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The following report covers the activities of the Department's astronomers and astrophysicists from October 1996 through September 1997.

1. INTRODUCTION

The Department of Physics & Astronomy has research groups with interests in astrophysics, condensed matter physics, gravity theory, nuclear physics, and particle physics. Six faculty (Carney, Cecil, Christiansen, Evans, Rose, and Thompson) conduct research in observational and theoretical astronomy. This group has led the development of SOAR, a new wide-field 4-m telescope with active optics, to be constructed in Chile in partnership with MSU, NOAO and Brazil. The nuclear physics group has begun an expansion in nuclear astrophysics, led by Champagne, who was joined by Assistant Professor Christian Iliadis in 1996. Jon Engel, a nuclear theorist, has been active recently in studies of *r*-process nucleosynthesis. There is also a closely associated program in gravity physics led by York and Evans, which has played a leading role in the NSF Grand Challenge Program to simulate colliding black holes. Astrophysics also has three adjunct faculty: Dr. Lee Shapiro, Director of the Morehead Planetarium, Dr. Robert McMahan, President of McMahan Electro-Optics in Research Triangle Park, and Dr. Suchitra Balachandran, currently at the National Air and Space Museum in Washington, DC.

1.1 Faculty (Astronomy, Theoretical Astrophysics, Nuclear Astrophysics and Gravity Physics)

Bruce W. Carney, Samuel Baron Professor (Ph.D. Harvard 1978) - *Observational astronomy — Galactic Structure and Evolution, Stellar Populations*

Gerald R. Cecil, Associate Professor (Ph.D. Hawaii 1987) *Active Galactic Nuclei, Herbig Haro Objects, Fabry-Perot Spectroscopy and Instrumentation, Jets*

Arthur E. Champagne, Professor (Ph.D. Yale 1982) - *Nuclear Astrophysics, Big-Bang Nucleosynthesis, Stellar Evolution and Explosion*

Wayne A. Christiansen, Professor (Ph.D. UC Santa Barbara 1968) - *Theoretical Astrophysics, Radio Astronomy, Quasars*

Jonathan Engel, Assistant Professor (Ph.D. Yale 1986) - *Theoretical Nuclear Physics, r-Process Nucleosynthesis*

Charles R. Evans, Associate Professor (Ph.D. Texas 1984) - *Numerical Relativity, MHD, Physics of Compact Objects*

Christian Iliadis, Assistant Professor (Ph.D. Notre Dame 1993) - *Nuclear Reactions; Nucleosynthesis and Energy Production in Stars*

James A. Rose, Professor (Ph.D. Yale 1978) - *Stellar and Extragalactic Spectroscopy, Stellar Populations, Structure and Evolution of Galaxies*

Christopher Thompson, Assistant Professor (Ph.D. Princeton 1988) - *Theoretical Astrophysics and Cosmology: Gamma-ray Bursts, Pulsars, Plasma Astrophysics, Accretion Disks*

James W. York, Jr., Agnew Bahnson Jr. Professor (Ph.D. N.C. State 1966) - *Classical, Statistical and Quantum Gravity Theory*

Cecil has been appointed Project Scientist of the SOAR Telescope, and has moved to Tucson, AZ to take up his duties. **Carney** stepped down as President of the Astronomical Society of the Pacific in March, 1997. He joined the Nominating Committee as an *ex officio* member. He was appointed chair of the Committee on Astronomy and Public Policy of the American Astronomical Society for a two-year term. He also continued to serve on the Time Allocation Committee of NASA's Infrared Telescope Facility. He was elected a member of the Observatories Council of AURA in 1997, and subsequently elected chair of the Council. He chaired the "Stellar Populations" panel of the Gemini workshop on "Astronomical Capabilities Needed to Support Large Telescopes" held in Tucson in September of 1997. Finally, he continued to serve as the UNC representative to the SOAR Telescope Interim Board of Directors.

Carney delivered an invited talk at the June 1997 meeting of the American Astronomical Society on "The Galaxy's Stellar Populations and Their Inter-relationships." and with Steve Majewski (UVA) organized a one-day topical session on "Old Stellar Populations in Other Galaxies." **Thompson** gave an invited talk on dissipation in relativistic outflows at the June 1997 conference on "Relativistic Jets in AGN" in Cracow Poland. **Evans** and Thompson together with John Blondin (NCSU) organized a one-day topical session on X-ray binaries at AAS 190.

1.2 Graduate Students and Undergraduates

The Department graduate program includes an astrophysics track, and we report here the research activities of current and recent graduate students. Anne **Fry** received her Ph.D. and accepted a postdoctoral position with Heather Morris at Case Western Reserve University. Lewis **Jones** completed a Ph.D. thesis with Rose on the integrated spectra of low-luminosity elliptical galaxies, and has accepted a postdoc position at the University of New South Wales (Australia). Tas **Philp** completed a Ph.D. thesis with Evans on a search for pulsar companions to runaway O/B stars, and a study of the termination shocks of pulsar winds in binary systems. David **Junkin** completed his thesis with Champagne on the development of a cryogenic microcalorimeter. Graduate students at earlier stages of research include Kristy Dendy and Andrew **Leonardi** (working with Rose), S. **Hale** and P. **Bertone** (with Champagne), D. **Powell** and honors undergraduate Chris **White** (with Iliadis), Brian **Brill** and Parker **Trois-**

cht (with Evans), and Serge **Naoumov**, Michael **Habgood**, Luisa **de Almeida**, and Jae-Woo **Lee** (with Carney).

2. SOAR

The SOAR Telescope Project has begun in earnest. UNC has pledged 7 M\$ toward capital construction, and our partners (NOAO, Brazil, Michigan State University) are contributing the remaining 21 to 22 M\$. NOAO will provide the bulk of the operations costs. The project completed an intensive 9-month scientific and technical process, which was reviewed by a distinguished external review board headed by Jerry Nelson (Lick). Thomas Sebring, having successfully completed the Hobby-Eberly telescope project, has been hired as Project Manager, and Gerald Cecil (UNC) has taken on the job of Project Scientist. Formal incorporation of the project will occur early in 1998.

The site will be near Gemini South on Cerro Pachon, and site preparation will begin in November, 1997. The key design goal for the telescope is to provide minimal degradation of the frequent 0.''4 seeing at that sight over a wide 15' field, with close to diffraction-limited performance in the near-IR and the ability to change from one instrument to another quickly during the night. The baseline configuration is a f/16 on-axis thin meniscus with 4.0-m aperture and altitude/azimuth mounting. After nearly a decade since UNC proposed this project, it is extremely gratifying to see it finally getting underway.

3. EDUCATION AND OBSERVATORY OUTREACH

W. **Christiansen** writes:

The Morehead Observatory Outreach Program relies upon the rapid spread of computer network access in the public schools of North Carolina to provide digital connections to the telescopes in Morehead Observatory. This outreach effort is capable of providing students with hands-on experience in using state-of-the-art astronomical equipment without the necessity for their physical presence in Chapel Hill to conduct the experiments. The idea is to export to the local schools, via the Information Highway, a simplified "control room" for a modern observatory. The number of schools participating is limited only by the extent of network access and the expertise of local teachers in providing the guidance for connecting and using the network. The primary constituency for this approach would be students in Middle and High School.

The Morehead Observatory is equipped with two SBIG CCD cameras (one at the Cassegrain focus and the other on a 7-inch long focus refractor). Data taken by UNC students and faculty is routinely stored on hard disks on computers in the observatory and is currently accessible to all students (both undergraduate and graduate) and faculty at UNC-CH and is exportable. There is presently a homepage on the World Wide Web which provides public access to many of the Morehead images on file.

However, simply providing public access to astronomical images, while interesting and useful to students and researchers, does not provide the experience in observational techniques or provide live, "hands on work" so vital in inspiring students to pursue science. Therefore, we have dedicated the CCD camera and tunable Lyot filter on the 7-refractor to

"daylight" observations of the Sun as a conduit for a live outreach program from the Observatory to classrooms state-wide via the Internet

In addition to providing the facilities for remote observations the Observatory would provide instructional materials for both teachers and the students showing them how the telescope and camera work; how the observations are setup and carried out; how to read and interpret their solar images (i.e. the nature of the sunspots, prominence etc. they will be seeing), and how to carry out the experiments. An NSF-Eisenhower grant is being sought to support workshops for teachers across the state who wish to participate in the outreach program.

Also, by pooling and exchanging data, again via the network, students from widely separated schools can leverage their own observations with others to study long-term effects on the Sun (e.g. determining the rotation speed of the sun by following sunspots or measuring the lifetimes of the spots). This could be a strong practical demonstration of the utility of networks in enhancing the productivity of individual researchers by promoting the exchange of data.

4. EQUIPMENT AND SOFTWARE

Arthur **Champagne**, graduate student D. **Junkin** and D. Haase (NC State) have continued their development of cryogenic microcalorimeters. These devices are similar to those designed for the AXAF mission and have been proposed as the basis for measurements of neutrino properties and dark matter. It has recently been decided to replace the present P-doped Si thermistors with Au:Ge since the latter can be fabricated more easily and more reproducibly. Testing of prototype detectors is in progress. A potential first use for these detectors is in a planned double-beta decay experiment.

5. RESEARCH

5.1 Stars—Luminosities & Abundances

Bruce **Carney**, J. Storm (ESO), W. Freedman (OCIW), and B. Madore (IPAC/Caltech) have completed *BVRI* photometry and echelle spectroscopy over the pulsation cycles of 5 SMC cepheids and 3 LMC cepheids. With D. Latham, radial velocities over the entire pulsation cycle of 23 galactic cepheids have also been obtained. These data are now being analyzed, primarily by Storm, via Baade-Wesselink methods to determine if there is any metallicity sensitivity in the cepheid period-luminosity relation.

Carney, Jae-Woo **Lee**, and Rodney **Jones** have completed data acquisition for a program aimed at redetermining the slope of the M_V -[Fe/H] relation for field RR Lyraes using the M_K -log P relation to derive good relative distances. The 56 field RR Lyraes were selected without any bias in metallicity, period, or magnitude. Optical and IR photometry was completed in June, 1997, and data reductions are underway, in collaboration with Tom Kinman (NOAO).

Carney and **Lee** are also working with Dr. Mike Corwin (UNC-Charlotte) to derive high-quality *BV* light curves for ≈ 150 RR Lyrae variables in the globular cluster M3 and ≈ 20 variables in M2. In both cases the goals are to delineate the pulsation periods, amplitudes, and other characteristics of

the light curves as functions of relative luminosities and temperatures. Further, the two clusters have very similar metallicities but different mean periods. A period-shift analysis should reveal, independent of metallicity, how the luminosities of the Oosterhoff I and Oosterhoff II globular clusters differ.

S. Balachandran (U. Maryland), **Carney**, Laird (Bowling Green St.), and L. Fullton (PhD 1995; STScI) obtained high-resolution spectra at $2.2 \mu\text{m}$ of three stars thought to be members of the heavily obscured, metal-rich globular cluster Liller 1 ($A_V \approx 9$ mag). The Fe I lines were weaker than expected, and it appears that the cluster is not as metal-rich as the Sun. The group recently completed observations of Si I lines to determine the $[\alpha/\text{Fe}]$ ratio for this very metal-rich inner halo globular cluster.

Graduate student Jonathan **Garrison**, recent graduate Laura **Fullton**, Anne **Fry**, **Carney**, and Sang-Gak Lee (on sabbatical leave from Seoul National University) have analyzed the chemical abundance patterns in three metal-poor halo dwarfs with abnormally high nitrogen abundances (HD 97916, HD 160617, and HD 166913). The latter two are subgiants, with normal halo population enhancements of $[\alpha/\text{Fe}]$, normal lithium abundances (for their temperatures) and enhanced s-process abundances, consistent with a mass transfer model. HD 97916 is a binary star, with a long period and a near-circular orbit, suggestive of Case C mass transfer.

Graduate student Michael **Habgood** and **Carney** analyzed high-resolution, very high-S/N echelle spectra of two relatively metal-rich field dwarfs with retrograde Galactic orbits, G4-19 and G232-18. They analyzed $[\text{O}/\text{Fe}]$ using the $[\text{O I}]$ line at $\lambda 6300$ and the O I triplet near $\lambda \lambda 7770$. $[\text{O}/\text{Fe}]$ is enhanced, as are the other “ α ” elements. Lithium, on the other hand, is extremely deficient, although the stellar temperatures place them on the “lithium plateau.” Perhaps their high metallicities, > -1 , play a role.

Graduate student Jeff **Wright**, **Carney**, and C. Sneden (U. of Texas at Austin) have obtained echelle spectra from the McDonald Observatory of 10 very metal-poor stars. Five of the stars have halo kinematics, but the other five appear to show disk kinematics, if the assumption that they are all dwarfs is correct. Four of the five “disk” stars were found to be subgiants, and a revision of their kinematics shows them to be halo stars. One of them, BD+80deg 245, was found to have sub-solar $[\alpha/\text{Fe}]$ ratios, despite its very low metallicity ($[\text{Fe}/\text{H}] \approx -1.5$). An expanded study of other extreme velocity stars is now underway, with **Carney** working with Inese Ivans and Chris Sneden of the University of Texas.

Carney and Sang-Gak Lee (Seoul National University) have completed *JHK* photometry for a large sample of stars selected from the LHS catalog via reduced proper motion diagrams. These stars, likely to be halo dwarfs, will provide a new estimate for the luminosity function of the halo field population.

Anne **Fry** completed her Ph.D. dissertation devoted to a recalibration of the cepheid distance scale. She obtained high resolution, high S/N spectra of 23 Galactic cepheids, including 15 of the cepheids in open clusters which have been used as primary calibrators of the P-L relation, in order to remove chemical composition effects from the zero point calibration

of the P-L relation. Eighteen of the cepheids at more than one phase to check their spectroscopic temperature scale. To check the applicability of static, LTE, plane-parallel stellar atmosphere models to pulsating supergiants such as cepheids, she observed 2 dwarfs in M 25, which contains the cepheid U Sgr. She finds a spread of 0.4 dex in $[\text{Fe}/\text{H}]$ among the cepheids. An outgrowth of this work is a new color-temperature relation for cepheids, which will be used in Baade-Wesselink analyses. **Fry** and **Carney** have also obtained new photometry of 9 of the clusters containing cepheids to derive new main sequence fitting distances. They have *UBVJK* photometry of NGC 6087 (S Nor), NGC 129 (DL Cas), NGC 7790 (CE Cas A and B and CF Cas), and M 25 (U Sgr), *UBV* photometry of NGC 5662 (V Cen), and *JK* photometry of Lyngå 6 (TW Nor), C1814-191 (WZ Sgr) and Trumpler 35 (RU Sct). The data for NGC 6087, NGC 7790, and M 25 have been reduced. When all of the photometry is reduced, they will be able to derive distances for all of these clusters relative to the Pleiades with higher precision than previously achievable.

Carney, Latham, and Laird completed a study of six metal-poor field blue stragglers, determining spectroscopic orbits for 4 of them, and signs of velocity variability in the other two. The orbits are all long period, > 100 days, and nearly circular, consistent with Case C mass transfer.

Carney, Latham, Laird, and Jon Morse have completed a radial velocity study of 90 metal-poor field red giants. Binary orbits for 13 such stars have been derived.

Art Wolfe and Jason Prochaska (UCSD) have obtained high-resolution, high-S/N spectra of 6 field stars that **Carney** believes belong to the “thick disk” population. The abundance patterns in these stars will be compared with abundance patterns in the damped Ly- α systems seen in quasars.

5.2 Stars—Supernovae

Thompson and Robert Duncan (U. Texas Austin) have continued their investigation of magnetism in nascent neutron stars, focussing on the effect on the surrounding supernova shock. The vigorous convection that occurs inside the neutrinosphere during the first few seconds, when scaled to the granular motion and intranetwork magnetic field of the Sun, implies r.m.s. magnetic fields in excess of 10^{15} G. They have studied the response of the surface magnetic field to rapid fallback onto the surface of the neutron star ($\dot{M} \sim 10^{-1} M_{\odot} \text{ s}^{-1}$) combined with rapid neutrino heating of the surface layers. Transfer of the gravitational binding energy of the accreting material to the magnetic field outside the neutrinosphere induces a large heating rate ($O(10^{52})$ erg s^{-1}) as long as accretion continues. Because the energy contained in the magnetic field is not effectively re-converted to neutrinos, this provides an additional source of pressure behind a stalled accretion shock that turns off when the shock succeeds.

5.3 Stars—Pulsars & Black Holes

Philp (UNC graduate student), **Evans**, Leonard, and Frail (1996) conducted a VLA search for radio pulsars at the positions of 44 nearby OB runaway stars. Recently, several

radio pulsars have been found in binary systems with massive B star companions. Like the class of low mass eclipsing radio pulsars (indeed one of these new pulsars also eclipses), these high mass systems provide another environment in which a pulsar wind encounters an obstacle and generates a shock. The search by Philp *et al.* was an attempt to locate more pulsars of this type.

We found no new binary pulsars in this search. However, the null result did provide a tight constraint on the frequency with which pulsars can be expected to be found orbiting runaway O and B stars, and this constrains the possible mechanisms that may produce runaways. If runaways result from a supernova explosion of one star in a massive binary, then our results imply that neutron stars are likely born receiving large momentum impulses, perhaps from an asymmetric supernova explosion.

Our observations involved both searching images for point sources of continuum emission and time series analyses. Our mean flux sensitivity to pulsars slower than 50 ms was 0.2 mJy. The size of the survey, combined with the high sensitivity of the observations, sets a significant constraint on the probability, f_p , of a runaway OB star having an observable pulsar companion. We find $f_p \leq 6.5\%$ with 95% confidence, if the general pulsar luminosity function is applicable to OB star pulsar companions. If a pulsar beaming fraction of 1/3 is assumed, then we estimate that fewer than 20% of runaway OB stars have neutron star companions, unless pulsed radio emission is frequently obscured by the OB stellar wind. Our result is consistent with the dynamical (or cluster) ejection model for the formation of OB runaways. The supernova ejection model is not ruled out, but is constrained by these observations to allow only a small binary survival fraction, which may be accommodated if neutron stars acquire significant natal kicks. According to Leonard, Hills and Dewey (1994), a 20% survival fraction corresponds to a 1-d natal kick of 240 km s⁻¹, or a 3-d kick of 420 km s⁻¹.

5.4 General Relativity

Evans and UNC undergraduate student Timothy **Perkins** extended the study of an example of critical phenomena in gravitational collapse (collapse of spherically-symmetric radiation fluid) discovered previously by Evans and Coleman (1994). Unlike the critical behavior observed in scalar field collapse (Choptuik 1993) and gravitational wave collapse (Abrahams and Evans 1993), the attractor in radiation fluid collapse exhibits a continuous self similarity, not a discrete self similarity. The continuous self similarity, present in the geometry and fluid on small length scales, indicates the existence of a homothetic Killing field. Evans and Perkins (1997) broadened the numerical and analytic investigation of self-gravitating fluid collapse to include other relativistic gases $p = (\gamma - 1)\rho$ with $1.01 < \gamma \leq 1.50$. (The upper limit on γ is presently set by onset of numerical instabilities.) These simulations confirm earlier analytic work by Maison who computed self-similar collapses and derived potential critical exponents via linear stability analysis. An improved numerical relativistic hydrodynamic scheme is being sought that will allow stable evolutions of fluids stiffer than $\gamma \approx 1.5$.

5.5 Galactic Structure

Carney, Laird (Bowling Green St.), Latham (CfA), and Aguilar (Obs. Nac., UNAM) have continued their work to remove the kinematic biases inherent in their large sample of proper motion stars. Aguilar has developed a $1/V_{max}$ algorithm to weight the stars properly, but the effects of “subgiant contamination” has become acute. Some subgiants have been identified using the new results from HIPPARCOS, but they are also exploring the identification of subgiants via synthetic spectra. New model atmospheres and synthetic spectra have been computed and initial tests are promising.

Graduate student **Serge Naoumov** and **Carney** are working with J. Laird (Bowling Green St.) and D. Latham (CfA) in a project aimed at determining the relationships between the thin disk and thick disk stellar populations. The first phase of the project is completed: the acquisition and digitization of at least 3 deep objective prism plates obtained using an interference filter in each of 11 fields, three toward the Galactic anticenter, three towards the center, and five toward the Local Standard of Rest. The stars are in the galactic plane to avoid uncertainties associated with the different scale heights of the thin and thick disk populations. About 1100 mid-G to mid-K dwarfs have been selected using the metal-insensitive line indices developed by **Rose** (AJ, 89, 1238, 1984). High-resolution, low-S/N spectroscopy have been obtained to determine radial velocities and metallicities.

Graduate student **Luisa de Almeida** completed reduction of extensive *UBVI* photometry in directions toward the southern galactic warp and in control fields at similar galactic longitudes but opposite latitudes to explore the reddening vs. distance relation and the color-magnitude diagram of the outer disk. In collaboration with **Carney**, she has been awarded observing time to obtain echelle spectra of young stars (cepheids) and old stars (red giants in the field and in old open clusters) at large galactocentric distances ($R_{GC} > 13$ kpc) to study the chemical history of the outer disk.

Carney and Laird (Bowling Green St.) have begun a collaboration with D. Ojha (IUCAA, Pune, India), O. Bienaymé, A. C. Robin, and M. Crézé (all at Strasbourg, France) to study the thin and thick disk populations. Proper motions complete to $V \approx 18$ have been obtained in three selected directions at intermediate latitudes ($b \approx 45$). Wide-field *UBV* CCD photometry were obtained at Kitt Peak for all the fields, and stars are now being selected over a narrow range of color, but cool enough so that all stars have lifetimes that exceed that of the Galaxy. The photometry has almost all been reduced by UNC graduate student Carrie **Rowland**. This will avoid biasing the sample against the ancient thick disk. The next step will be multi-fiber high-resolution, low-S/N echelle spectra to provide 3-d motions and metallicities out to distances of 4 kpc, and over 2 kpc from the plane. These in situ samples should help resolve the relationship of the two disk populations.

Graduate student **Habgood** and **Carney** have obtained high resolution (28000) spectra for multiple red giant stars in several Galactic globular clusters. NGC 5927 (3 stars) and NGC 6397 (8 stars) represent the metal-rich and metal-poor extremes of clusters with disk kinematics, while NGC 362 (5

stars) and NGC 4590 (7 stars) represent the extremes of the ‘‘young halo’’ population. The analyses will determine if the $[\alpha/\text{Fe}]$ ratios in these clusters are the same or different, indicating the speed at which they formed.

Habgood and **Carney** also have obtained *BVI* photometry for the clusters NGC 288, NGC 362, and NGC 6397. The goal is to improve the precision of the photometry for the brighter stars in each cluster, from the region of the main sequence turn-off to the tip of the red giant branch.

Laura Fullton (PhD 1995), **Carney**, and Peterson Stetson (DAO) obtained V_i WFPC2 images of the globular cluster NGC 6287, whose blue horizontal branch and relatively high metallicity have indicated that it may be among the oldest clusters in the Galaxy. Additional NICMOS observations have been approved for NGC 6287, as well as the very metal-rich inner halo clusters Liller 1 and Palomar 6.

5.6 Extragalactic–Galactic Evolution

Graduate student Andy **Leonardi** is working with James **Rose** on age-dating starbursts in post-starburst galaxies observed in integrated light. They have developed a technique using absorption feature spectral indices to remove the degeneracy between burst age and strength in a spectrum composed of a post-starburst population superimposed on an underlying old galaxy population.

Currently, **Leonardi** and **Rose** are investigating the effects of the chemical composition of the starburst population on the age-dating technique. With the assistance of Dr. Guy Worthey (St. Ambrose U.) they have adapted his population synthesis models to young (≤ 1 Gyr) populations using synthetic spectra computed by Robert Kurucz’s SYNTH program. This allows the age, strength and chemical composition of a starburst population to be independently determined for a given system.

Currently, **Leonardi** and **Rose** are using the age-dating method to investigate different types of starburst systems including: over 30 star clusters in the Magellanic clouds representing pure starburst populations, nearby dynamically disturbed systems such as NGC 5018, NGC 2865, and NGC 3921, and a spectrophotometric library of galaxy merger systems suspected of being sites for starburst activity.

5.7 Extragalactic–Structures

Rose, in collaboration with Nelson Caldwell (SAO), is continuing an investigation of the evolution of nearby rich clusters of galaxies. In Caldwell & Rose (1997a) they discuss multi-fiber spectroscopy of early-type galaxies in five nearby clusters, including the Coma cluster. The main results are that a surprisingly large fraction ($\sim 15\%$) of the early-type galaxies in present-epoch rich clusters show evidence for ongoing or recent starbursts and that this star formation activity appears to be linked to merging substructures in these clusters. Moreover, they find evidence that in at least some clusters the star formation bursts are only triggered during (or after) the subcluster passes through the center of the main cluster (Caldwell & Rose 1997a).

Caldwell and **Rose**, in collaboration with Ray Sharples (Durham), Richard Bower (Durham), and Richard Ellis

(Cambridge), have acquired WFPC2 B and I band images of a number of starburst and post-starburst galaxies in the Coma cluster and in the cluster DC2048-52. While the currently starbursting galaxies show centrally concentrated star formation that appears to resemble minor merger simulations of Mihos & Hernquist (1995, *ApJL*, 425, L13), the ~ 1 Gyr post-starburst galaxies have very regular disk morphologies.

Rose and graduate student Kristi **Dendy** are carrying out N-body simulations of rich clusters (using the publicly available NEMO stellar dynamical software) to evaluate how frequently minor mergers occur when a subcluster passes through the main cluster. The purpose is to evaluate whether minor mergers occur frequently enough to explain the number of recently star-forming galaxies in the Coma cluster and other nearby clusters.

Caldwell and **Rose** have recently submitted for publication (Caldwell & Rose 1997b) a study of nine low-luminosity early-type galaxies ($M_B > -17.5$) in the Coma cluster. The spectra, which were obtained with the Multiple Mirror Telescope, exhibit a large variation in Balmer line strengths. When compared to population synthesis models, the variation in Balmer line strengths among the Coma galaxies indicates a range in luminosity-weighted mean age of from ~ 1 Gyr to ~ 12 Gyr. The two youngest galaxies are shown to be in a post-starburst state, i.e., they are not simply former spirals whose star formation was recently terminated. Moreover, the ~ 1 Gyr ages of these two youngest low-luminosity galaxies are similar to that of the brighter post-starburst galaxies in the SW region of Coma found by Caldwell *et al.* (1993, *AJ*, 106, 473).

5.8 Extragalactic–AGNs & Quasars

Cecil, working with J. Morse (Colorado), Z. Tsvetanov (Johns Hopkins), and A. Wilson (U. Maryland) completed an analysis of the apparently deviant velocity field of the ionized gas in the S0 galaxy NGC 5252. They mapped the velocity field using the Rutgers/CTIO Fabry-Perot Interferometer on the 4m at CTIO, and then linked it to the nuclear ‘‘mini spiral’’ revealed by their HST images and FOS spectroscopy. Gas motions are well accounted for with the rotation curve defined by the stars, but now moving on a plane of quite different inclination whose spin axis changes abruptly with radius. This is the expected behavior as gas from a merger precesses in the galaxy potential.

Cecil, working with J. Higdon (Australian National Telescope Facility), used the Mt. Stromlo 2.3m to map gaseous excitation, stellar velocities, and gaseous kinematics across the rings and ‘‘spokes’’ of the Cartwheel galaxy, a complex generated by the impact of two gas-rich galaxies. This work showed that the rings are density waves, not shocks. Numerous embedded H II regions are found along the spokes. Subsequent work with the Taurus-2 Fabry-Perot at the AAT exploited this emission to measure the velocity field of the spokes. These measurements are being compared to numerical simulations of the galaxy collision.

Christiansen continued his work on hypersonic wind cloud interactions under varying physical conditions. New studies have been initiated on the destruction of host galaxy interstellar media by quasar activity. Galaxies with thin,

cold, dense disks survive quasar activity relatively unscathed, although large kpc scale holes are blown in their disks. The inner surfaces of these holes are Rayleigh-Taylor unstable and can, therefore, be source of clouds, some of which are swept into wind creating high velocity absorption features such as are seen in the BAL quasars. Furthermore, large mass instabilities on from the hole surface can also fall through the wind onto the central accreting black hole causing an increase in the wind luminosity. Since the minimum mass for a cloud to fall through the wind depends on the wind luminosity, there is a strong feedback effect on accretion. It can be shown in simplified models that the mechanism for feeding quasar accretion can lead to classical chaotic fluctuations in quasar luminosity. Further refinements of these models are currently underway.

5.9 Plasma Astrophysics

Christiansen has continued studies of relativistic electron acceleration via current sheets created by magnetic reconnection. The observed polarization of synchrotron radiation is used to set the bias in a Monte Carlo calculation of the rate of energy gain by relativistic electrons accelerated by electric fields in current sheets. Power-law frequency spectra commonly occur in these models even though, in many cases, the underlying relativistic electron spectra are NOT power-laws. This happens because the magnetic field intensity in a turbulent, reconnecting plasma is itself a power-law which drives the synchrotron spectra toward power laws no matter how the relativistic electron spectra behave.

Omer Blaes (UCSB) and Chris **Thompson** have developed two new Lagrangian formulations of relativistic magnetohydrodynamics and calculated the non-linear couplings between colliding waves, demonstrating the equivalence of the two formulations. In the relativistic regime, the assumption of incompressibility can never be made and two Alfvén modes undergo a three-mode interaction with the fast mode. As a result, dynamical interactions between waves are lower order in the wave displacement than in a non-relativistic incompressible magnetofluid. They have emphasized how the shape and amplitude of a non-linear cascade of Alfvén wave turbulence is sensitive to boundary conditions. In the magnetosphere of a neutron star, only a tiny fraction of the turbulent energy need be converted to charged particles to provide sufficient current density to support the waves. The damping rate of the turbulence therefore depends on the strength of the non-linear MHD couplings between waves. The cascade is terminated when the waves are either damped by Compton drag, or become charge starved. Above a critical rate, injection of Alfvén waves into the magnetosphere of a neutron star leads to the formation of a trapped photon-pair plasma. This provides a promising initial condition for soft gamma repeater bursts. Upper limits on the gamma-ray flux are used to constrain the Alfvén wave emission rate during pulsar glitches.

5.10 Gamma-Ray Bursts

Christopher **Thompson** has continued his study of γ -ray emission from ultraluminous relativistic MHD winds. Al-

most all calculations of non-thermal X-ray and γ -ray emission from energetic outflows have focussed on radiative processes at large distances from the source, without making direct contact with the inner boundary conditions of the flow. In fact, the radiation advected by the outflow can be the dominant source of Compton seeds for high energy emission. The interplay between this radiation and electron-positron pairs is qualitatively different in a relativistic outflow, than in a quasi-static medium. The pairs feed back on the efficiency of leptonic dissipation and on the Compton heating rate to select out regions of the flow with non-thermal spectra in sources of very high compactness. Detailed solutions of the Kompaneets equation for the photon spectrum in a wind with hotspots confirm the results of simple loss-probability arguments. Both non-thermal and thermal states in gamma-ray burst and extragalactic jet sources are being investigated. Optically thick outflows with lower Lorentz factor are an attractive source of soft components in γ -ray burst sources and MeV Blazars.

PUBLICATIONS

- The publication list includes all papers published or submitted between October 1996 and September 1997.
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