the distribution. We derived that an amplitude limit of 0.15mag gave a good fit to Maxwellian distribution. So, it seems that 0.15mag is a good measure of the typical variability caused by albedo. We studied the short-term variability of binary TNOs thanks to unresolved lightcurves. Based on our results and those from the literature, we come up with a sample of 32 systems with a rotational period and/or lightcurve amplitude value. We have shown that rotational and physical properties of the binary population and non-binary sample are different. Binaries have a higher mean rotational rate possibly due to tidal effects, and it seems that they present higher lightcurve amplitude.

508 – TNOs and Centaurs 2: Trojans, Albedo, Size Distribution

508.01 – Characterizing the Neptune Trojan Orbit Distribution

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The Neptune Trojan swarms are large, stable minor planet populations, and their orbit distribution encodes information about Neptune's late-stage migration and the properties of the planetesimal disk that Neptune encountered. However, extracting a meaningful model of the Neptune Trojans' orbit distribution is made difficult by the uncharacterized biases present in the very small observed sample. I will describe a survey-agnostic statistical method for quantifying the range of plausible orbit distribution models for the Neptune Trojans, using priors gleaned from other resonant minor planet populations, and present quantitative limits on the orbital properties of Neptune Trojans. I will also discuss the results of a suite of Neptune Trojan capture simulations designed to explore the implications of their measured present-day orbital properties; I find that migrating Neptune into a pre-heated disk is required to reproduce the inclinations seen in the extant Trojans, and that capture efficiency remains high even as disk excitation increases. This indicates that some process was responsible for pre-heating the planetesimal disk prior to Neptune's arrival, such as an earlier epoch of interactions with a giant planet.

508.02 – The first known Uranian Trojan and the frequency of temporary giant-planet co-orbitals

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We report the first discovery of a Uranian Trojan (2011 QF99) in 2011-2012 CFHT Megacam imaging taken for a 20 square degree

outer Solar System survey designed to detect and track Trans-Neptunian Objects and Centaurs. The orbit of the newly discovered object was constrained with 29 astrometric measurements over 7 dark runs with a total arc of 419 days. Numerical integrations of both the nominal orbit and all other orbits within the (already small) orbital uncertainties show 2011 QF99 oscillates around the L4 Lagrange point 60 degrees ahead of Uranus for >70 kyr and remains co-orbital (in 1:1 resonance) for ~1 Myr before becoming a Centaur. We performed additional orbital integrations to investigate the possibility the object could have evolved to its current orbit from a nearby, stable niche of phase-space. However, test particles started on orbits in the small region of phase-space surrounding the nominal orbit remained co-orbital for <100 Myr, most for <10 Myr. This leads to the conclusion that 2011 QF99 must be a temporary co-orbital instead of being a primordial Trojan. To investigate the frequency and duration (to factor of two accuracy) of temporary co-orbital captures with Uranus and Neptune, we construct a model of Centaurs supplied from the transneptunian region over 1 Gyr, building a relative orbital distribution for the a<34 AU region. The simulation output interval of 300 yr for the planets and all a<34 AU particles allows the 1:1 resonant argument to be well sampled; to our knowledge, this is the first time such a meticulous search for short-term co-orbitals of giant planets has been performed for an armada of incoming scattering objects. Analysis of the particle histories showed that at any given time, significant fractions (0.4% and 2.8%) of the a<34 AU Centaur population will be Uranian and Neptunian co-orbitals, respectively. We show for the first time that the high fraction (~3%) of the transient co-orbital Centaurs in the IAU Minor Planet Center database is that expected under transneptunian supply. This research was supported by the Canadian National Sciences and Engineering Research Council.

508.03 – CAPTURE OF TROJANS BY JUMPING JUPITER

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Jupiter Trojans are thought to be survivors of a much larger population of planetesimals that existed in the planetary region when planets formed. They can provide important constraints on the mass and properties of the planetesimal disk, and its dispersal during planet migration. Here, we tested a possibility that the Trojans were captured during the early dynamical instability among the outer planets (the Nice model), when the semimajor axis of Jupiter was changing as a result of scattering encounters with an ice giant. The capture occurs in this model when Jupiter's orbit and its Lagrange points become radially displaced in a scattering event and fall into a region populated by planetesimals (that previously evolved from their natal transplanetary disk to ~5 AU during the instability). Our numerical simulations of the new capture model, hereafter jump capture, satisfactorily reproduce the orbital distribution of the Trojans and their total mass. The jump capture is potentially capable of explaining the observed asymmetry in the number of leading and trailing Trojans. We find that the capture probability is (6-8) × 10^-7 for each particle in the original transplanetary disk, implying that the disk contained (3-4) × 10^7 planetesimals with absolute magnitude H < 9 (corresponding to diameter D = 80 km for a 7% albedo). The disk mass inferred from this work, M_disk ~ 14-28 M_Earth, is consistent with the mass deduced from recent dynamical simulations of the planetary instability.

508.04 – A Herschel-PACS view of 16 Centaurs

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The goal of this work is to characterize a set of Centaurs in terms of their size, albedo, and thermal properties. The Herschel open time key program 'TNOs are Cool!'' observed 130 Centaurs and TNOs in 2009-2012. In this particular work we use Herschel/PACS three-band photometry to obtain monochromatic flux densities at 70, 100 and 160 μm. Additionally, we also incorporate Spitzer/MIPS flux densities at 24 and 70 μm when available. We use a consistent method for data reduction and aperture photometry to finally determine sizes and albedos of 16 Centaurs using radiometric techniques. We study the correlations between the size and albedo resulting from our models and other physical (i.e spectral slope) and orbital parameters using a more extended sample (obtained from literature). The final sample comprises 36 objects: 18 Centaurs observed with Herschel/PACS; 10 observed only with Spitzer and 8 SDOs. The first conclusion is that the albedo of the Centaurs is not determined by their orbit. Similarly we do not find any correlation between diameter and orbital parameters. We also find that most of the objects in our sample are dark (p_V < 7%) and most of them are small (D < 120km). However, we do not find any correlation between albedo and diameter, in particular for the group of the small objects we can find albedo values homogeneously distributed from 4 – 15%. When it comes to correlation with the color of the objects, we find that the red objects are all small (mean diameter 65 km), while the gray ones are either small or large (mean diameter 120 km). Also, the gray objects seem to be darker, with a mean value of 5.6%, while for the red objects the albedo can vary from 5 to 15%, with a mean value of 8.5%. All of this shows that there are other physical properties (size and albedo distribution) that make differences between the gray and red objects, even if we do not yet have a physical explanation for the origin of this bimodality.

508.05 – TNOs are Cool! Summary Results from the Herschel Key Programme

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Contributing teams: 27 more members of the Herschel 'TNOs Are Cool!' team

I will present a summary of results from our Herschel 'TNOs Are Cool' Key Programme to measure the thermal emission from over 130 trans-Neptunian objects and other outer solar system bodies. The sample includes TNOs in each of the dynamical classes, including Centaurs, and 2 satellites. The data were used to determine diameters and albedos for over 100 of those targets. We were also able to constrain the temperature distribution on the surfaces of over 80 objects, in many cases by combining the Herschel data with shorter-wavelength Spitzer measurements. The temperature distribution is controlled by the thermal inertia and roughness of the surface, and so gives deeper insight into surface processes in the outer Solar System. We also obtained thermal lightcurve observations for a few interesting targets (e.g. Haumea), and more extensive wavelength coverage (into the submm) characterization of dwarf planets (e.g. Makemake) and other bright object. Finally, the diameters measured in this program have been combined with mass-determinations for binary systems to give an intriguing first-look at the density of TNOs as a function of size. The results of the program were published in 14 journal articles so far, so I will focus on statistical properties of the sample, and a few highlights.

508.06 – Centaurs and Scattered Disk Objects in the Thermal Infrared: Analysis of WISE/NEOWISE Observations

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Contributing teams: WISE team, PTF team

The Wide-field Infrared Survey Explorer (WISE) observed 52 Centaurs and Scattered Disk Objects in the thermal infrared, including discoveries of 15 previously unknown objects. At this writing, this is the largest published collection of thermal infrared measurements of Centaur and SDOs. We present analyses of these observations to estimate sizes and mean optical albedos derived from photometry of the WISE images taken simultaneously at wavelengths of 3.4, 4.6, 12, and 22 microns. We find mean visual-wavelength geometric albedos of 0.08, +/- 0.04 standard deviations, for the entire data set. Thermal fits yield average beaming parameters of 0.9 +/- 0.2 that are similar for both SDO and Centaur sub-classes, and there appears to be no trend of beaming with heliocentric distance. Raw cumulative size distributions for objects with diameters > 20 km yield size-frequency distribution power law indices ~ -1.7 +/- 0.3. The data also reveal a relation between albedo and color at the 3-sigma level, with those objects with visual-wavelength B-R colors < 1.4 magnitudes having significantly lower albedos than those with B-R colors exceeding 1.4 magnitudes. No significant relation between diameter and albedos is found. We will also discuss the implications of these survey results concerning the related comet and TNO populations.

508.07 – The density of mid-sized Kuiper belt object 2002 UX25 and the formation of the dwarf planets

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The dramatic difference in rock-to-ice ratio – and thus density – between the ~350 km diameter and smaller objects in the Kuiper belt, which all have densities consistent with values below 1~g/cm3, and the ~850 km and larger objects, which all have densities above this value, is difficult to explain in any standard accretion scenario. An important clue to the cause of this density bifurcation could come from the measurement of the density of mid-sized Kuiper belt objects with diameters in between the two measured regimes. Here we report the orbital characterization, mass, and density determination of the 2002 UX25 system in the Kuiper belt. For this object, with a diameter of ~650 km, we find a density of 0.82 +/-0.11g/cm3, making it the largest known object in the Kuiper belt with a measured density below that of pure water ice. None of the currently proposed explanations for the high density of large Kuiper belt objects is supported by the existence of such a large low density system in the Kuiper belt. If the currently measured densities of Kuiper belt objects are a fair representation of the sample as a whole, standard pairwise accretion cannot build the ~1000 km and larger Kuiper belt objects with densities of ~2 g/cm3 from smaller objects with densities below 1 g cm3. Alternative formation mechanisms for dwarf planets, such as direct collapse from over dense regions of the disk, might provide more natural explanations of the observations.

508.08 – The 5:1 Resonance as Probed by the Canada-France Ecliptic Plane Survey

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We examined the 5:1 resonant Kuiper Belt Object (KBO) detections in the Canada-France Ecliptic Plane Survey (CFEPS) and calculated a population estimate for this significant dynamical sub-population. The CFEPS survey identified and classified KBOs in over 700 square degrees of sky, split between near ecliptic and high latitude fields. One object near the 5:1 resonance with Neptune was detected in the ecliptic fields, and three additional objects were detected in the CFEPS high latitude fields. Understanding the significance of object detections in a survey requires knowledge of the survey depth and followup observations in order to determine detection efficiencies for an underlying population. The detection biases against finding these distant resonators are additionally complex due to the phase relationships between resonant objects and Neptune. Objects in a 5:1 resonance with Neptune can only reach perihelion at approximately 70, 180, or 290 degrees from Neptune, with the width of these resonant islands dependent on libration amplitude. CFEPS only detected 5:1 resonant objects near perihelion due to their large semi-major axes, approximately 88 AU. Because of this perihelion dependence, the survey pointings introduce a significant bias into the detection efficiency. The large eccentricities and inclinations of the detected objects also suggests a significant underlying population. The 5:1 resonant population is a cosmogonic lever which provides insight into the evolutionary history of the solar system.

508.09 – Trojans and Plutinos as probes of planet building

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Planetesimals formed during planet formation are the building blocks of giant planet cores; some are preserved as large trans-neptunian objects (TNOs). Previous work has shown steep power-law distributions for TNOs of diameters > 100 km. Recent results claim a dramatic roll-over or divot in the size distribution of Neptunian Trojans and scattering TNOs, with a significant lack of intermediate-size D<100 km planetesimals. One theoretical explanation for this is that planetesimals were born big, skipping the intermediate sizes, contrary to the classical understanding of planetesimal formation. Exploration of the TNO size distribution requires more precisely calibrated detections in order to improve statistics on these results. We have searched a 32 sq.deg. area near RA=2 hr to a r-band limiting magnitude of m_r=24.6 using the Canada-France-Hawaii Telescope. This coverage was near the Neptunian L4 region to maximise our detection rate, as this is where Trojans reside and where Plutinos (and several other resonant populations) come to perihelion. Our program successfully detected, tracked and characterized 77 TNOs and Centaurs for up to 17 months, giving us the high-quality orbits needed for precise modelling. Among our detections were one Uranian Trojan (see Alexandersen et al. 2013 & abstract by Greenstreet et al.), two Neptunian Trojans, 18 Plutinos and many other resonant objects. This meticulously calibrated survey and the high-quality orbits obtained for the detected objects allow us to create and test models of TNO size and orbital distributions. We test these models using a survey simulator, which simulates the detectability of model objects, accounting for the constraints and biases of our survey. Thus, we set precise constraints on the size and orbital distributions of the Neptunian Trojans, Plutinos and other resonant populations. We show that the Plutino inclination distribution is dynamically colder than found by the Canada-France Ecliptic Plane Survey. We also show that the Plutino size distribution cannot continue with the same slope for diameters < 100 km; a best-fit alternative will be presented. This research was supported by the Canadian National Sciences and Engineering Research Council.

509 – Jovian Planets 2: Atmospheric Dynamics and Saturn's 2010 Storm

509.01 – Off-equatorial jets in Jupiter's and Saturn's atmospheres

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Jupiter and Saturn have similar radii, rotation rates, and atmospheres. Yet their off-equatorial jets differ markedly: Jupiter has 15~20 off-equatorial jets, with speeds at the level of the visible clouds around 20 m/s; Saturn has only 5~10 wider off-equatorial jets, with speeds around 100 m/s. Here it is shown that the differences between the off-equatorial jets can be accounted for by differences in the magnetohydrodynamic (MHD) drag the jets experience in the planetary interiors. The relation between jet characteristics and drag strength is examined systematically through simulations with a general circulation model (GCM). The GCM domain is a thin spherical shell in the upper atmosphere of a giant planet, with flow parameters relevant for Jupiter. Rayleigh drag at an artificial lower boundary (with mean pressure of 3~bar) is used as a simple representation of the MHD drag the flow on giant planets experiences at depth. The drag coefficient is varied to investigate how it affects characteristics of off-equatorial jets. As the drag coefficient decreases, the eddy length scale and eddy kinetic energy increase. Jets become wider and stronger, with increased interjet spacing. Generally, the jet widths scale with the Rhines scale, which is of similar magnitude as the Rossby radius in the simulations. The jet strengths increases primarily through strengthening of the barotropic component, which increases as the drag coefficient decreases because the overall kinetic energy dissipation remains roughly constant: an increasing mean flow

strength in the drag layer roughly balances a decreasing drag coefficient to lead to the same kinetic energy dissipation. The overall kinetic energy dissipation remains roughly constant presumably because it is controlled by baroclinic conversion of potential to kinetic energy in the upper troposphere, where differential solar heating has an influence; this baroclinic conversion is only weakly dependent on bottom drag and barotropic flow variations. For Jupiter and Saturn, these results imply that the wider and stronger jets on Saturn may arise because the MHD drag on Saturn is weaker than on Jupiter.

509.02 – Modeling the Transition From Jets to Polar Turbulence in Giant Planet Atmospheres

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The atmospheric dynamics of Jupiter and Saturn can be characterized by their cloud-top zonal mean wind. At the equator, both Jupiter and Saturn have strong superrotating eastward jets. Away from the Equator, jets alternate eastward and westward. The spaces in between are filled with vortices. Near the poles, the cloud-top dynamical structures diverge. Poleward of 65 S and N on Jupiter, no jets are observed; vortices come to dominate the flow. We identify the high-latitude, vortex-dominated dynamic regime as polar turbulence. On Saturn, the regime of mixed zonal jets and vortices continues to the pole. We propose that the stability of jets and/or their ability to form at high latitudes is the determining condition for polar turbulence on Jupiter. We have investigated the conditions under which jets form with three-dimensional simulations on the beta-plane with the EPIC model. These simulations receive a continuous random forcing of positive, local mass pulses balanced by compensatory negative mass addition. The result is a turbulent forcing that does not change the uniform static stability of the model atmosphere. A previous study of jet formation from freely-evolving turbulence using EPIC suggested that jet formation was strongly controlled by the Rossby deformation radius (the scale on which the flow is significantly affected by the Coriolis force) and the Rhines length (the scale to which vortices can grow by merger). By modifying the Coriolis parameter, the Rossby deformation radius can be specified. The Rhines length freely evolves with the simulation but can be somewhat controlled a priori. We will present these simulations, which explore: (1) a wide phase space of deformation radius and Rhines length at a characteristic gravity value for Jupiter; (2) similar phase space at a characteristic gravity value for Saturn; and (3) simulations that investigate the sensitivity of the simulations to certain characteristics of the turbulent forcing. Analysis of (1) has identified optimal and non-optimal phase spaces for jet formation that are broadly consistent with prior study of freely evolving turbulence. Our study is supported by NASA Outer Planet Research Program grant NNX12AR38G.

509.03 – Atmospheric Circulation of Highly Tilted Planets

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For planets with axial tilts greater than 54 degrees such as Uranus, the poles will receive greater insolation than the equator when averaged over the year. This raises fundamental questions concerning the atmospheric circulation on such a planet. What is the behavior and directionality of the resulting Hadley Cell on such a planet? Does it flow in the opposite sense to most other planets? Observations of Uranus show a remarkably constant temperature structure with latitude, suggesting whatever the dominant meridional heat transport mechanism might be, it is likely efficient. What is the strength and directionality of the zonal winds? This defining characteristic of planetary climate presents a question of competing effects. As the temperature increases from the equator to the poles, the thermal wind equation suggests retrograde mid-latitude zonal jets should develop. On the other hand, meridionally propagating Rossby waves generated in the mid-latitudes by baroclinic instabilities will converge eastward momentum into the instability latitude, suggesting the development of prograde mid-latitude zonal winds. It is not immediately obvious which effect will prevail for a given set of atmospheric parameters, and perhaps Uranus' prograde jets are only one possible outcome. To explore these questions, we have created a modified form of the Held-Suarez benchmark using the MITgcm with a hot pole-cold equator temperature gradient. We present simulation results for a variety of radiative and drag time constants, as well as varying stratification. We describe how the overall dynamics (including the Hadley cell, mid-latitude baroclinic eddies, and zonal jets) differ in this regime relative to the standard hot-equator, cold-poles configuration. Implications for Uranus/Neptune and exoplanets will be discussed.

509.04 – Global climate modeling of Saturn's atmosphere: fast and accurate radiative transfer and exploration of seasonal variability

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Recent observations of Saturn's stratospheric thermal structure and composition revealed new phenomena: an equatorial oscillation in temperature, reminiscent of the Earth's Quasi-Biennal Oscillation ; strong meridional contrasts of hydrocarbons ; a warm "beacon" associated with the powerful 2010 storm. Those signatures cannot be reproduced by 1D photochemical and radiative models and suggest that atmospheric dynamics plays a key role. This motivated us to develop a complete 3D General Circulation Model (GCM) for Saturn, based on the LMDz hydrodynamical core, to explore the circulation, seasonal variability, and wave activity in Saturn's atmosphere. In order to closely reproduce Saturn's radiative forcing, a particular emphasis was put in obtaining fast and accurate radiative transfer calculations. Our radiative model uses correlated-k distributions and spectral discretization tailored for Saturn's atmosphere. We include internal heat flux, ring shadowing and aerosols. We will report on the sensitivity of the model to spectral discretization, spectroscopic databases, and aerosol scenarios (varying particle sizes, opacities and vertical structures). We will also discuss the radiative effect of the ring shadowing on Saturn's atmosphere. We will present a comparison of temperature fields obtained with this new radiative equilibrium model to that inferred from Cassini/CIRS observations. In the troposphere, our model reproduces the observed temperature knee caused by heating at the top of the tropospheric aerosol layer. In the lower stratosphere (20mbar

509.06 – Cassini ISS Analysis of Saturn's Northern High-Latitudes and the Aftermath of the 2010 Great Storm

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We present our analysis of Saturn's northern hemisphere using images captured by Cassini ISS camera. Saturn's north pole emerged from winter darkness in August 2009; however, the spacecraft stayed in the equatorial plane and the polar regions remained out of view. The spacecraft went into a high-inclination orbit in late 2012 and started returning visible-light images of the north pole. Our images revealed a large cyclonic vortex centered on the north pole. In the System III reference frame (rotation period of 10h39m19s, Seidelmann et al 2007), the wind speed peaks at about 150 m s^{-1} at 89 degree N planetocentric latitude. The vorticity peaks at the pole at 8.9×10^{-4} s^{-1}. The zonal wind speed drops to 10±10 m s^{-1} at around 80 degree N, and peaks again at 100±10 m s^{-1} at 76 degree N. The 76 degree N zonal jet follows the outline of the Hexagon originally discovered during the Voyager flybys (Godfrey, 1988). We detect a non-zero westward propagation speed of the Hexagon with respect to the System III reference frame. We also present an update on the aftermath of the 2010-2011 Great Storm on Saturn as the region continues to evolve. The anticyclonic vortex that was spawned by the storm continues to drift eastward. The 42 degree N eastward jet has developed a dark streak in a bright band, reminiscent of its appearance during the Voyager flybys when the wave was called the Ribbon. We also continue to monitor the zonal wind speed. Our study is supported by the Cassini Project, NASA Outer Planet Research Program grant NNX12AR38G, and NSF Astronomy and Astrophysics grant 1212216.

509.07 – IRTF/TEXES observations of Saturn's stratospheric beacon

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On December 5th, 2010, a giant convective storm erupted in Saturn's Northern Hemisphere as each Saturnian year at least since 1876. For the first time, a huge thermal and chemical stratospheric disturbance associated with this large convective event was detected from ground-based and Cassini observations (Fletcher et al. 2011). This stratospheric disturbance is named the beacon. Here, we present high spectral resolution observations of the beacon obtained by the Texas Echelon Cross Echelle Spectrograph (TEXES) mounted on the IRTF during 6 nights from July 15th, 2011 to July 20th, 2011. We targeted several different CH4 lines between 1230 and 1280 cm-1, probing the stratospheric temperature between 5 hPa and 0.05 hPa, and the H2 S(1) quadrupolar and collision-induced lines at 587 cm-1, probing the stratospheric temperature between 150 hPa and 5 hPa. The stratospheric temperatures are retrieved from the dataset using a forward radiative model coupled with a constrained linear inverse method. Within the core of the beacon the maximum temperature inferred from the data is 178K at 40°N, hence about 50K warmer than the mean temperature measured before the occurrence of the storm. However, the TEXES data unambiguously demonstrate that this warming is not vertically homogeneous but rather confined in a specific pressure range between 1-5 hPa, overhung by a cold layer between 0.1 and 1 hPa. This vertical behavior is evident from the CH4 line spectral profiles with the core of the lines in absorption and the wings in emission. Moreover, our data demonstrate that the altitude of the local temperature maximum increases northwards. We will present how this thermal structure can help deciphering the stratospheric heating sources. On the western side of the beacon, the stratospheric heating is concentrated at lower pressures, hence higher altitudes, than within the beacon, between 0.1 and 0.01 hPa. We interpret this structure as being caused by convective motions within the beacon, and westward advection associated with a vertical shear of stratospheric zonal winds.

509.08 – Evidence for Ammonia and Water Ices as the Primary Components of Cloud Particles in Saturn's Great Storm of 2010-2011

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Saturn's Great Storm of 2010-2011 was a major convective eruption that lofted deep atmospheric aerosols up to the visible cloud tops, providing a rare view of normally hidden materials produced at great depths. These materials produce absorption near 3 microns, which is not seen on Saturn outside of storm regions. We used near-infrared spectra of the storm, obtained by the Visual and Infrared Mapping Spectrometer on the Cassini orbiter, to constrain the composition of the cloud particles. We found compelling evidence that the storm cloud contains a multi-component aerosol population comprised primarily of ammonia ice, with water ice the best-defined secondary component. The most likely third component is ammonium hydrosulfide or some weakly absorbing material similar to what dominates visible clouds outside the storm region. Horizontally heterogeneous cloud models favor ammonium hydrosulfide as the third component, while horizontally uniform models favor the weak absorber. Both models rely on water ice absorption to compensate for residual spectral gradients produced by ammonia ice from 3.0 microns to 3.1 microns and need the relatively conservative third component to fill in the sharp ammonia ice absorption peak near 2.96 microns. The best heterogeneous model has spatial coverage fractions of 55% ammonia ice, 22% water ice, and 23% ammonium hydrosulfide. The best homogeneous model has an optically thin layer of weakly absorbing particles above an optically thick layer of water ice particles coated by ammonia ice. These Cassini data provide the first spectroscopic evidence of water ice in Saturn's atmosphere. The presence of water ice in this major storm supports the hypothesis that these convective storms are powered by condensation of water and originate in the 10-20 bar depths of Saturn. This research was supported by NASA's Outer Planets Research Program under grant NNX11AM58G.

509.09 – Modeling Saturn's Giant Storms: Water, Ammonia, and the 30-Year Periodicity

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A giant planet-encircling storm occured on Saturn at the end of year 2010. The storm produced lightning at a rate greater than 10 SEDs per second. It wrapped around the planet, with a wake depleted in ammonia, and after 6 months it died. These kinds of storms are rare and episodic. They happen every 20-30 years. In this study, we discuss the role of moist convection on the development of the storm and explain the observed post-storm ammonia depletion. The study is composed of two parts. First, thermodynamcis on Saturn indicates that strong convection is prohibited by the waterloading-effect when the troposphere is warm. After 20-30 years, the troposphere has cooled below a critical value so that deep convection develops at the base of the water cloud. The deep water mixing ratio is best estimated as 1.2% relative to H2 so as to match the cooling time. Second, strong convection can produce a warm convective column that overshoots into the stratosphere. We solve the cylindrically symmetric hydrostatic primitive equations to investigate the large scale response of the ambient flow to the geostrophically unbalanced column. We find that during the subsequent large scale adjustment, ammonia vapor condenses and precipitates out of the troposphere, causing high residual brightness temperatures as observed by Cassini/RADAR (Janssen et al., 2013; Laraia et al., 2013). Further, for a deep water mixing ratio of 1.2%, we find that the ammonia vapor is depeleted down to 5 bar, that the speed of remaining anticyclonic vortex is about 30 m/s, and the residual large scale warming is about 10 K. These values are consistent with observation within the measurement uncertainties.

510 – Origins 2: Giants and Pebbles

510.01 – Enhancement of the Accretion of Jupiter's Core by a Voluminous Low-Mass Envelope

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We present calculations of the early stages of the formation of Jupiter via core nucleated accretion and gas capture. The core begins as a seed body of about 350 kilometers in radius and orbits in a swarm of planetesimals whose initial radii range from 15 meters to 100 kilometers. We follow the evolution of the swarm by accounting for growth and fragmentation, viscous and gravitational stirring, and for drag-induced migration and velocity damping. Gas capture by the core substantially enhances the cross-section of the planet for accretion of small planetesimals. The dust opacity within the atmosphere surrounding the planetary core is computed self-consistently, accounting for coagulation and sedimentation of dust particles released in the envelope as passing planetesimals are ablated. The calculation is carried out at an orbital semi-major axis of 5.2 AU and an initial solids' surface density of 10 grams per square centimeter at that distance. The results give a core mass of 7 Earth masses and an envelope mass of ~ 0.3 Earth mass after 500,000 years, at which point the envelope growth rate surpasses that of the core. The same calculation without the envelope gives a core mass of only 4 Earth masses.

510.02 – On the Minimum Core Mass for Giant Planet Formation

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In the core accretion hypothesis, giant planets form by accreting gas from the protoplanetary disk onto a solid core. Ten Earth masses (10 M_E) is often quoted as the minimum or critical core mass required to form a gas giant. However, the critical core mass can vary greatly depending on various quantities, including: the location in and conditions of the disk, the atmospheric composition and opacity (which may differ from the disk) and the accretion rate of planetesimals or smaller solids. To investigate these issues, we consider the growth of atmospheres in the limiting case of a fixed core mass with no ongoing accretion of solids. We thus obtain absolute lower limits on the critical core mass because additional heat sources limit the ability of the atmosphere to cool and undergo Kelvin-Helmholtz contraction. To study this contraction over a wide range of parameter space, we develop a simplified two-layer cooling model. The model's main approximation is that atmospheric luminosity is primarily generated in the convective interior, so that the luminosity generated in the radiative exterior can be neglected. We focus our attention on the outer region of protoplanetary disks, where our approximations are more valid, and where direct imaging searches are finding giant planets that constrain formation models. To form a gas giant, we require that runaway gas growth occurs within 3 Myr, a characteristic disk lifetime, though the time to grow the core (in situ or otherwise) is not included. Our main finding is that the critical core mass declines with distance in the disk. For our standard model, the critical core mass drops from 8.5 M_E at 5 AU to 3.5 M_E at 100 AU. This result arises primarily from lower disk temperatures. A lower disk density or pressure (at fixed temperature) only modestly increases critical core masses. Lowering the opacity also gives lower critical core masses. We also develop a simplified analytic cooling model, which explains the basic trends and shows that atmospheric self-gravity plays a crucial role in atmospheric growth – even when the atmosphere is less massive than the core.

510.03 – Pebble formation at the water ice line

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Particle growth to pebble-sizes is an important first step towards the formation of planets, but dust coagulation models and experiments show that growth by collisions of rocky particles becomes inefficient at millimeter-sizes. However, close to ice lines growth can proceed both by condensation and via collisions involving sticky ice particles. We have developed a dynamical model of condensation and sublimation at the water ice line and find rapid growth from millimeters to several centimeters on a time scale of 10 000 years in turbulent protoplanetary discs. Small ice grains are coupled to the gas via drag forces and move in a turbulent diffusion, modelled as a random walk. Some of these particles diffuse either inwards or upwards from the outer, cold midplane region and sublimate. The resulting vapour recondenses onto already existing particles, leading to growing pebbles that decouple from the turbulent eddies and sediment towards the cold midplane. We model condensation and sublimation in a Monte Carlo scheme, and ignore collisions. We find resulting particles that are large enough to grow further into planetesimals and planets through dynamical instabilities, such as the streaming instability, and through pebble accretion.

510.04 – Formation and Composition of Giant Planets by Pebble Accretion

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In the core accretion scenario a giant planet forms by the accretion of a gaseous envelope onto a solid core. The accumulation of solid material needs to be completed before dissipation of the protoplanetary disc within approximately 3 Myr. Forming these cores with planetesimal collisions within the available time is challenging at wide orbital distances beyond 10 AU. However, recently we found that core growth by the accretion of pebbles, particles of approximately cm sizes, is sufficiently rapid to explain the in situ formation of wide orbit giant planets. In this talk, we show how fast pebble accretion and the associated high luminosity influences the composition of giant planets. We find that gas giants naturally form in regions behind the ice line, while at even wider orbital distances we naturally form planets with an ice giant composition.

510.05 – Gas Accretion by Giant Planets: 3D Simulations of Gap Opening and Dynamics of the Circumplanetary Disk

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What sets the terminal mass of a giant planet once the latter enters into a runaway gas-accretion phase? The formation of a gap around the planet's orbit may be an answer, provided that the gap is wide and deep enough. A wide-spread idea is that this happens if the viscosity in the circumstellar disk is small, i.e. if planets form in the 'dead zone'. With 3D hydrodynamical simulations we study the formation of a gap in details. We find an interesting 4-step meridional loop in the gas dynamics: (1) the gas flows into the gap at the top layer of the disk; (2) then it falls towards the disk's midplane; (3) the planet keeps the gap open by pushing this infalling gas back into the disk; (4) the gas rises back to the disk's surface, which closes the loop. The gas flow in this loop is governed by the viscous timescale at the surface of the disk. It is generally accepted that the surface layer of the disk is MRI-active and viscous, even if a dead zone is present near the midplane. Thus, there should always be enough gas flowing into the gap for a Jupiter-mass planet to accrete at a fast rate, in absence of other regulation mechanisms. However, only a very small portion of the gas flowing into the gap is directly accreted by the planet. Most of the gas falling towards the planet forms a circumplanetary disk (CPD), due to angular momentum conservation. If the CPD is MRI-inactive, as suggested by Turner et al. (2010) and Fujii et al. (2011), it can act as a bottle-neck for planet accretion. We find that the main mechanism that allows the CPD to lose angular momentum is the torque exerted by the star via a spiral density wave. We compute that this promotes the accretion of 0.025% of the mass of the CPD per year, for a Jupiter mass planet at 5.2 AU, independent of viscosity. By balancing the pressure of the vertical inflow with that internal to the CPD, we estimate that the CPD should contain less than 1% of the planet's mass. This leads to a mass-doubling timescale for Jupiter longer than half a My, i.e. of the order of the timescale of existence of circumstellar disks. A wide variety of giant planets terminal masses can result from the equivalence of these two timescales.

510.06 – Giant Planet Formation with Pebble Accretion

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In the core accretion model, a giant-planet core forms from dust in a protoplanetary disk and accretes gas when the core reaches a critical mass. Both stages must occur in a few My before the disk disperses. The slowest stage may be oligarchic growth in which a core grows by sweeping up planetesimals. Here, I describe new simulations of oligarchic growth that include (i) planetesimal fragmentation due to mutual collisions, (ii) the capture of planetesimals by a core's atmosphere, (iii) drag with the disk gas during encounters with the core ("pebble accretion"), (iv) particle velocities due to turbulence and drift caused by gas drag, and (v) a population of small "pebbles" that represent the transition between disruptive collisions between larger particles, and mergers between dust grains. Planetesimal collisions rapidly form a large population of pebbles. The rate at which a core sweeps up pebbles is controlled by pebble accretion dynamics, and depends strongly on pebble size. Large pebbles lose energy during an encounter with a core due to drag, and settle towards the core, greatly increasing the capture probability. Small pebbles are tightly coupled to the gas and most are swept past the core rather than being captured. The strength of turbulence in the gas mainly affects the scale height of pebbles in the disk, altering the rate at which they are accreted. Planetesimal size mainly determines the rate of mutual collisions and pebble production. Critical-mass cores can form at 5 AU from the Sun within 3 My if pebbles are 3 cm to 1 m in diameter, and the solid surface density is at least 8 g/cm^2 .

510.07 – Terrestrial Planet Formation in a protoplanetary disk with a local mass depletion: A successful scenario for the formation of Mars

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Models of terrestrial planet formation have been successful in producing terrestrial-class planets with sizes in the range of Venus and Earth. However, these models have generally failed to produce Mars-sized objects around 1.5 AU. The body that is usually formed around Mars' semimajor axis is, in general, much more massive than Mars. Only when Jupiter and Saturn are assumed to have very eccentric orbits, or alternately, if they have experienced a wide inward-then-outward migration in a gas-rich phase, simulations have been able to produce Mars-like bodies. In this work, we have examined a different scenario for the formation of Mars in which a local depletion in the density of the protosolar nebula results in a non-uniform formation of planetary embryos. We have carried out extensive numerical simulations of the formation of terrestrial planets in such a disk for different scales of the local density depletion, and for different orbital configurations of giant planets. Our simulations point to the possibility of the formation of Mars-sized bodies around 1.5 AU, specifically when the scale of the disk local mass-depletion is moderately high (50-75%) and Jupiter and Saturn are initially in their current orbits. In these systems, Mars analogs are formed from the protoplanetary materials that originate in the region of disk where there is no local mass-depletion. Results also indicate that in the same systems Earth-sized planets can form around 1 AU with a substantial amount of water due to accretion of water-rich material originated from past 2 AU. We present the results of our study and discuss their implications for the formation of terrestrial planets in our solar system.

510.08 – Experimental Studies of Low-Velocity Dust Aggregate Collisions

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Small particles and aggregates (centimeter-sized and smaller) may collide with very low relative velocities (< 1 m/s) in proto-planetary disks and planetary ring systems. These relatively gentle collisions may play a crucial role in the growth of larger bodies, eventually building up to planetesimal sizes. We have developed an experimental apparatus with which we can simulate these low-velocity collisions in a laboratory vacuum environment. Collisions are initiated by launching two aggregates toward each other in a vacuum bell-jar system. Using this design, we can achieve a variety of pre-collision relative velocities, with minimum values

~ 0.7 m/s. We describe a set of experiments that uses powdered chalk as the primary aggregate material because of its highly cohesive properties. We are also exploring the use of other materials, such as regolith simulants. Parameters varied include mass, size, and aggregate structure. We observe the pre-, during, and post-collision motion of the colliding bodies with a high-speed, high-resolution digital video camera. The resulting videos are then processed to determine the coefficient of restitution of the aggregates as a function of aggregate properties and collisional velocity. In addition we can determine under what conditions there is mass transfer, fragmentation, and sticking of the colliding aggregates. By measuring the coefficient of restitution we can develop an improved empirical model of collisional outcomes that will lead to a better understanding of proto-planetesimal collisional growth and planetary ring collisional evolution.

510.09 – Re-accretion Efficiencies in Small Impactor – Large Target Collisions

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During the formation process of planets, small dust particles grow to km-sized planetesimals via collisions. While the collision partners are equally sized in early phases, fragmentation, catastrophic destruction and other recycling processes can lead to collisions between partners with various size ranges. The gas in protoplanetary disks exerts size- and mass-dependent drag forces on the dust particles and bodies present which is why the relative velocities between the small particles and larger bodies increase. A field of investigation are the small-impactor large-target collisions where (partial) erosion can occur and small ejected dust particles can be produced. These ejecta can couple to the gas quite rapidly and can then be recaptured by the target and stick to it in secondary collisions. We use a Monte-Carlo code to calculate re-accretion efficiencies under certain conditions i.e. in free molecular flow regime (stream lines end on target body; impactors are completely coupled to the gas). Using experimental data we developed a model for the amount, masses, directions, and velocities of the ejecta depending on the impactor mass and velocity and the position of impact. The amount of re-accreted ejecta as well as the total re-accreted mass can be determined by using the solution of the equation of motion for particles in gaseous environments. Both – the amount dependent efficiency as well as the mass dependent efficiency – are highly dependent on the seven free parameters (impact velocity, impactor size and density, target size and density, gas pressure and temperature) but generally benefit from high gas velocities and a large size difference between target and impactor. Our final intention is to provide an analytical expression for the re-accretion efficiencies in respect to the free parameters and to use this in different disk models for sweeping the free parameters dependent on the distance to the central star. One major advantage of our code is the possibility of implementing and changing calculation models for every parameter very quickly. In this context future stages of development can include gas flow profiles which can highly affect the motions of the ejecta or even those of the impactors.

511 – TNOs and Centaurs 3: Dynamics and Occultations

511.01 – The size-distribution of scattering TNOs observed by La Silla - QUEST

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Now in its final year of operation, the La Silla - QUEST (LSQ) survey for distant solar-system objects [1] has covered most of the southern hemisphere to magnitude limit R = 21.4. The total number of detected TNOs and Centaurs exceeds 108, more than any other full-hemisphere survey of the outer system. These bodies have been found at distances ranging from 10 to 100 AU, at ecliptic latitudes ranging from 0 to 40 deg, and over a size range of 15 to 2500 km. Nearly all have well-determined orbits from observations covering wide arcs or multiple oppositions. The efficiency of the survey has also been well characterized, with careful attention to maintaining a constant level of sensitivity. Remarkably, the LSQ observations of actively scattering TNOs spans the ~100 km knee in the size distribution which has been difficult for smaller-area, deeper surveys to detect. The results of the LSQ survey thus present a unique opportunity to constrain the total number and size distribution of the Centaurs and their likely parent population at the same time. Here we present preliminary results for the R-band absolute magnitude distribution of the actively scattering TNOs and discuss the implications for the existence of a 'divot' at ~100 km as reported by Shankman et al [2]. [1] Rabinowitz, D. et al. 2012, AJ, 144, 140; [2] Shankman, C. et al. 2013, ApJ, 764, 2

511.02 – The incremental size distribution of scattered disk TNOs from that of JFCs between 0.2 and 6 km effective radius.

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Under the assumptions that the scattered disk TNO population (SDs) can be considered in a steady state over a timescale of approximately 100 My and that the level of observed activity among the Centaurs has a negligible effect on their size distribution, we deduce the current incremental size (effective radius) distribution of SDs from the observed JFC size distribution in the range from approximately 0.2 to 6 km. This range of effective radius is of particular interest since it almost spans an observationally unexplored region between larger, measured, TNOs (above 15 km) and an estimate of the TNO population near 0.2 km by Schlichting et al. (2012). The existence of a dynamical linkage between SDs, Centaurs and JFCs like that worked out numerically by Levison and Duncan (1997) is also presumed to operate and is essential to this work. We deduce a continuous version of the incremental JFC distribution from a range of published results and, based on a model for observational selection worked out by Meech et al. (2004), approximately remove the effects of observational selection. The resulting distribution is then adjusted by an observationally based correction for mass-loss in the JFC region to yield the size distribution of the JFC source population, which is, following the assumptions noted above, identical with that of the SDs. The deduced distribution function has a slope at the larger end similar to that observed for larger TNOs and, when transferred to the Kuiper belt, can pass through Schlichting et al's. occultation point at the small end providing that the mass-loss experienced by JFCs is larger than that expected for H2O sublimation alone. This work is part of an ongoing, larger, study, that has been supported in part by the NASA Stardust-Next and EPOXI missions, which is designed to address the question of whether the comet nuclei observed by these and other missions are primitive agglomerations or collisional fragments (possibly rubble piles) either of which has experienced considerable evolution while a JFC.

511.03 – A dynamical pathway to produce the Hot Kuiper Belt orbits

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After the first discoveries of trans-Neptunian objects in the early 1990's, it has become increasingly clearer that the Kuiper Belt would be very different from what was first conjectured. Perhaps the most intriguing feature is related to very inclined orbits with respect to the ecliptic plane (where supposedly all Solar System bodies had formed). In this work we propose a dynamical mechanism to form the hot component of the classical Kuiper Belt ($39.4 < a < 47.8$au and $i > 4$ deg). The mechanism requires that scattered particles from the primordial planetesimal disk are trapped by external mean motion resonances (MMRs) with Neptune. Once in MMR, they are able to enter the Kozai resonance, where coupled variations in eccentricity and inclination appear. When the MMR critical angle has a very high libration amplitude, some particles can access the so-called hibernating mode, where they usually stay with low eccentricity and high inclination for a long time. If these proccess occur while Neptune is still experiencing a residual migration, many of the hibernating objects can be detached. We show that a large fraction of objects in the hot classical belt can be formed following this dynamical pathway. The proposed mechanism is generic in the sense that it can occur both in Nice and smooth models. Our results are consistent with the actual hot population, after debiased with the CFEPS simulator.

511.04 – Beyond the Kuiper Belt Edge: Sednoids and the Inner Oort Cloud

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The Kuiper Belt is thought to be a relic from the original protoplanetary disk. This region contains some of the least processed material in the solar system and is the suspected source of the Centaurs and short period comets. Currently there are over one thousand Kuiper Belt objects known with perihelion between about 30 and 50 AU. Only one object is known to have a perihelion significantly beyond 50 AU (Sedna at 76 AU) even though shallow surveys to date should have found many such Sednoids if the size distribution beyond this ` `edge'' is similar to what has been seen elsewhere in the Kuiper Belt. The strong size and heliocentric distance dependence of the flux density of sunlight scattered from an object requires a survey to obtain very faint magnitudes in order to access the population of objects of size 100 km and less beyond 50 AU. Kuiper Belt surveys to date have not been optimized to survey beyond the Kuiper Belt edge at 50 AU as they have either covered large areas but been to shallow depths (less than 23rd mag), have gone deep but covered a very small area of sky (a few square degrees), or do not have the required cadence to detect the ultra slow moving Sednoids or inner Oort cloud objects that are well beyond 50 AU. We are performing an ultra-deep wide-field outer solar system survey with the wide-field imagers on the large class Magellan 6.5 m and Subaru 8 m telescopes to determine if the objects beyond 50 AU are fainter than expected, if there is truly a dearth of objects, or if the Kuiper Belt continues again after some sizable gap possibly caused by a planet sized object. This survey is the widest deepest survey for such distant objects ever obtained. We will constrain the origin of Sedna and determine if this eccentric, distant body is unique (as once believed for Pluto) or just the first of a new class of object in the outer Solar System.

511.05 – A Search for Extremely Distant Sedna-Like Objects Using DECam

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We present initial results of a survey for the most distant objects in the solar system. Our survey utilizes the Dark Energy Camera (DECam) on the prime focus of the Cerro Tololo Inter-American Observatory (CTIO) 4m Blanco telescope. DECam, with its 3 square degree field of view, is the largest camera in the world on a 4 meter class (or larger) telescope. Our primary survey goal is to find new Sedna-like objects. Sedna has a perihelion of 76 AU, significantly larger than any other object in the solar system. It is difficult to explain the formation of such objects without invoking external dynamical interactions, such as a primordial close passage between our young solar system and another star. Conservative assumptions suggest that a Sedna-like population could easily outnumber the Kuiper Belt Objects (KBOs). To date, Sedna is the only member of its class. Our goal is to find more Sedna-like bodies to measure basic population and orbital statistics of this interesting dynamical class. DECam provides a unique combination of survey depth (red magnitudes of 24 or deeper) and breadth (a large 3 square degree field of view) allowing unparalleled constraints on the Sedna population. We discuss our basic survey methodology and analysis methods for this data-intensive campaign; roughly 120 Gigabytes of survey field data are collected per clear night. We also present object statistics from a few nights of DECam observations where we surveyed a few hundred square degrees to depths beyond red magnitude 24. In addition to detecting hundreds of KBOs, we have found several objects beyond 60 AU. We are refining the orbits of these distant objects to determine if they could be newly discovered members of the elusive Sedna population.

511.06 – The UT 8 February 2013 Sila-Nunam Mutual Event & Future Predictions

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A mutual event of the Kuiper Belt binary system (79360) Sila-Nunam was observed over 15.47 hours on UT 8 February 2013 by a coordinated effort at four telescopes: Telescopio Nationale Galileo in the Canary Islands, the du Pont telescope at Las Campanas Observatory, ARC at Apache Point Observatory and the IRTF on Mauna Kea. It is the first full event observed from start to finish for this binary system. The lightcurve is consistent with two objects of similar, but perhaps not identical, size and albedo. We will present the results from this event and predictions for future events which have been refined by this and other mutual event observations obtained since the events began.

511.07 – High Precision Lightcurves of A Mutual Event of Transneptunian Binary (79360) Sila-Nunam From Gemini Observatory

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Cold-classical Kuiper Belt binary (79360) Sila-Nunam is in the midst of a decade-long mutual event season in which its nearly equal-sized components occult and eclipse each other as viewed from Earth (Grundy et al. 2012 Icarus 220, 74-83). On 14 February 2013 UT, the Gemini Multi-Object Spectrograph (GMOS-N) camera at Gemini Observatory on Mauna Kea, Hawai'i imaged nearly an entire inferior event in which Nunam, the smaller of the two objects, eclipsed and occulted Sila. Alternating 200-second exposures in Sloan r' and i' filters continuously during the 9.3-hour event produced lightcurves containing information about sizes, colors, shapes, and albedo patterns on the system components. This mutual event is a rare opportunity to determine physical characteristics of a surface which has likely been unaltered since the time of Solar System formation. A. Verbiscer acknowledges support from NASA Planetary Astronomy. W. Grundy acknowledges support from NSF Planetary Astronomy.

511.08 – TNO Occultations with RECON

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One highly prized measurement of any object is to know its size so that if you know the density you can work out the mass, or, if you know the mass you can derive the density. Thermal measurements have been made from many facilities, including the Spitzer Space Telescope and the Herschel Space Telescope. These observations, combined with thermal models, provide useful constraints on sizes of trans-Neptunian objects (TNOs). Similar efforts on asteroids shows the value of such measurements. However, models need to be validated in the much colder conditions of the outer solar system. A complementary method for measuring size is to observe stellar occultations by TNOs and use these measurements to refine thermal models. Additionally, occultations of binary TNOs can provide independent sizes of both objects, something that is very difficult to do with thermal techniques. The biggest challenge to obtaining an occultation is in predicting ground-tracks. Several of the largest and brightest TNOs have been successfully measured in this way. Our project focuses on objects down to 100km in diameter and includes more than half of the known population. This size range is particularly important for measuring properties of the cold-Classical TNOs – objects in low eccentricity and low inclination orbits near 43AU. These objects also happen to be the most likely to be binaries. These binaries are particularly interesting since we already have system masses and size is all that remains for determining an accurate density. The cold-Classicals have also turned out to be problematic in being high in albedo and thus colder making it much harder to get thermal measurements. This presentation will cover a newly funded NSF project to build a network for the purpose of getting occultation diameters of TNOs. Our pilot project uses 28-cm telescopes with time-tagged video cameras and are hosted in communities ranging from Tulelake, CA down to Tonopah, NV. The pilot network has been in operation since April 2012 and we will report on the the project design, TNO astrometry and predictions, and observational campaigns from the first 6 months of operation. This work was funded by NSF Grant AST-1212159.

511.09 – Predicting Occultations by Kuiper Belt Objects

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Observation of stellar occultations by a planetesimal is a powerful technique to characterize many properties of the occulting object, including its size, shape, and atmospheric extent. This technique is extremely useful for Kuiper Belt Objects, the proximities of which make it virtually impossible to determine shape and atmospheric properties with any other remote sensing technique currently available. Our group has devised a new technique to predict when these rare occultations will occur. The technique makes use of a small (~1 hr) set of observations with the MegaCam, from which a master point source catalog is produced with ~0.02" astrometric accuracy. The MegaCam observations are also used to correct the ephemerides of the target KBOs. The combined result is occultation predictions with precision of 2000 km or better - similar to the size of the target KBOs - as far into the future as 2016. I will present the results of a pilot study of 7 objects, and some preliminary efforts to catch the object, Quaoar, in the act of occultation. With observations made by the Acquisition Camera on Gemini-N of Quaoar's close passage to a star, we have been able

to place stringent upper limits on Quaoar's atmosphere, with a surface pressure no more than ~90 nanobars and a mean surface temperature of no more than 44 K. These observations demonstrate the utility of occultation observations in characterizing remote planetesimals.

512 – Jovian Planets 3: Magnetospheres, Upper Atmospheres, and Interiors

512.01 – Quasi-Periodic Electron Bursts in the Jovian Magnetosphere

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In early 2007, the New Horizons spacecraft flew through the Jovian magnetosphere on the dusk side. During the flyby, the Alice FUV spectrograph proved that in addition to detecting FUV photons, it was also quite effective at detecting MeV electrons, which can penetrate the relatively thin instrument housing and interact with the microchannel plate detector. Radiation modeling shows that Alice is sensitive primarily to electrons with energies between 1-8 MeV. Alice cannot determine the spatial distribution of these MeV electrons, nor does it have any energy resolution, but it does have large count rates (up to 15000 counts/s) and a time resolution of 1s–among the highest of any electron detector flown to Jupiter. Along New Horizons' trajectory from 60 R_J upstream of Jupiter to closest approach at 32 R_J on the dusk side to 60 R_J downstream of Jupiter, we find the flux of MeV electrons to be highly variable on timescales of minutes to hours. There are numerous factor of two changes in electron flux (both increases and decreases) that occur over 50-100s. Frequently, though not always, the MeV electron flux exhibits quasi-periodic variations with timescales of 1-3 minutes. The amplitude of these bursts can vary, sometimes abruptly, from a few percent to factors of several. We also see evidence of larger amplitude 20-45 minute QP bursts with smaller amplitude 1-3 minute bursts superimposed. During two incidences of particularly strong 1-3 minute QP bursts, we find the magnetic field lines passing through the spacecraft map back to Jupiter's ionosphere just inside the main auroral oval to the same location where 1-3 minute QP flares have been seen in the FUV aurora. We therefore suggest that these auroral flares are not caused by magnetic reconnection at the dayside magnetopause, but rather by some acceleration mechanism internal to the magnetosphere.

512.02 – The Variability of Saturn's Plasma Torus

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Cassini observations of the plume of material from Enceladus suggest that the escape rate may vary by up to a factor of four. Since this plume is the major source of plasma for Saturn's torus, the plasma properties are expected to change as well. We investigate these changes using a 2-D model of the radial transport and chemistry. We change the neutral source and look at the plasma response. Initial results indicate that a doubling of the neutral density leads to a similar increase in plasma densities, but the ion composition shows significant changes, The H3O+ increases throughout the inner magnetosphere, OH+ decreases, and other ions show changes which depend on radial distance.

512.03 – The thermosphere of Saturn from Cassini UVIS occultations

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Stellar and solar occultations observed by the Cassini UVIS instrument probe Saturn's upper atmosphere at altitudes from 300 km to 3000 km above the 1 bar level. In particular, the solar and stellar occultations in the EUV channel of the instrument can be used to retrieve the density of H2 and thus the temperature in the thermosphere. This is important because the temperatures outside of the auroral region are known to be much higher than expected based on solar heating only, and the missing energy source is still unknown. We analyzed 15 solar occultations that probe the atmosphere at latitudes ranging from 70S to 70N, and stellar occultations near the equator to constrain energy deposition and meridional temperature gradients in the thermosphere. We find that the exospheric temperature ranges from 370 K to 540 K, with an uncertainty of about 5 – 15 K, and that our density and temperature profiles are consistent with earlier Voyager results. The temperature increases with latitude from the equator to the pole by 100 – 150 K. This trend is qualitatively consistent with auroral heating near the poles and subsequent redistribution of energy to lower latitudes, but the observed gradient is much shallower than that predicted by current circulation models. We locate the exobase of Saturn at 2700 – 3000 km above the 1 bar level, and use the data to constrain the shape of the isobars in the thermosphere. We find that the shape of the upper atmosphere deviates significantly from a simple spheroid predicted by potential theory and demonstrate that the deviations can be explained by significant meridional variations in the temperature-pressure profiles, although this needs to be confirmed by further observations and analysis.

512.04 – The Ionosphere of Saturn as Observed by Cassini Radio Science

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The Cassini spacecraft has accumulated over 60 individual radio occultation measurements of the vertical electron density profile in the ionosphere of Saturn from 2005 to 2013. These measurements extended from the Cassini Prime Mission from 2005 t0 2008, the Equinox Mission (2009-2010), and the present Solstice Mission (2011-2013). The rings of Saturn limit the latitudes that can be explored by radio occultation. When the rings are approaching their maximum opening, all but the equatorial latitudes are blocked, as was the case in 2005, and very shortly will be after 2013, making further observations impossible. Over the span of the eight-year observation window, ionosphere profiles were collected at various latitudes. ranging from North polar to South polar, as well as including equatorial and mid-latitudes. The peak electron densities clearly show a strong dependence on latitude, with the lowest densities at near-equatorial and low latitude regions, and the highest at latitudes above about 50 deg.. These data will be presented, as well as some thoughts on the possible effect of the rings on the latitudinal dependence of the density of the Saturn ionosphere.

512.05 – Cassini UVIS Saturn Auroral Images from the 2013 HST/Cassini Campaign

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Contributing teams: Cassini UVIS Team, Hubble Auroral Campaign Team
In 2013 coordinated observations of Saturn by the Cassini spacecraft and Hubble Space Telescope (HST) were obtained. During these observations the Cassini spacecraft provided a high-latitude view of Saturn's auroras. Intense auroras were observed by the Ultraviolet Imaging Spectrograph (UVIS) from close range (about 5 Saturn radii away). A 6-frame UVIS movie has been constructed from some of the observations from May 20-21, 2013 showing the evolution of two bright auroral features. We report on the UVIS images, the corresponding spectra, and compare the UVIS data to HST images and data from other Cassini instruments.

512.06 – Saturn's Ring Rain: Initial Estimates of Ring Mass Loss Rates

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We estimate rates of mass loss from Saturn's rings based on ionospheric model reproductions of derived H3+ column densities. On 17 April 2011 over two hours of near-infrared spectral data were obtained of Saturn using the Near InfraRed Spectrograph (NIRSPEC) instrument on the 10-m Keck II telescope. The intensity of two bright H3+ rotational-vibrational emission lines was visible from nearly pole to pole, allowing low-latitude ionospheric emissions to be studied for the first time, and revealing significant latitudinal structure, with local extrema in one hemisphere being mirrored at magnetically conjugate latitudes in the opposite hemisphere. Even more striking, those minima and maxima mapped to latitudes of increased or increased density in Saturn's rings, implying a direct ring-atmosphere connection in which charged water group particles from the rings are guided by magnetic

field lines as they "rain" down upon the atmosphere. Water products act to quench the local ionosphere, and therefore modify the observed H3+ densities. Using the Saturn Thermosphere Ionosphere Model (STIM), a 3-D model of Saturn's upper atmosphere, we derive the rates of water influx required from the rings in order to reproduce the observed H3+ column densities. As a unique pair of conjugate latitudes map to a specific radial distance in the ring plane, the derived water influxes can equivalently be described as rates of ring mass erosion as a function of radial distance in the ring plane, and therefore also allow for an improved estimate of the lifetime of Saturn's rings.

512.07 – Kronoseismology: Determining Saturn's acoustic normal mode frequencies using density waves in the rings.

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The frequencies and amplitudes of low-order normal-mode oscillations inside a giant planet can provide important information about the planet's internal structure, but measuring these parameters have proven to be quite difficult. Twenty years ago, Marley & Porco [1993, Icarus 106, 508] pointed out that Saturn's normal mode oscillations could potentially produce detectable signatures in the rings, but the data available at that time were insufficient to securely identify whether particular ring features were generated by specific planetary oscillations. Using stellar occultation data obtained by the Visual and Infrared Mapping Spectrometer (VIMS) onboard the Cassini spacecraft, we investigate six C-ring waves located between 80,900 and 87,200 km from Saturn's center. In other parts of Saturn's rings, such waves are generated by Lindblad resonances with Saturn's various moons, but these C-ring features are not near any known resonance with any known moon. Instead the number of arms in each spiral pattern and the speeds at which these patterns rotate around the planet are consistent with those predicted for resonances with low-order (m=2,3 and 4) acoustic oscillations (f-modes) within the planet [Marley & Porco 1993, Icarus 106, 508]. These features therefore provide precise estimates of Saturn's normal-mode oscillation frequencies, and should therefore place strong constraints on Saturn's internal structure. Furthermore, we identify multiple waves with the same number of arms and very similar pattern speeds, indicating that multiple sectoral (l=m) modes may exist within the planet. The implications of this discovery are still unclear.

512.08 – Giant Planet Seismology: Constraining the Interior Structure of Saturn from Waves in its Rings

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The internal structures of gaseous giant planets remain largely unconstrained. Planetary structures can be inferred through seismic techniques, but directly detecting oscillations in gaseous planets is difficult with current instrumentation. However, a recent analysis of Cassini data by Hedman & Nicholson (2013) (HN13) reveals the presence of waves in Saturn's rings that appear to be excited by oscillation modes within Saturn. Intriguingly, the observations of HN13 indicate an apparent fine-splitting between mode frequencies, unexpected in standard seismic theories, which may harbor important information on the internal structure of Saturn. We investigate the properties of oscillation modes in gaseous giant planets, with the purpose of interpreting the results of HN13. Our calculations include the elastic response of a solid core, which allows for the presence of core shear modes ignored in previous studies. We also calculate the effects of rotational mode mixing induced by the Coriolis force, which can cause core modes to mix with fundamental oscillation modes (f-modes). We find that mode mixing between core modes and f-modes can produce a mode frequency spectrum with characteristics similar to the observations of HN13, possibly indicating the presence of a solid core within Saturn. Future calculations (including the effects of the centrifugal force and planetary oblateness) will place new constraints on Saturn's interior structure and may be able to confirm or reject the presence of a solid core.

512.09 – Diamond and other forms of elemental carbon in Saturn's deep atmosphere

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The energetic lightning storms in the Saturn atmosphere will dissociate molecules into atoms, ions and plasma. Specifically, methane will be dissociated into elemental carbon, most probably in an amorphous form, such as fluffy turbostratic carbon or irregular soot particles. Once formed, this non-crystalline carbon sinks down through the atmosphere reaching an altitude of similar density. Amorphous carbon is converted to graphite under pressure. Graphite has a density of ~2.2 g/cc at room temperature. The density of diamond is ~3.3 g/cc at STP. However, at much higher pressures, the density of diamond increases dramatically, up to 9 grams/cm3 at P=1500 GPa (15 Mbar). As carbon descends through the atmosphere, amorphous carbon becomes graphite which then is converted into diamond, creating various strata of carbon allotropes according to their densities. Densities of the planets increase with depth. Eventually, at great depths, diamond will melt, forming liquid diamond. The melting point of diamond varies with pressure, reaching a high of ~ 8000 K at 500 GPa (5 Mbar). Using updated adiabats and equation-of-state data from Nettelmann et al. (2011), we determined the altitude at which diamond reaches its melting point on each planet. Combining these adiabats with new data for the carbon phase diagram from high-pressure shockwave experiments indicates that diamond may be a stable layer in the atmospheres of Jupiter and Saturn. Previously, only Uranus and Neptune were thought to have conditions in their interiors that would allow the formation of diamond at their cores. It appears that the interior of Jupiter gets hot enough to reach the liquid diamond region of the carbon phase diagram, whereas the interior of Saturn includes regions of temperature and pressure where carbon could exist as solid diamond. At the boundaries (locations of sharp increases in density) on Jupiter and Saturn, there may be diamond rain or diamond oceans sitting as a layer. However, in Uranus and Neptune, the temperatures never reach as high as 8000 K. The cores are ~5000K, too cold for diamond to melt on these planets. Therefore, it appears that diamonds are forever on Uranus and Neptune but not on Jupiter and Saturn.

513 – Origins 3: Disks, Moon, and Terrestrial Planets

513.01 – Collision Dynamics of Decimeter Bodies

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The collision dynamics of decimeter bodies are important for the early phase of planet formation. Planets form by accretion of km-sized objects, the so called planetesimals. These planetesimals evolve from small grains, but their formation process is not yet understood entirely. Two groups of models try to explain the formation process. Decimeter bodies and their collision behavior play a vital role in both groups. The threshold between bouncing and fragmentation is especially interesting for coagulation models, as decimeter bodies are the direct precursors to meter sized bodies. But the collision dynamics are also relevant for the models, which describe planetesimal formation by gravitational collapse in dense regions of the protoplanetary disk. We will present preliminary results of our collision experiments. Previous experiments on mutual collisions of decimeter dust agglomerates showed that the threshold between bouncing and fragmentation lies at a collision velocity of 16.2 cm/s, which corresponds to a specific kinetic energy of 5 mJ/kg. We expand these experiments to investigate the conditions for "catastrophic disruption" of decimeter dust bodies. Here, "catastrophic disruption" means that the largest fragment of a collision partner has only half the mass of the original body. Furthermore, we extend the parameter range to ice aggregates. We will present first experimental results of collisions of ice aggregates in the decimeter range. In these first experiments we will analyze the threshold conditions for solid ice. We will investigate the collision dynamics for both central and non-central collisions.

513.02 – Mercury-like Planets: Separating Metals and Silicates by Photophoresis

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Particles at the inner edge of protoplanetary disks are embedded in gas and are illuminated by starlight. This leads to photophoretic forces which – acting best on low thermal conductivity particles – push silicates outward. Metal grains remain behind and get separated from the silicates. If planetesimal formation is set on top of this separation an outward migrating edge will naturally lead to a metal-silicate gradient. Metal rich bodies like Mercury will form close to the star and metal poor bodies will be located further outward. This is consistent with chondrites being mostly metal poor and it is consistent with the smallest rocky planets CoRoT-7b and Kepler-10b – found close to their host star – being Mercury-like. In contrast to high temperature processing

photophoresis does not change the abundance of volatile elements. We started to model the particle transport in the transition region between the optical thin disk gap and the optical thick outer protoplanetary disk. Also, first drop tower experiments have been carried out to quantify the strength of the photophoretic force on silicate grains.

513.03 – The Tethered Moon

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Cosmic collisions between terrestrial planets resemble somewhat the life cycle of the phoenix: worlds collide, are consumed in flame, and after the debris has cleared, shiny new worlds emerge aglow with possibilities. And glow they do, for they are molten. How brightly they glow, and for how long, is determined by their atmospheres, and by their moons. stop. It is well known that the atmosphere's thermal blanketing effect prevents a magma ocean from cooling rapidly. Several models have considered thick H2O-CO2 atmospheres over cooling magma oceans. These models address how the magma ocean freezes, how long it takes to freeze, and how, when, and what is degassed. stop. The atmosphere over a magmasphere is very hot and so contains the geochemical volatiles that can evaporate from a magma ocean, such as sulfur, alkalis and halogens, in addition to H2O and CO2. We compute 1-D non-gray radiative-convective atmospheric structure models that include all the molecular and atomic opacity sources that would be present in equilibrium over a magma ocean. We use these to compute cooling rates for hot post-giant-impact terrestrial planets. Our model is in excellent asymptotic agreement with two recent independent calculations of the runaway greenhouse limit for H2O-CO2 atmosphere. For cooling of the magma ocean itself, we use parameterizations recommended by Solomatov. stop. Tidal heating of the Earth by the Moon is important, because it is a big term, and because it occurs mostly in mantle materials that are just beginning to freeze, which frustrates freezing. The Moon is entwined with Earth by a negative feedback between thermal blanketing and tidal heating that comes from the temperature-dependent viscosity of the magma ocean. Because of this feedback, the rate that the Moon's orbit evolves is limited by the modest radiative cooling rate of Earth's atmosphere, which in effect tethers the Moon to the Earth. Consequently the Moon's orbit evolves orders of magnitude more slowly than in conventional models. Slow orbital evolution promotes capture by orbital resonances that may have been important in the Earth-Moon system.

513.04 – Accretion of the Moon from non-canonical impacts

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The generally accepted scenario for the formation of the Moon involves the impact of a Mars-size object into the proto-Earth, resulting in the formation of a disk from which the Moon accretes (Cameron and Ward 1976). In a first paper (Salmon & Canup 2012), we showed that the disks resulting from these "canonical" impacts can lead to the accretion of a 1 lunar mass object on a timescale of order 10^2 yr. Recent works have focused on alternative impact configurations: bigger impactors (Canup 2012) or higher speed impacts into a fast spinning Earth (Cuk & Stewart 2012). These impacts leave the Earth-Moon system with an angular momentum about twice that in the current system. This quantity can be made consistent with its current value if the newly formed Moon is captured for a prolonged period in the evection resonance with the Sun (Cuk & Stewart 2012). The protolunar disks that are formed from these "non-canonical" impacts are generally more massive and more compact, containing a much greater fraction of their total disk mass in the Roche-interior portion of the disk, compared to canonical impacts. We have investigated the dynamics of the accretion of the Moon from such disks. While the overall accretion process is similar to that found from disks typical of canonical impacts, the more massive, compact disks typically produce a final moon with a much larger initial eccentricity, i.e. > 0.1 vs. 10^-3 to 10^-2 in canonical disks. Such high initial eccentricities may substantially reduce the probability of capture of the Moon into the evection resonance (e.g., Touma & Wisdom 1998), which is required to lower the angular momentum of the system in the non-canonical impacts. We will discuss which disk configurations can lead to the successful formation of the Moon, and how the Moon's initial orbital properties vary for different impact scenarios.

513.05 – Formation of the Terrestrial Planets from an Annulus - LIPAD Simulations with Dynamics, Accretion and Fragmentation

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We present preliminary simulations of the formation of the terrestrial planets from an annulus using a new Lagrangian code known as LIPAD (Levison, Duncan, and Thommes, 2012, AJ). LIPAD, which stands for 'Lagrangian Integrator for Planetary Accretion and Dynamics,' is a particle-based code that models the fragmentation, accretion and dynamical evolution of a large number of planetesimals through the entire growth process from km-sizes up to planets. We report on preliminary simulations where initially the solids in the disk are planetesimals with radii between 10 and 50 km, and where the disk mass was varied from one to a few minimum mass solar nebula in different simulations. The simulations were designed to examine the idea that some aspects of the terrestrial planets can be explained, particularly the Earth/Mars mass ratio, when they form from a truncated disk with an outer edge at 1.0 AU (Hansen 2009, Walsh et al. 2011). Therefore, we describe simulations that initially have planetesimals between 0.7--1.0 AU, and others that begin with material from 0.7–1.5 AU and were truncated at various times during the evolution of the disk. Preliminary analysis shows that planetesimals are depleted rapidly due to collisional fragmentation, but that the mass/semi-major axis distribution of final planets remains similar to previous studies that investigated a truncated disk. Other differences from the standard model will be discussed.

513.06 – Small mass planets migration in radiative discs

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The migration of small mass planets towards the central star in a isothermal disc is known to occur on timescales shorter than the disc's lifetime. More complete models taking into account viscous and thermal diffusion have provided a solution to this puzzling problem showing a change in the direction of migration for small mass planets. However the lowest mass for this to happen is not well known. Precisely, outward migration occurs in radiative discs when the negative Lindblad torque is compensated by a positive corotation torque acting on low-mass planets. Outward migration is expected to stop as soon as the contribution from the horseshoe drag becomes too small. The lowest mass for this to happen is not well known. With the hydro-dynamical code FARGO that we have extended to 3D we numerically simulate the evolution of small mass planets in fully radiative 3 dimensional discs. We use a set of discs parameters for which outward migration as been shown (Kley et a. 2009) for masses in the range [5,35] Earth masses and we extend the computation down to 2 Earth masses. We recover previous results and we find that the transition from outward to inward migration occurs for masses in the range [2,5] Earth masses. Qualitatively this results is in agreement with the Paardekooper et al. (2011) formula for the torque obtained with a 2D model. However, we have found that the transition from outward to inward migration is due an unexpected phenomenon, the formation of an asymmetric cold and dense finger of gas driven by circulation streamlines. We have recovered the formation of the cold finger of gas in 2D simulations where we control the cooling effects through a simple modeling of the energy equation. This phenomenon promote inwards migration of small mass planets.

513.07 – Structure of evolving Accretion Discs and their Implications to the Formation of Planetary Cores

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Two features in a protoplanetary disc can have profound effects on planet formation. The first feature is 'pressure bumps', i.e. local maxima in the gas surface density distribution that can arise e.g. at the inner edge of the dead zone. Pressure bumps stop the inward migration of small bodies undergoing gas drag (Brauer et al., 2008), promote the onset of the streaming instability (Johansen and Youdin, 2007), help the accretion of planetary embryos by the pebble-accretion process (Lambrechts and Johansen, 2012) and stop inward type-I migration by the planet-trap mechanism (Masset et al., 2006). The second feature is 'scale height bumps', that originate from opacity transitions. The regions of the disc that are shadowed, where H/r decreases with r, allow planetary cores to migrate outwards due to entropy gradient effects (Paardekooper and Mellema (2006), Baruteau and Masset

(2008)), until they reach the local minimum of the H/r profile (Bitsch et al. 2013). Thus, it is important to model the existence and the location of these structures in realistic protoplanetary discs. The structure of the disc is dependent on the mass-flux (accretion rate) through the disc, which determines the evolution of the density profile. This mass-flux changes in time, as the whole disc gets accreted onto the central star. We will show using 2D hydrodynamical models how the change of the accretion rate affects the disc structure and how this will change the sweet-spots for saving planetary cores from too rapid inward migration. We will focus here on 'scale height bumps' in the disc that will change the alpha-viscosity and consequently the gas surface density (as the mass-flux is constant through the disc). Therefore the formation of pressure bumps is possible, whose prominence and effects on migration will be investigated in detail. This will give important indications of where and when in the disc the cores of giant planets and thus giant planets can form.

513.08 – Exposing the Long Lives of Circumplanetary Disks

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Flows from a protoplanetary disk to a newborn giant planet form a disk due to the conservation of angular momentum.
Since satellites are thought to be formed in these circumplanetary disks, understanding of the disk properties is crucial for satellite formation theories. The balance of gas supply from a protoplanetary disk and gas accretion towards the central planet determines the surface density of the circumplanetary disk, and the gas supply flux has recently been analyzed through 3D hydrodynamical simulations. Thus, we focus on the viscous evolution of circumplanetary disks. At present, turbulence driven by the magnetorotational instability (MRI) is believed to be the most promising mechanism for angular momentum transport in accretion disks. For a disk to be MRI-active, gas in the disk should be sufficiently ionized. In order to evaluate the MRI-activity, we calculate the ionization degree, accounting for the effect that the MRI is stabilized in the upper layer of the disk. As a result, we find that circumplanetary disks are mostly MRI-inactive. This is because the length scales of circumplanetary disks are smaller than those of protoplanetary disks and magnetic field diffuses faster in circumplanetary disks. Unless some other mechanisms promote mass accretion, the lifetimes of circumplanetary disks are longer than previously thought, and possibly longer than the lifetimes of the "parental" protoplanetary disks. In this case, we would have more opportunity to observe circumplanetary disks. To find out if this is the case, we need to investigate other possible mechanisms of mass accretion, such as spiral density waves.

513.09 – Constraining the Feasibility of Planet Formation in Close Binaries

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Several exoplanets have been discovered in close binaries (a<100 AU) to date, including γ Cephei, HD 41004, and GL 86, to name a few. The fact that planets can form in these dynamically challenging environments says that planet formation must be a robust process. Disks in these systems should be tidally truncated to within a few AU, so if they form in situ, the efficiency of planet formation must be high. While the dynamical capture of planets is also a possibility, the probability of these interactions is low, so in situ formation is the more plausible explanation. I examine the truncation of protoplanetary disks in close binary stars, studying how the disk mass is affected as it evolves from higher accretion rates to lower rates. In the γ Cephei system, a protoplanetary disk around the primary star should be truncated to within a few AU, but enough mass still remains for planets to form. However, if the semimajor axis of the binary is too small or its eccentricity is too high, the disk will have too little mass for planet formation to occur. I present a way to characterize the feasibility of planet formation based on binary orbital parameters such as stellar mass, companion mass, eccentricity and semi-major axis. Using this measure, we can quantify the robustness of planet formation in close binaries and better understand the overall efficiency of planet formation in general.

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