University of North Carolina
Department of Physics and Astronomy
Chapel Hill, North Carolina 27599-3255

The following report covers the Department activities from October 1995 through September 1996.

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 lead 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. 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. During 1994-96, the Department was very fortunate to have Dr. Andrew Abrahams in residence as a Visiting Assistant Professor in gravity physics. He left in August 1996, to become staff scientist at the NCSA in Urbana-Champaign. 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)

Andrew M. Abrahams, Visiting Assistant Professor (Ph.D. Illinois 1988) - *Theoretical Astrophysics: Compact Objects, Gravity Physics*

Bruce W. Carney, Samual 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*

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*

Carney continued as President of the Astronomical Society of the Pacific. He served on the AURA Board of Directors, and continues to serve as a member representative to AURA and as a member of the Nominating Committee. He is also a SOAR Interim Board member. **Champagne** chairs the Holifield Radioactive Ion-Beam Facility Executive Committee and is a member of the Nuclear Astrophysics working group for the Isospin Laboratory. Carney gave invited talks at ''Formation of the Galactic Halo…Inside and Out'' in Tucson AZ (1995), at the Brazilian Astronomical Society (1995), and at the Whitford Symposium at Lick Observatory (1996). Champagne was invited to speak on ''Nuclear Probes of Stellar Evolution'' at the meeting of the Southeast Section of the APS in Tallahassee (1995) and on ''Reaction Rates for Na and Al,'' at the Workshop on the Origin of Galactic Radioactivity, Clemson University (1996). **Thompson** gave an invited review of the Soft Gamma Repeaters at the introductory workshop to the program on ''Astrophysical Gamma-Ray and Non-Thermal Sources'' at the ITP (Santa Barbara) and spent an additional two months at the workshop. He also reviewed SGR models at the Third Huntsville Symposium on Gamma-Ray Bursts.

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. Christopher **De Pree** completed a thesis on ''Multifrequency Imaging Spectroscopy of Four Galactic Star Forming Regions,'' under the direction of Cecil. He has taken up a position at Ogglethorpe University in Atlanta, Georgia. Lewis **Jones** completed a Ph.D. thesis with Rose on the integrated spectra of low-luminosity elliptical galaxies, and has accepted a postdocal position at the University of New South Wales (Australia). Two students completed masters theses with Carney: Jeffrey S. **Wright**, on ''Chemical Abundance Analyses of Very Metal-poor Halo and Possible Disk Stars,'' and Jonathan **Garrison**, on ''[X/Fe] Ratios in Three Nitrogen-Rich Halo Stars.'' **Wright** is now an instructor at Elon College. Anne **Fry** is expected to complete her Ph.D. thesis with Carney, on a recalibration of the Cepheid distance scale, in spring 1997. Graduate students at earlier stages of research include Andrew **Leonardi** (working with Rose), D. **Junkin**, D.C. **Powell**, S. **Hale** and

P. **Bertone** (with Champagne), Colin (Tas) **Philp** and Parker **Troischt** (with Evans), and Serge **Naoumov**, Michael **Habgood**, Luisa **de Almeida**, and Jae-Woo **Lee** (with Carney).

Two undergraduates, Timothy **Perkins** and Jon **Lenaghan**, completed senior honors theses with Evans and have moved on to graduate school. Perkins has accepted a Marshall scholarship at Cambridge University, and Lenaghan will pursue graduate studies at Yale. Ivy **Dick** spent a summer working with Carney.

2. SOAR

The SOAR Telescope Project bas begun in earnest. UNC has pledged 6 M$ toward capital construction. The other partners contributing to the total 28 M$ construction costs are, in order of joining the project, NOAO (2 M$), Brazil (14 M$), and Michigan State University (6 M$). At a meeting of the partners held in Chapel Hill during August 29-30, 1996, three working groups were formed to expedite the planning prior to formal incorporation and hiring of a project team. An Interim Board was formed, as was a science and design committee, and an operations committee. By early 1997, the partnership should be fully incorporated. The Interim Board or the new Board will also decide whether to form a primary mirror with a 10 cm or a 20 cm thickness, and should contract for the completion of the work with Corning. Decisions will also be made regarding siting the telescope atop Cerro Tololo or Cerro Pachon, and whether to continue with the ''baseline'' design of an f/15 on-axis thin meniscus or an off-axis option and a superpolished primary to reduce scattered light for high dynamic range studies. Gerald **Cecil** has moved to Tucson to assume the task of interim project scientist and chair of the science and design committee. All the final decisions will be made with the telescope's primary goals in mind: optimal image quality and the ability to change from one instrument to another quickly during a night. After nearly a decade since UNC proposed this project, it is extremely gratifying to seeing it finally getting underway.

3. TEACHING

Wayne **Christiansen** in collaboration with the English Department at UNC-CH continues the development of an Astronomy course which is ''Linked'' to a required English Composition course. The writing in this course ranges from units based on simulated observing proposals to units in which students first write review papers and then act as editors writing referee's reports on other student's papers. We are currently assessing the effectiveness of such a course.

Christiansen was the first receipient of the John L. Sanders Award at UNC-CH which is given in ''Recognition of demonstrated excellence and exceptional ability in undergraduate teaching and service. He was also invited to deliver a lecture on the topic of ''The Place of Life in the Universe'' as part of the College of Arts and Sciences lecture series, ''College Lights.''

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−Formation

The Compton Gamma Ray Observatory (GRO) has provided a map of gamma emission from the decay of 26Al in the plane of the galaxy. This flux implies a 26Al/27Al ratio in the ISM that is ten times smaller than what is derived from the 26Mg abundance in meteorites. Clearly, the early solar system was quite different from the present ISM. A hint about conditions in the early solar system may come from GRO observations of gamma rays from 12C*(4.43) and 16O*(6.13) in the direction of the Orion nebula. These lines are presumed to arise from collisions of accelerated 12C and 16O with ambient H and He. Better observations and measurements of gamma-ray production cross sections at low energies are needed in order to uncover the energy source in Orion. Nonetheless, it is reasonable to ask whether our solar system underwent a similar phase of cosmic-ray acceleration. The record of such a period is stored in the meteorites in the form of isotopic anomalies and extinct radionuclides, e.g. 26Al, 53Mn, etc. N.P.T. Bateman (Yale), P.D. Parker (Yale) and **Champagne** have measured the 12C(16O,pn)26Al cross section for energies relevant to the Orion phenomenon. They find that this scenario requires an excessive amount of cosmic-ray power and therefore advocate a stellar origin for 26Al.

5.2 Stars−Luminosities & Abundances

Although the solar-neutrino problem seems to involve suppression of the flux of 7Be neutrinos, attention has also centered on the role of uncertainties in the cross section for 7Be(p,g)8B. The analog reaction, 7Li(n,g)8Li has been measured by postdoctoral fellow **Blackmon**, **Champagne**, Hofstee, Powell (graduate student), J.K. Dickens (ORNL), J.A. Harvey (ORNL), S. Kopecky (Wien), D.C. Larson (ORNL), S. Raman (ORNL) and M.S. Smith (ORNL). Its excitation function is consistent with that of a simple direct-capture process. Therefore, the reaction mechanism for 7Be(p,g) appears well-understood despite perceived deficiencies in the data. These results are also relevant to nucleosynthesis during an inhomogeneous big bang and imply that calculations involving 7Li should be reexamined. We have also begun a new 7Be(p,g) measurement which should greatly reduce the uncertainty in this cross section. This work is being undertaken by **Champagne** and post-doctoral fellow Vera **Hansper** in collaboration with H.R. Weller (Duke), D.M. Moltz (LBNL), J. Powell (LBNL), and M.A. Hofstee (Colorado School of Mines). A test run has been completed and further work awaits the construction of a new accelerator facility at TUNL.

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. When combined with similar data for Galactic cepheids, and the color-temperature relation for cepheids recently derived by Anne **Fry**, Baade-Wesselink analyses will be undertaken to test the metallicity sensitivity of the cepheid P-L relation.

Rodney Jones (PhD 1988) and **Carney** have completed a modelling of *K*-band light curves of RR Lyraes, enabling them to derive good mean *K* magnitudes from only a single observation. They have also been re-evaluating 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. An additional sample, selected without any magnitude or period that might produce a sample biased in favor of evolved variables, is being observed with the IR arrays on the KPNO 2.1m and 4m telescopes, in collaboration with T. Kinman (KPNO). Observations should be completed in 1997.

S. Balachandran (U. Maryland), **Carney**, and Laird (Bowling Green St.) have undertaken a study of oxygen abundances in halo and thick disk stars using the OH lines near 1.6μm, and the CO lines near 2.3μm using the cryogenic echelle (CSHELL) on NASA's IRTF. First results, including discussion of the temperature scale, gf values, and results for HD 103095, have been published. Analyses of 9 more stars is underway.

S. Balachandran (U. Maryland), **Carney**, Laird (Bowling Green St.), and L. Fullton (PhD 1995; STScI) obtained high-resolution spectra at 2.2 μm 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.

Graduate student Jonathan **Garrison**, recent graduate Laura **Fullton**, Anne **Fry**, and **Carney** 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 [α/Fe], normal lithium abundances (for their temperatures) and enhanced s-process abundances, consistent with a mass transfer model.

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.

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 [α/Fe] ratios, despite its very low metallicity ([Fe/H] ≈ -1.5).

Carney and Sang-Gak Lee (Seoul National University) have almost 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.

R. Peterson, **Carney**, and H. Smith (Michigan State) obtained HST GHRS spectra in the B I (2497 Å) and Be II (3160 Å) regions of RR Lyrae during its pulsational cycle as it changed from high temperature (7100 K) to low temperature (6200 K) conditions to study what elements might be present that could affect abundance estimates of boron and beryllium in other stars. To check the ephemeris of the star, undergraduate Ivy **Dick** used the Morehead Observatory 24-inch telescope and photoelectric photometer to monitor the star from May through August, 1996.

For her Ph.D., Anne **Fry** is working with **Carney** on a recalibration of the cepheid distance scale. They obtained high resolution, high S/N spectra of 24 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. They observed 18 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, they observed 2 dwarfs in M 25, which contains the cepheid U Sgr. They find a spread of 0.4 dex in [Fe/H] among the cepheids.

Fry and **Carney** are working with Martinez Roger (IAC, Tenerife) to apply the infrared flux method to an expanded set of cluster and association cepheids. For 11 of the above cepheids, echelle spectra over a range of phases have been obtained in order to compare the temperatures derived spectroscopically to those derived from the infrared flux method. Using Fry and Carney's spectroscopic temperatures and published photometry, they are able to derive cepheid color-temperature relations. These relations will be useful in future studies: Baade-Wesselink studies to test the metallicity sensitive of the cepheid P-L relation and abundance analyses of extragalactic cepheids with the new 8m and 10m telescopes.

Fry and **Carney** have 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). When the photometry is completed, they will be able to derive distances for all of these clusters relative to the Pleiades with higher precision than previously achievable.

5.3 Stars–Evolution

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 abundance of O and enhance-

ments in Al are accompanied by depletions in Mg. It has been suggested that deep mixing can produce these effects. However, large uncertainties (of up to a factor of 104) are known to plague some of the reactions within the NeNa cycle so it is not clear if the nuclear data base is precise enough to allow any conclusions to be drawn. Measurements of the 22Ne(3He,d)23Na reaction have been undertaken by **Champagne**, graduate student **S. Hale** and **V. Hansper** in order to probe the reaction which is responsible for producing the Na signature: 22Ne(p,g)23Na. This work has required construction of a new, high-resolution focal-plane detector for the TUNL Enge magnetic spectrometer. The detector has met its design goals and preliminary data have been taken that indicate a reaction rate near the current lower limit. If this finding is confirmed then it implies that mixing will have to go quite deep in order to bring Na to the surface. Similar measurements (by **Iliadis** with graduate student **D. Powell**, **Champagne** and **Hansper**) have been started for the reactions that are responsible for producing Al.

Balachandran, **Carney**, and Agostinho (Univ. of Lisbon) are analyzing high-S/N echelle spectra of roughly 70 very metal-poor stars, primarily to map out the general trends and intrinsic scatter of lithium as a function of evolutionary state. Field stars with $[Fe/H] < -2$ from the cool main sequence to the red giant branch tip are included. Extensive spectra have also been obtained for G183-9, a 6.1-day double-lined spectroscopic binary. The measured mass ratio yields good luminosity ratios so that the spectra of both stars may be analyzed to see if lithium depletion has been affected or halted by the tidal locking.

R. Peterson (Lick), **Carney**, and D. Latham (CfA) completed a study of the rotation of RR Lyrae variables. Some blue horizontal branch stars in globular clusters and in the field have been found to have rotational velocities of up to 30 km/sec. The slightly cooler, slightly larger RR Lyrae variables should also manifest rotation, but a study of roughly two dozen field and cluster variables failed to show any signs of rotation above the instrumental resolution of 10 km/sec. Details were published in ApJL.

5.4 Stars–Pulsars & Black Holes

Charles **Evans** and graduate student Colin **Philp** reported on their search for radio pulsar companions to ''runaway'' OB stars. The search was carried out in 1994 at the National Radio Astronomy Observatory Very Large Array (NRAO-VLA) in collaboration with Dale Frail (NRAO) and Peter Leonard (U. of Maryland).

Andrew **Abrahams** with Arlen **Anderson** and Jimmy **York** and Yvonne Choquet-Bruhat (Paris) has worked on hyperbolic versions of Einstein's equations of general relativity. One of these new formulations is being used by the Binary Black Hole Grand Challenge project.

Abrahams with Richard Price (Utah) and John Baker and Jorge Pullin (Penn. State) and Peter Anninos, Steven Brandt and Ed Seidel (NCSA) have worked on perturbative approaches to calculated waveforms and energies from black hole collisions. These methods have been shown to be a useful alternative to numerical calculations for some interesting cases.

5.5 Galactic Structure

Carney, Laird (Bowling Green St.), Latham (CfA), and Aguilar (Obs. Nac., UNAM) completed data acquisition for an expanded sample of proper motion stars. Improved metallicities, kinematics, and Galactic orbits were presented (AJ, 107, 2240, 1994), and results were published in AJ. It appears that there are at least three distinct populations of metal-poor stars. The stars far from the plane (and some closer) show net retrograde rotation, no radial metallicity gradient, and young ages, consistent with an accretion origin. High-velocity, metal-poor stars closer to the plane show prograde rotation, a weak radial metallicity gradient, and older ages, consistent with a relation to the earliest stages of the formation of the Galaxy's disk. A population with intermediate kinematics like those of the intermediate-age population identified by Preston *et al.* (AJ, 108, 538, 1994) is also seen. There may be structure in the V velocity vs. R_{apo} plane suggesting discrete merger events. The thick disk population is very old, based on its limiting blue colors, the ages of its clusters, and in the transition period between circular and eccentric orbits in its binary stars. It may show weak radial and vertical metallicity gradients. Analyses of the data are continuing with a new algorithm that computes $1/V_{max}$ weights in physical and proper motion space. An additional 474 metal-poor stars from the work of Ryan & Norris (AJ, 101, 1835, 1991) have been selected for study, and a total of over 3300 velocities, at least 3 per star, have been obtained. Finally, roughly 1600 velocities have been obtained for 83 field metal-poor red giants to study their binary characteristics in comparison with those of the metal-poor dwarfs.

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 are being obtain to determine radial velocities and metallicities.

Carney and undergraduate Jon **Fulbright** collaborated with D. Terndrup (Ohio State) and Nick Suntzeff and Alistair Walker (CTIO) to obtain *K* photometry of 58 RR Lyraes in Baade's Window. Using the metallicity-insensitive and reddening-insensitive M_K-log P relation, they obtained a distance estimate for the Galactic center of 7.8 ± 0.4 kpc. This puts the Galactic center and globular cluster distance scales on the same footing. This was Fulbright's senior honors thesis, and details were now published in AJ.

Carney completed a study of the [O/Fe] and $[\alpha/Fe]$ ratios in globular clusters. In contradiction to common claims, both ratios are constant as a function of either [Fe/H] or age, and over wide ranges in both. There is no sign of a Type Ia supernovae contribution, suggesting that its timescale is ei-

ther very long ($>$ 4 Gyrs) or that the old halo, young halo, and disk globulars have had independent origins.

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. 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 [α/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 VI_cWFPC2 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.

Finally, Spectroscopic analysis of the metal rich halo stars G232-18 and G4-19 has been completed. These two stars have very high velocities, and are on retrograde galactic orbits, yet have been found to be fairly metal-rich. The [Fe/H] value for each star respectively is -0.78 and -0.63. The [O/Fe] and [alpha/Fe] values are +0.31 and +0.31 for G232-18 and +0.63 and +0.24 for G4-19. These result match those of lower metallicity halo stars but are somewhat discrepant with comparable metallicity disk stars, suggesting independent origins. The results will be published in a forthcoming paper.

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.

Previous work consisted of using model spectra at solar metallicity only. Currently, **Leonardi** and **Rose** are investigating the effects of the chemical composition of the starburst population on the age-dating technique. They are working with Guy Worthey (U. of Michigan) to adapt his population synthesis models to young ($\leqslant$1 Gyr) populations using synthetic spectra computed by Robert Kurucz's SYNTHE program. Once completed, the age, strength and chemical composition of a starburst population will be able to be independently determined for a given system.

Leonardi and **Rose** have obtained high resolution long-slit spectroscopy of over 30 star clusters in the Magellanic clouds to calibrate the behavior of the spectral indices in a single burst population. Using systems of known age and chemical composition will enable the indices to be calibrated empirically, complementing the population model calibration.

5.7 Extragalactic−Structures

Rose, in collaboration with Nelson Caldwell (SAO), is continuing an investigation of the evolution of nearby rich clusters of galaxies. They have obtained multi-fiber spectroscopy of several hundred early-type galaxies in five nearby clusters with the KPNO and CTIO 4-m telescopes. The main result of this study is that $\sim$15% of the early-type galaxies show signs of ongoing or recent star formation, a rather unexpected result. The starburst and post-starburst nature of these unusual galaxies is reminiscent of that seen in distant clusters, although at a reduced frequency and burst strength. Thus activity similar to that seen in distant clusters is still ongoing, at a reduced level, in present-epoch rich clusters. The fact that the nearby clusters are more than ten times closer by than the typical distant cluster studied in the ''Butcher-Oemler effect'' presents an excellent opportunity to study the nature and source of the starbursts with unprecedented detail.

Caldwell and **Rose** also find evidence in the spatial and kinematic structure of several of the clusters that subclusters have recently passed through the main clusters and are now emerging out the other side. This inference is based on a comparison of the spatial and kinematic cluster data with N-body simulations of infalling clusters. If, as the simulations imply, the subclusters passed through the main clusters more than a Gyr ago, then the post-starburst timescales of $\sim$1 Gyr found for many of the galaxies imply that the star formation bursts are only triggered during (or after) the subcluster passage through the center of the main cluster. It may be that shocks induced in the collisions of the cluster and subcluster ICM's may trigger the galaxy starbursts. These results have been written up in Caldwell and Rose (1996).

Rose, Caldwell, R. Bower (Durham), R. Ellis (IoA-Cambridge), and R. Sharples are continuing to collect multi-fiber data of nearby clusters in an effort to better understand the connection between starbursts in individual cluster galaxies and evolution of the substructure in clusters. They have also begun to collect HST B and I images of some of the starburst and post-starburst galaxies as well as MMT long-slit spectra to map out the spatial and kinematic nature of the starbursts.

Cecil completed work on stellar kinematics in the elliptical galaxy NGC 1700 with Statler (Ohio University) and

Smecker-Hane (UC Irvine). This work analyzed deep long-slit optical spectra obtained with the 4.5m MMT that reached the effective radius along 4 position angles. Higher-order moments of the absorption profiles were used to constrain the intrinsic shape and rotational motion of this galaxy.

5.8 Extragalactic–AGNs & Quasars

In a Ph.D. thesis, graduate student Christopher **De Pree** presented the results of extensive multi-frequency, multi-configuration observations of four massive star-forming regions at different galactocentric radii using the Very Large Array (VLA). He observed the luminous regions Sagittarius B2 (Sgr B2, near the Galactic center) and W49A ($D=11.4kpc$), and two smaller regions: K3-50 ($D=8.5kpc$) and NGC 6334 ($D=1.7kpc$). The VLA observations have spatial and spectral resolutions as high as 0.″3 and 3.5 km s^{-1}, respectively. Within each of the two largest regions (Sgr B2 and W49A), there is a striking variety of morphologies (spherical, bipolar, shell and ''cometary'') and a large number of resolved sources. In Sgr B2, 49 HII regions are detected within a $\sim$2.5 pc radius, centered on the bright source F. The most compact HII regions in Sgr B2 ($d\sim0.01pc$) are spatially coincident with two known massive molecular outflows. In W49A, 45 regions are detected within a $\sim$3.5 pc radius of the central source G. In each of the four regions, he also also imaged the ionized gas kinematics, crucial to the interpretation of the morphologies observed. In K3-50A and NGC 6334A for example, continuum morphologies and velocity gradients consistent with bipolar ionized outflows have been detected. This study is the first in which both the line and continuum parameters for such a large number of sources have been examined. In a small number of sources De Pree has detected very broad recombination lines ($\Delta V_{FWHM}\geqslant$ 60 km s^{-1}) and rising spectral indices ($\alpha\sim$ 1) at centimeter wavelengths. These sources are most likely very young, still coming into pressure equilibrium with their environments. These VLA observations of the ionized and molecular gas along with existing molecular gas observations of these sources have been used to address several issues, including: the lifetime paradox of ultracompact HII (UCHII) regions, Galactic helium abundances, ionized outflows from massive stars, and UCHII region evolution.

Gerald **Cecil** continued multi-frequency studies of high-velocity gas flows in galaxies. The analysis is based on spectral grids obtained with Fabry-Perot area spectrometers, correlated with images and areal spectra from other wavebands. A particular focus has been on the large-scale jets of the nearby Seyfert NGC 4258, a galaxy of particular interest because its nucleus houses the best observed case of an accretion disk around a supermassive black hole. With Morse (STScI) and Veilleux (Maryland), **Cecil** discussed the LINER-like emission-line profiles along the twisted ''jets'' of NGC 4258. Models of shock excitation predict emission-line flux ratios in general agreement with the observed values if shock velocities are 600-800 km/s. These values are similar to the velocity discontinuities observed along the jet.

Cecil, **De Pree**, J. Moran (CfA), and L. Greenhill (CfA), have obtained high-resolution VLA flux and polarization images of the jets. The jet from 1–25″ radii is found to align with the spin axis of the accretion disk, suggesting no strong source precession within the last few Myrs. At 25″ the jet changes direction abruptly, which may reflect a significant change in the nature of the fuel supply.

In addition, HST WFPC2 imaging and FOS spectra of the S0 galaxy NGC 5252 were discussed in a paper with Tsvetanov (Johns Hopkins), Morse (STScI), and Wilson (Maryland). An inclined, counter-rotating nuclear disk was found, spanning radii out to a few arc-seconds. Subsequent FOS spectra were obtained of bright features in the disk, to map the gaseous velocity field around the putative black hole at sub-arcsecond scales. Strong velocity gradients are observed, compatible with Keplerian motion around a 10^7 solar mass object. Gaseous excitation gradients are also being studied, and reveal strong oxygen emission characteristic of a LINER nucleus.

Cecil, Veilleux, and Bland-Hawthorn (Anglo-Australian Observatory, Sydney) have completed analysis of the kinematical and gaseous excitation patterns in Fabry-Perot datacubes of the edge-on active galaxy NGC 3079. Emission scale-heights are different for each gaseous species. Numerous ionized superbubbles are seen, with properties indicating that they arise from the ongoing starburst.

Cecil, Bland-Hawthorn, and Veilleux produced a summary of their work on active galaxies for Scientific American. The article illustrated examples of applications of Fabry-Perot imaging spectrometers to unravelling gas flows powered by putative black holes in galactic nuclei, and by circumnuclear starbursts.

Christiansen, in collaboration with J. Knerr (UNC-Greensboro) continued his work on ablative hypersonic wind-cloud interactions by extending high resolution numerical studies to 3D. The importance of radiative cooling in enhancing the survival of wind accelerated clouds is confirmed in 3D. Further, these studies show that even when the wind accelerated clouds appear to be ''shredded'' by the onset of nonlinear Raleigh-Taylor instabilities, relatively cool gas ($T\sim10^4$ K) remains in the fragmented cloudlets. Simulated spectra from these swarms of ablated cloudlets also closely approximate observed line profiles of BAL quasars.

5.9 Plasma Astrophysics

Christiansen has continued studies of relativistic electron acceleration in turbulent regions of active radio sources. Model simulations of electron acceleration via current sheets created by magnetic reconnection are underway using a biased Monte Carlo code to model the expected electron spectrum including radiative losses.

Evans and **Philp** have also been investigating the interaction of a highly relativistic magnetized pulsar wind with the non-relativistic wind emanating from an OB star. These investigations are general, but were motivated by the interaction of PSR B1259-63 with its companion B star.

5.10 Gamma-Ray Bursts

Christopher **Thompson** has continued his study of γ-ray emission from ultraluminous relativistic MHD winds, with a focus on time-dependent effects and a goal of making detailed comparisons with cosmological γ-ray bursts. An outflow of luminosity $\sim 10^{50}-10^{51}$ erg s^{-1} is plausible in any burst scenario that leads to the formation of a rapidly rotating neutron star or torus. The requirement that the outflow have a high entropy implies the presence of a strong magnetic field. Matter blown into the wind by cooling neutrinos enforces the MHD condition. Quasi-thermal radiation advected by the wind undergoes adiabatic cooling, and is Compton upscattered at large radius by MHD turbulence after regions of the wind with variable $\vec{B}$ come into causal contact. This suggests a mechanism for generating a median photon energy ~ 1 MeV with no fine tuning. Recent work has focussed on the effects of pair creation by photon collisions, which greatly amplifies the Compton heating rate in regions of the flow with relatively hard photon spectra. A loss-probability analysis suggests that a broken power-law spectrum is generated in two stages, with a low energy -1 photon index arising at intermediate radius where the photon diffusion length is smaller than the coherence length of the turbulence, and a high energy index $\leqslant -2$ further out. Adiabatic losses inside the scattering photosphere lead to a very strong dependence of the emergent γ-ray flux on matter loading, and the effect of time-dependent matter loading on γ-ray time profiles is being investigated. Thermal emission with an approximately Wien spectrum occurs when the matter loading is large enough to damp the turbulence inside the electron-ion photosphere, which may provide an explanation for soft precursors and post-cursors. Hard electrons and positrons swept up at oblique forward shocks near the γ-γ photosphere Compton upscatter the primary burst photons; the resulting delayed emission (which is systematically higher in energy) is being investigated.

Omer Blaes (UCSB) and Chris **Thompson** have calculated the non-linear cascade of Alfvén wave turbulence in a dense relativistic, magnetized plasma. 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.

PUBLICATIONS

The publication list includes all papers published or submitted between October 1995 and September 1996.

Abrahams, A., **Anderson, A.**, Choquet-Bruhat, Y, & **York, J.W. Jr.** 1995, ''Einstein and Yang-Mills theories in hyperbolic form without gauge-fixing,'' Phys. Rev. Lett., 75, 3377

Abrahams, A. & Price, R. 1996, ''Applying black hole perturbation theory to numerically generated spacetimes,'' Phys. Rev., D75, 1963

Abrahams, A. & Price, R. 1996, ''Black hole collisions from Brill-Lindquist initial data: predictions of perturbation theory,'' Phys. Rev., D75, 1872

Abrahams, A. & **York, J.W. Jr** 1996, ''3+1 General Relativity in Hyperbolic Form,'' to appear in Proceedings of Les Houches Conference, (Cambridge: Cambridge University Press)

Abrahams, A., **Anderson, A.**, Choquet-Bruhat, Y, & **York, J.W. Jr.** 1996, ''Geometrical Hyperbolic Systems for General Relativity and Gauge Theories submitted to Classical and Quantum Gravity,'' Class. Quant. Grav., in press

Abrahams, A., **Anderson, A.**, Choquet-Bruhat, Y, & **York, J.W. Jr.** 1996, submitted to C.R. Acad. Sci. Paris

Arnould, M., Mowlavi, N., & **Champagne, A.E.** 1995, ''Non-Explosive Hydrogen Burning: Where Do We Stand?,'' Proc. 32nd Liege Astrophysics Conference

Baker, A., **Abrahams, A.**, Anninos, P., Brandt, S., Price, R., Pullin, J., Seidel, E. 1996, submitted to Phys. Rev. D.

Balachandran, S. & **Carney, B. W.** 1996, ''The Oxygen Abundances in Halo Dwarfs. I. HD 103095,'' AJ, 111, 946–961

Bateman, N.P.T., Parker, P.D., & **Champagne, A.E.** 1996, ''On the Production of 26Al in the Early Solar System by Low Energy Cosmic Rays,'' to be published in Ap. J. Letters

Blackmon, J.C., **Champagne, A.E.**, Dickens, J.K., Hofstee, M.A., Larson, D.C., Ralston, D.C., Raman, S., & Smith, M.S. 1996, ''Measurement of the 7Li(n,g0)8Li Cross Section at Low Energies,'' Phys. Rev. C54, 383

Caldwell, N., **Rose, J. A.**, Franx, M., & **Leonardi, A.** 1996, ''Spatial Distribution of the Starbursts in Post-Starburst Coma Cluster Galaxies,'' AJ, 111, 78

Caldwell, N. & **Rose, J. A.** 1996, ''The Butcher-Oemler Effect at Low Redshift: Spectroscopy of Five Nearby Clusters of Galaxies,'' AJ, in press

Carney, B. W. 1995, ''Halo Field Stars and Globular Clusters: Clues to the Origin of the Milky Way,'' in The Formation of the Milky Way, ed. E. Alfaro and G. Tenorio-Tagle (Cambridge, Cambridge Univ. Pr.), pp. 305–315

Carney, B. W. 1995, ''The Formation of the Milky Way: Conference Finale,'' in The Formation of the Milky Way, ed. E. Alfaro and G. Tenorio-Tagle (Cambridge, Cambridge Univ. Pr.), pp. 347–360

Carney, B. W. 1996, ''The Constancy of [α/Fe] Among the Globular Clusters,'' PASP, in press

Carney, B. W. 1996, ''Multiple Histories Among Metal-poor Field and Cluster Stars,'' in Formation of the Galactic Halo... Inside and Out, ed. H. Morrison and A. Sarajedini (San Francisco, ASP), pp. 103–112

Carney, B. W., **Fulbright, J. P.**, Terndrup, D. M., Suntzeff, N. B., & Walker, A. R., ''The Distance to the Galactic Center Obtained by Infrared Photometry of RR Lyrae Variables,'' AJ, 110, 1674–1685

Carney, B. W., Laird, J. B., Latham, D. W., & Aguilar, L. A. 1996, ''A Survey of Proper Motion Stars. XIII. Kinematics vs. Metallicity,'' AJ, 112, 668–692

Cecil, G., Morse, J.A., & Veilleux, S. 1995, ''Spectral Evidence for Shock-ionized Gas along the Jets of NGC 4258,'' ApJ, 452, 613

Christiansen W., Pellegrino J., De Pree C., Wright J., Leonardi A. 1996, ''Teaching Introductory Astronomy as a Linked Course in the Writing Curriculum,'' to appear in ''Negotiating the Margins: College Composition at the Turn of the Millenium,'' eds. Michelle Hall Kells and Cathy Downs

Degraff D. & **Christiansen W.** 1996, ''Chaos in the Lobes: Observations and Simulations,'' published in Cygnus A: A Study of a Radio Galaxy (Proc. of a NATO Workshop) eds C. Carilli and D. E. Harris, Cambridge Press, pp 221-230

Fullton, L. K. & **Carney, B. W.** 1995, ''The age of the Galactic inner halo and bulge,'' in The Formation of the Milky Way, proceedings of a workshop held in Granada, Spain, (Cambridge, Cambridge Univ. Pr.), pp. 251–254

Fullton, L. F. & **Carney, B. W.** 1995, ''The Age of the Galactic Inner Halo,'' in IAU Sym. No. 164, Stellar Populations, ed. P. C. van der Kruit and G. Gilmore (Dordrecht, Kluwer), p. 398

Fullton, L. K. & **Carney, B. W.** 1996, ''New Age and Abundance Estimates for NGC 6723: Implications Regarding Formation of the Inner Halo,'' in Formation of the Galactic Halo . . . Inside and Out, ed. H. Morrison and A. Sarajedini (San Francisco, ASP), pp. 265–268

Fullton, L. K., **Carney, B. W.**, Olszewski, E. W., Zinn, R., Demarque, P., Da Costa, G. S., Janes, K. A., & Heasley, J. N. 1996, ''The Age of NGC 5927: Comparison with Other Disk and Halo Clusters,'' in The Formation of the Galaxy . . . Inside and Out, ed. H. Morrison and A. Sarajedini (San Francisco, ASP), pp. 269-272

Hahn, K.I., Bateman, N., Lund, B., Smith, M.S., Utku, S., Howard, A.J., Parker, P.D., Garca, A., Magnus, P.V., Adelberger, E.G., Markoff, D.M., Swartz, K.B., Berg, G.P.A., Bacher, A.D., Stephenson, E.J., Liu, J., Vogelaar, R.B., Mao, Z.Q., **Champagne, A.E.**, & **Blackmon, J.C.** 1996, ''Structure of 18Ne and the Breakout of the Hot CNO Cycle,'' to be published in Phys. Rev.

Jones, R. V., **Carney, B. W.**, & Fulbright, J. P. 1996, ''Template K Light Curves for RR Lyrae Stars,'' PASP, in press

Leonardi, A. & **Rose, J. A.** 1996, ''The Ages of Starbursts in Post-Starburst Galaxies,'' AJ, 111, 182

Peterson, R. C., **Carney, B. W.**, & Latham, D. W. 1996, ''The Rotation of RR Lyrae Stars,'' ApJL, 465, L47–L50

Philp, C.J., **Evans, C.R.**, Leonard, P.J.T., & Frail, D.A. 1996, ''Do OB Runaways Have Pulsar Companions?,'' AJ, 111, 1220-1226

Sneden, C., Basri, G., Boesgaard, A.. M., Brown, J. W., **Carney, B. W.**, Kraft, R. P., Smith, V., & Suntzeff, N. B. 1995, ''Stellar Population and Abundance Studies at High Resolution with Very Large Telescopes,'' PASP, 107, 9997–1003

Statler, T.S., Smecker-Hane, T., & **Cecil, G.N.** 1996, ''The Post-Merger Elliptical NGC 1700: Stellar Kinematic Fields to Four Effective Radii,'' AJ, 111, 1512

Thompson, C. 1996, ''Astrophysics of the Soft Gamma Repeaters,'' in Third Huntsville Symposium on Gamma-Ray Bursts, ed. C. Kouveliotou, M.S. Briggs and G.J. Fishman, AIP, in press

Thompson, C. 1996, ''Gamma-Ray Emission from Compact Relativistic MHD Winds,'' in Third Huntsville Symposium on Gamma-Ray Bursts, ed. C. Kouveliotou, M.S. Briggs and G.J. Fishman, AIP, in press

Thompson, C. and Duncan, R.C. 1996, ''The Soft Gamma Repeaters as Very-Strongly Magnetized Neutron Stars - II. Quiescent Neutrino, X-ray and Alfvén Wave Emission,'' ApJ, in press

Tsvetanov, Z.I., Morse, J.A., Wilson, A.S., & **Cecil, G.** 1996, ''Complex Gaseous Structure in the Nucleus of NGC 5252,'' ApJ, 458, 172

Veilleux, S., **Cecil, G.**, & Bland-Hawthorn, J. 1996, ''Colossal Galactic Explosions,'' Sci. Am., 274, 86

Vogelaar, R.B. , Mitchell, L.W. , Kavanagh, R.W., **Champagne, A.E.**, Magnus, P.V., Smith, M.S., Howard, A.J., Parker, P.D., & O'Brien, H.A. 1996, ''Predicting 26Al+p Resonances Using 26Al(3He,d)27Si,'' Phys. Rev. C53, 1945

Christopher Thompson