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The following report covers the activities of the Department's astronomers and astrophysicists from October 1997 through September 1998.

1. INTRODUCTION

The Department of Physics & Astronomy has research groups with interests in astrophysics, condensed matter physics, gravity theory, nuclear physics, and particle physics. Christopher **Clemens** left Caltech in August to join us as an assistant professor. In all, seven faculty (Carney, Cecil, Christiansen, Clemens, 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 a growing interest in nuclear astrophysics, led by Champagne, Engel and Iliadis. 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 two adjunct faculty: Dr. Lee Shapiro, Director of the Morehead Planetarium, and Dr. Robert McMahan, President of McMahan Electro-Optics in Research Triangle Park.

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*

J. Christopher Clemens, Assistant Professor (Ph.D. Texas 1994) - *Stellar Seismology, Interacting Binaries, Instrumentation*

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

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 is currently Project Scientist of the SOAR Telescope, on leave in Tucson, AZ. **Christiansen** was elected Chairman of the Division of Basic and Applied Sciences at UNC serving a three year term through 2001. **Thompson** joined the editorial board of Physical Review Letters as a Divisional Associate Editor in the field of astrophysics. **Carney** is Past President of the Astronomical Society of the, Pacific, having stepped down in March, 1997. He joined the Nominating Committee as an *ex officio* member, and will complete his term in early 1999. He completed his two-year term as chair of the Committee on Astronomy and Public Policy of the American Astronomical Society in June, 1998, as well as a similar term on the Telescope Time Allocation Committee for NASA's Infrared Telescope Facility. He served as Chair of the Hubble Fellows Selection Panel at STScI in January 1998. He continues to serve as UNC's Member Representative to AURA, and was re-elected to a three-year term on the Observatories Council. The Council re-elected him to a one-year term as Chair. He was a Visiting Committee member for the Carnegie Institution's Department of Terrestrial Magnetism in September, 1998. He continues as a Shapley Lecturer for the AAS. Finally, he has continued to serve as the UNC representative to the SOAR Telescope Interim Board of Directors.

Carney gave an invited talk at the Third Stromlo Symposium on ''The Galactic Halo'' in August, 1998. He also gave a series of nine lectures as part of the ''Saas-Fee'' lectures sponsored by the Swiss Astronomical Society in April, 1998. The lectures will be published next year. **Champagne** was invited to speak on ''Sodium and Aluminum in globular clusters: reaction studies'' at Nuclei in the Cosmos (Volos, 1998). **Iliadis** was invited to speak on ''Element production in hydrogen burning scenarios'' at the APS meeting in Columbus (1998).

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. Rebecca **Surman** recently completed a thesis under the supervision of Engel, on the synthesis of the rare-earth-element peak and the effects of neutrino scattering on r-process nucleosynthesis. Steven **Hale** will complete his Ph.D. thesis with Champagne in early 1999. His project deals with measurements of reaction rates in the NeNa cycle. Denise **Powell** is expected to complete her Ph.D. thesis with Iliadis, on a measurement of the

$^{24}Mg(p,\gamma)^{25}Al$ reaction rates, in spring 1999. Graduate students at earlier stages of research include Serge **Naoumov**, Michael **Habgood**, Luisa **de Almeida**, and Jae-Woo **Lee** (working with Carney); Peter **Bertone** (with Champagne); Brian **Brill** and Parker **Troischt** (with Evans); Jennifer **Mosher** and Carrie **Rowland** (with Iliadis); and Kristy **Dendy** and Andrew **Leonardi** (with Rose). Undergraduate Peter **Bermel** has started a research project with Christiansen

2. SOAR

The SOAR Telescope Project bas 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 be completed in early 1999.

The site will be near Gemini South on Cerro Pachon, and site preparation began late last year. 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 4.2-m aperture and altitude/azimuth mounting. After nearly a decade since UNC proposed this project, it is extremely gratifying to seeing it finally getting underway.

3. EDUCATION AND OBSERVATORY OUTREACH

The Morehead Observatory Outreach Program to the public schools led by **Christiansen** is a major effort to fuse astronomy with the earth-space science curriculum in the North Carolina Public Schools. By the year 2000 all students graduating from high school in North Carolina must have completed a one year unit of study in either earth-space science or environmental science. At UNC-CH the initial effort currently underway is the SOLAR (Students On Line As Researchers) Program. The focus of SOLAR is on remote observing using Morehead Observatory facilities which are connected to the intern*et al.*lowing teachers and their students to control the telescope and CCD camera from their classrooms anywhere in the State. The emphasis is on solar imaging so that the experiments can be scheduled during regular classroom hours. Both white light and H-alpha solar images are taken by students, the latter through a tunable Lyot filter. A new set of solar experiments has been written by Christiansen, Nancy West (William & Mary) and Andy **Leonardi** (UNC-CH) utilizing NIH Imaging software to allow students to combine their own solar images with a larger student generated database which is maintained on the LEARN-NC home site. Experiments have been written involving simplified techniques for cleaning images as well as experiments for measuring movements and secular changes in sunspots, plages and prominences. The first remote observations began in the Fall of 1998 and will continue as long as there is interest and funding. SOLAR is just the beginning of a more extensive outreach program which also involved night-time astronomy. The Morehead facilities will also be made available for limited amounts of time for more advanced classes to carry out individualized observing projects. These advanced student projects will be scheduled by the Observatory staff on the basis of (student) peer-reviewed student proposals.

4. EQUIPMENT AND SOFTWARE

Chris **Clemens** has completed initial design studies for a high throughput spectrograph for the SOAR telescope in collaboration with Antonio Kanaan (Universidade Federal de Santa Catarina, Brazil). He has also begun testing and evaluation of spectrograph gratings with UNC undergraduate Scott **Seagroves**.

Christian **Iliadis** and graduate student J. **Mosher** are developing a new experimental method for measuring (p,α) reactions of astrophysical importance. The experiments are performed by detecting the reaction α−particles in coincidence with the corresponding heavy recoil nuclei. The recoil nuclei are measured with a microchannel plate detector. Testing of the setup is in progress.

Champagne and Iliadis are constructing a new low-energy nuclear astrophysics (LENA) laboratory at the Triangle Universities Nuclear Laboratory. LENA is designed to produce the world's most intense beams of protons for the study of astrophysical cross sections.

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. Initial results suggest a change in the zero point of the P-L relation of about 0.2 mag per dex in [Fe/H].

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 **J.-W. Lee** are also working with Dr. Mike Corwin (UNC-Charlotte) to derive high-quality *BV* light curves for $\approx$ 150 RR Lyrae variables in the globular cluster M3 and 30 variables in M2, of which 13 are new discoveries. 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 reveals that the M2 variables are about 0.15 mag brighter than those in M3. Thus there may be a dichotomy in the M_V(RR) *vs.* [Fe/H] relation. A main sequence fit between the two clusters confirms the offset, and that M2 may be up to 2 Gyrs older than M3. A kinematic analysis of the Oosterhoff I and II clusters shows different velocity dispersions and Galactic rotational velocities. Papers on the RR Lyrae photometry and the age/kinematic differences are in preparation.

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 [O/Fe] using the [O I] line at λ6300 and the O I triplet near $\lambda\lambda$7770. [O/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.

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.

Fry and **Carney** have also obtained new photometry of 9 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 nine metal-poor field halo blue stragglers, determining spectroscopic orbits for 5 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.

5.2 Stars–Nucleosynthesis and Evolution

Jonathan **Engel** worked on several aspects of r-process nucleosynthesis. In collaboration with student Rebecca **Surman** he calculated neutrino scattering rates from important waiting point nuclei (which refuse to accept more neutrons and must beta decay before rapid neutron capture can continue). These rates are larger than previous estimates and constrain the neutrino flux that can exist at the r-process site. Surman presented her thesis, which contained a novel explanation of the poorly understood rare-earth-element peak (in collaboration with Engel, and Brad Meyer at Clemson). The peak forms only when the free neutrons begin to disappear. At that point beta decay occurs on the same timescale as neutron capture and the nuclei that are populated are therefore less neutron rich than during the main part of the r-process. Finally, together with postdoctoral fellow Michael **Bender**, Engel has just completed a systematic and self-consistent calculation of beta decay half-lives along the r-process path. The half-lives are generally shorter than in previous calculations and reduce the time required to complete the r-process. This work is currently being written up for submission to Phys. Rev. C.

Iliadis, Endt (Utrecht), Prantzos (Paris) and **W.J. Thompson** (UNC) have completed a project related to explosive nucleosynthesis in neon novae and type I X–ray bursts. This work was specifically concerned with reactions of astrophysical interest that involve unstable target nuclei. Improved nuclear theoretical methods are presented in order to calculate the reaction rates of astrophysical interest. The improved reaction rates have been incorporated into large–scale reaction network calculations. The nuclear energy generation, residual hydrogen abundances and final isotopic abundances after the explosion were investigated for different temperature–density conditions. Parameter studies have been performed by varying key reaction rates within their assigned uncertainties in order to better understand the connection between microscopic (nuclear physics) and macroscopic (astrophysics) properties describing explosive events. A complete discussion of the results can be found in Iliadis *et al.* (1998). Measurements to evaluate the nuclear-structure database used in this work have been undertaken by **Hansper**, **Champagne** and **Iliadis** and analysis is underway.

A program of measurements relevant to explosive nucleosynthesis using radioactive beams has recently been initiated at Oak Ridge National Laboratory. A collaboration involving Bardayan (Yale), Blackmon (ORNL), Smith (ORNL), Kozub (Tenn. Tech), Parker (Yale), **Champagne**, **Hansper** and coworkers have begun a measurement of the ^{1}H(^{17}F,^{17}F)^{1}H reaction in an effort to locate a resonance thought to be responsible for the ^{17}F(p,γ)^{18}Ne reaction in novae. This reaction leads ultimately to ^{18}F whose subsequent decay may provide the heat responsible for the early evolution of the nova light curve.

Surprisingly large enhancements of Na and Al have been observed in stellar atmospheres within a number of globular clusters. In general, the abundances of these elements show an anticorrelation with the abundances of O and enhancements in Al are accompanied by depletions in Mg. It has been suggested that deep mixing can produce these effects. However, large uncertainties are known to plague some of the reactions involving nuclei in the NeNa and MgAl regions. In the former cycle, uncertainties in the ^{22}Ne(p,γ)^{23}Na reaction are very large and compromise the usefulness of calculations of nucleosynthesis at low temperatures. Resonances in this reaction have been studied by **Champagne** with graduate student **S. Hale**. Although the rate for this reaction is now reduced, it does appear that mixing can produce an O vs. Na anticorrelation. Measurements of the ^{24}Mg(p,γ)^{25}Al reaction have been performed by **Iliadis** and graduate student **D. Powell** in order to explain the observed Mg–Al anomaly. Preliminary experimental results show that the ^{24}Mg+p reaction rate at low stellar temperatures is in-

deed larger than previously thought, but the rate is not large enough in order to convert a substantial amount of ^{24}Mg to Al. Analysis of the data is in progress.

Champagne and graduate student **P. Bertone** have begun a study of the various reaction components that contribute to the $^{14}N(p,\gamma)^{15}O$ reaction at low temperatures. This reaction regulates energy production in stars that burn hydrogen via the CN cycle. Further work with El Eid (AUB) indicates that changes in this rate will lead to measurable differences in the predicted abundances for some isotopes on the surfaces of massive red giants. One of these isotopes is ^{17}O, which is a useful probe of mixing. To help put predictions for the abundance of ^{17}O on a firmer footing, **Champagne** and Blackmon (ORNL) have measured the $^{17}O(p,\gamma)^{18}F$ reaction. Data analysis is in progress.

5.3 Stars–White Dwarfs

Clemens research interests include pulsating white dwarfs, interacting binaries, and time-variable phenomena in general. This year he, Reid and Gizis (Caltech) and O'Brien (Iowa State) published a new and simpler explanation for the existence of a well-known gap in the orbital period distribution of cataclysmic variable stars. A follow-up paper addressing published responses to this model is in preparation. His other main research effort, with Marten van Kerkwijk (University of Utrecht) and Yanqin Wu (Queen Mary and Westfield College), has concentrated on understanding time-resolved spectra of pulsating white dwarfs acquired with the Keck LRIS spectrograph. This year's results include a method for mode identification in the ZZ Ceti pulsators, and a numerical model for spectral line variations. These results have been submitted as two papers to Monthly Notices of the Royal Astronomical Society.

5.4 Stars–Supernovae

C. Thompson, N. Murray (CITA) and R.C. Duncan (U. Texas Austin) have continued their investigation of magnetism in nascent neutron stars, focussing on transport processes and the effect of reconnection outside the neutrinosphere on the surrounding supernova shock. The vigorous convection that occurs inside the neutrinosphere during the first few seconds, when scaled from the granular motion and intranetwork magnetic field of the Sun, implies r.m.s. magnetic fields in excess of 10^{15} G. We have studied the response of the surface magnetic field to rapid fallback onto the surface of the neutron star ($\dot{M} \sim 10^{-1} M_\odot$ 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 reconnection rate as large as ($O(10^{51})$ erg s^{-1}) while accretion continues. Because the energy contained in the magnetic field is not effectively re-converted to neutrinos, this provides an additional source of pressure around a stalled accretion shock, which turns off when the shock succeeds. Transport of the remnant magnetic field through the degenerate interior of the newborn neutron star, after convection turns off, is limited by the rate at which the charged particle density relaxes to its beta-equilibrium value.

5.5 Galactic Structure

Cecil, Bland-Hawthorn (AAO), Veilleux (U. Maryland), Putman and Gibson (Mount Stromlo), and Maloney (Colorado) published analysis of ''staring Fabry-Perot'' spectra of several H I high-velocity clouds. The high-efficiency of the AAT Taurus FP, when operating in this non-scanning mode, enabled the first detection of these clouds in H-alpha and [N II]. Their kinematics and especially ionization state are consistent with a location in the Magellanic Stream.

Rose continued a long-term study of the vertical structure of our Galaxy with J. Stock (CIDA, Venezuela) and R. Agostinho (Univ. of Lisbon, Portugal). They have used digital objective prism spectroscopy extracted from opposed dispersion plate pairs taken with the CTIO Curtis Schmidt with an effective 10 degree prism to obtain astrometric positions and relative radial velocities for over 7000 stars at high Galactic latitude. The methods used to derive positions, proper motions, and radial velocities, as well as a catalog of 107 high radial velocity stars is published in Stock, Rose, and Agostinho (1998). They are continuing to extract information on the spectral types and surface gravities of these stars from the digitized spectra.

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, threee 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, based on several thousand spectra.

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. The photometry has been reduced, by Carrie **Rowland**, and targets selected for follow-up multi-fiber high-resolution, low-S/N echelle spectra to provide 3-d mo-

tions 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 bf 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 begun obtaining 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. One run at Kitt Peak and one at Cerro Tololo were successful, and one more run at each site is scheduled.

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 [α/Fe] ratios in these clusters are the same or different, indicating the speed at which they formed.

S. Balachandran (U. Maryland), **Carney**, Laird (Bowling Green St.), and L. Fullton (Geneva) obtained high-resolution spectra at 2.2 μm of three stars thought to be members of the heavily obscured, metal-rich globular clusters Liller 1 and Palomar 6, including orders containing Fe I and Si I lines. Optical echelle spectra were also obtained for NGC 6287, a very metal-poor inner halo cluster. All three clusters have been recently observed with HST/NICMOS (Fullton, PI).

J.-W. Lee and **Carney** have obtained good echelle spectra for one or more stars in six metal-poor and metal-rich inner halo globular clusters, all of which have been observed with HST/WFPC2 (Zinn, PI). The clusters are NGC 5927, NGC 6293, NGC 6333, NGC 6541, NGC 6624, and NGC 6637.

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.

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. **Naoumov** has completed stellar atmospheric parameter estimations for several of the stars.

5.6 Extragalactic−Galaxies

Cecil and Higdon (Australia National Telescope) continued their work on the dynamics of ionized gas in the Cartwheel galaxy. A high spatial resolution (< 1'') H-alpha datacube was obtained with the Taurus FP. Limits on streaming motions along the ''spokes'' of the Cartwheel are being examined in the context of several dynamical models.

Rose and graduate student Andrew **Leonardi**, as part of Leonardi's thesis project, are analyzing the integrated spectra of Large Magellanic Cloud star clusters to determine as uniquely as possible, their ages and chemical compositions. Using integrated-light spectral indices in conjunction with the evolutionary synthesis models of G. Worthey (St. Ambrose U.) which can detect a young stellar population embedded within an older one, the results obtained will serve as a springboard to applying the same procedure to poststarburst systems. Determining the ages and chemical compositions of the young starburst population can then be used to constrain possible triggering scenarios for the burst.

Leonardi and G. Worthey have also nearly completed a study of the possibility that a young stellar population resides in the shell galaxy, NGC 5018. Certain abnormalities in the spectral energy distribution of NGC 5018 and its spectral indices, specifically Mg2, have created a mild controversy in the literature whether NGC 5018 is a metal-poor system or contains a young population. The results, in preparation for publishing, show conclusively that NGC 5018 needs to contain a young population of at least solar metallicity.

5.7 Extragalactic−Structures

Rose continued studies of the evolution of nearby rich clusters of galaxies. The primary motivation for this work has been the discovery of many starburst (SB) and poststarburst (PSB) early-type galaxies in several rich clusters, based on multi-fiber spectroscopy. In follow-up work designed to clarify the nature of these starbursts, **Rose**, in collaboration with Nelson Caldwell (SAO), and UNC graduate student Kristi **Dendy**, completed an analysis of *HST* WFPC2 B and R images of nine SB/PSB galaxies in the nearby rich clusters Coma and DC2048-52, The *HST* images reveal these SB/PSB galaxies to be heterogeneous in morphology. Nevertheless a common theme is that many of them, especially the SB galaxies, tend to have centralized spiral structure that appears simply as a bright ''bulge''on ground-based images. In addition, while some PSB galaxies exhibit distinct spiral structure, on the whole they have smoother morphologies than the SB galaxies. The morphologies and luminosity profiles are generally consistent with substantial starbursts in the form of centralized spiral structure (the SB galaxies) which fade into smoother morphologies (the PSB galaxies), with lingering spectroscopic evidence for past central starbursts. An important point is that the PSB galaxies retain disks, i.e, they have not evolved into spheroidal systems. While the morphologies revealed in the *HST* images are heterogeneous, and thus may not fit well into a single picture, here is evidence in several cases that the morphologies and centralized star formation have been driven by external tidal perturbations. These results are discussed in Caldwell, Rose, and Dendy (1999).

UNC graduate student, Kristi **Dendy**, and thesis advisor **Rose** in collaboration with Caldwell (SAO) have initiated a study of low-luminosity early-type galaxies in the Virgo cluster. To date, spectra for six of these galaxies have been obtained and show signs of recent, enhanced star formation. Age dating techniques indicate that a large variety of ages are present in the sample with five of the six galaxies having had star formation episodes within the last few Gyr. The aim

of Dendy's thesis project will be to study the variation in the star formation properties of these galaxies, to determine the frequency of the bursts and to investigate the connection, if any, between the episodes of star formation and the cluster environment.

5.8 Extragalactic–AGN & Quasars

Cecil and collaborators J. Morse (CASA/Colorado), A. Wilson (U. Maryland), and Z. Tsvetanov (Johns Hopkins U.) published analysis of deviant circumnuclear gas motions in the lenticular galaxy NGC 5252. This galaxy shows striking ionization cones that arise from beamed radiation from the active galaxy nucleus. The gas distribution was mapped using HST WFPC2 images in various emission lines and the Rutgers Fabry-Perot (FP) system at CTIO. Contrary to previous work, their analysis showed that the gaseous kinematics of both ionized and neutral gas are consistent with simple circular orbits in the potential of the galaxy (as defined by the observed star motions.)

Cecil continued work with DePree (Agnes Scott College), Greenhill (Harvard CfA), and Moran (CfA) on HST WFPC2 images and FOS spectra, and high S/N VLA images of the jets in NGC 4258. The combined images show clear bow shocks that confirm the jet-origin of the linear ionized filaments. This argues against a spiral disk shock origin for the ''anomalous arms'' in this famous galaxy. A deep AXAF grating spectrum of hot, ionized gas associated with the jets will be obtained.

Christiansen continued his work on numerical simulations of hypersonic wind cloud interactions in broad absorption line quasars (BALs). These numerical models clearly demonstrate that the ISM of any host galaxy will likely be blown out by powerful sub-relativistic winds. The ejected clouds display a characteristic absorption line spectrum which is primarily due to the continual stripping of gas from the cloud surfaces caused by instability growth. These simulations also demonstrate that the instabilities themselves have fractal spectra. The resultant hierarchy of ablated cloudlets creates the observed Doppler shifted absorption patterns in velocity space. Christiansen is now creating a data-base of synthetic spectra based on the fractal cloudlet model which will be used to interpret the observed spectra of BALs.

5.9 Plasma Astrophysics

Christiansen is now developing detailed models of the MHD turbulence in extended extragalactic radio sources. Given the fact that the surface brightness the lobes of extended radio sources exhibit multi-fractal properties, these models can be tested by comparison with the observed multifractal spectra. These models have the advantage that relativistic electron acceleration (which is necessary for maintaining the observed synchrotron emission) is automatically included as a result of the vigorous magnetic reconnection which must be happening the these sources.

5.10 Gamma-Ray Bursts

C. Thompson and R.C. Duncan (Texas) have collaborated with the MSFC group (Kouveliotou *et al.*) to interpret their observations of the spindown of SGR 1900+14. The spindown rate exceeds that expected for magnetic dipole radiation from a magnetar of period 5.16 sec coeval with the adjacent SNR G 42.6 + 0.8, but is consistent with the mechanism of particle-aided spindown predicted by Thompson and Blaes. In this model, short term fluctuations in the quiescent particle flux from the SGR induce changes in the magnetic field strength at the light cylinder, and hence in the spindown rate. The inferred high proper motion of SGR 1900+14 can be ascribed to one of two mechanisms originally suggested by Thompson and Duncan: anisotropy in the neutrino flux from the newborn neutron star driven by the interaction of magnetic and convective stresses (''neutrino starspots''); or an asymmetric *matter-loaded* jet driven by the rapid spindown of the hot, newborn neutron star.

Thompson has continued his work on the magnetar model for the Soft Gamma Repeaters, on several fronts. 1) Extending the original predictions (by Thompson and Duncan) of afterglow X-ray emission from the heated surface of the neutron star to include power-law time indices. Observation of afterglow is a potent diagnostic both of the surface magnetic field strength, and of the presence of a trapped fireball in the SGR burst. 2) Extending previous calculations of quiescent X-ray and particle emission to include the effects of magnetospheric Compton scattering and particle amplification, with a focus on non-thermal spectra. One important implication of this model is that pulsed radio emission will be suppressed by induced Compton scattering in active magnetars. 3) Extending previous calculations of photon transport, which combined the effects of Compton scattering and photon splitting, to include hydrodynamic effects more completely.

Thompson has calculated the prompt synchrotron pulse resulting from the propagation of a second (non-relativistic) shock through a pre-existing blast wave. The rapid decay in the synchrotron flux following the collision between the two shocks is being compared with observations of prompt radio afterglow following the giant August 27 burst from SGR 1900+14. The model has interesting implications for the effectiveness of magnetic field amplification in blast waves with very high energy densities.

Thompson and **Christiansen** have examined the possible connection between magnetars and cosmological γ-ray burst sources. The interaction of an energetic relativistic jet with a stellar envelope was quantified, with a focus on the conditions necessary for successful ejection of relativistic material are quantified. A cylindrical shock propagating away from the jet axis can eject the right amount of trans-relativistic material to explain the soft burst GRB/SN 980425. A central engine (neutron star or black hole) fed by an accretion disk is predicted to have a continuous, declining luminosity with a time index slightly steeper than -1, in marked contrast to an isolated neutron star (index -2). Because the magnetic field of the neutron star can be recycled during the last stages of disk accretion, it is tentatively suggested that gamma-ray bursts are not the birth events of the soft gamma repeater sources, even though the two classes of sources may be closely related.

Thompson, **Christiansen** and **Evans** have examined af-

terglow radiation from a blast wave that expands *non-relativistically* over the entire observed phase of powerlaw decay. In the presence of a continuous, declining output from the central engine, the reverse shock is an efficient radiator, and a large photon compactness at the forward shock eliminates the need for enormous post shock amplification of the ambient magnetic field. The effects of induced Compton scattering on the emergent low frequency spectrum are taken into account, and a comparison made with the + 12 day afterglow spectrum of GRB 970508 and the + 1 month spectrum of GRB 980329. The coordinated rise in the X-ray and optical afterglow of GRB 970508 at + 1 day can be ascribed to the onset of Compton transparency. The extended afterglow emission is expected to be brighter when the ambient medium i) is pair-loaded by hard gamma-rays from the prompt burst; and ii) has a high density (about a million times that of the ISM).

Thompson has continued his work examining the influence of inner and outer boundary conditions on the observed output of a highly compact, relativistic outflow. Photon creation and spectral evolution are calculated self-consistently in the presence of continuous heating. The dominant Compton seeds for the prompt gamma-ray emission are argued to be photons advected outward from large scattering depth. Soft (No-High-Energy) components of gamma-ray bursts are naturally produced by dissipation inside the electron-ion photosphere. This model implies strict limits on the magnetic and/or non-thermal particle energy densities at high compactness, with interesting implications for dissipative physics. Pair creation via photon collisions feeds back strongly on the efficiency of Compton dissipation, and drives the minimum non-thermal $e^{\pm}$ (rest-frame) Lorentz factor toward unity. Multiple-peaked bursts *can* arise from wrinkled relativistic shells: if the expansion Lorentz factor decreases away from a central axis, then propagation delays produce a softening trend from subpulse to subpulse, as observed in a number of bursts. The application of this physics to Blazar sources is also being investigated.

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