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This report covers the period from September 1, 1996 to August 31, 1997.

1. PERSONNEL

1.1 Faculty

The regular members of the faculty during the academic year 1996-1997 were Professors Peter Mészáros (Department Head), Eric Feigelson, Gordon Garmire (Evan Pugh Professor), Lawrence Ramsey, Douglas Sampson, Peter Usher, Daniel Weedman, and Alexander Wolszczan (Distinguished Professor); Associate Professors Robin Ciardullo, Donald Schneider, and Richard Wade; Assistant Professors Matthew Bershady, Jane Charlton, Pablo Laguna, and Louis Winkler were joined by William Brandt (formerly of Harvard CfA); and Senior Scientist/Professors David Burrows and John Nousek.

James Beatty, Associate Professor of Physics, holds a joint appointment as Associate Professor in Astronomy & Astrophysics. Curt Cutler, Assistant Professor of Physics, also holds a joint appointment as Assistant Professor of Astronomy & Astrophysics.

Research Associates in the program were George Chartas, Margaret Chester, Christopher Churchill (ECOS Distinguished Postdoctoral Scholar), Audrey Garmire, Zhiyu Guo, Scott Horner, Eugene Moskalenko, James Neff (also a member of the Graduate Faculty), Hans Peter Nollert, Jerome Orosz, Philippos Papadopoulos, George Pavlov, Frederick Ringwald, and Leisa Townsley. Chester was appointed Visiting Assistant Professor of Physics at Bucknell University for the 1996-97 academic year. Joining the department as Research Associates were Karen Camarda (formerly of the University of Illinois at Urbana-Champaign), Jorg Rachen (formerly of the Max-Planck Institut fur Radioastronomie), and Rita Sambruna (formerly of NASA Goddard Space Flight Center). Joseph Pesce (formerly of the Space Telescope Science Institute) joined the department as a Lecturer/ Research Associate.

Adjunct Associate Professor was Hans Kraus at the Oxford University Nuclear and Astrophysics Laboratory.

1.2 Visitors to the Department

Visitors to the department included William Krivan and Johannes Ruoff (from the University of Tubingen) and Peter Anninos (from the National Center for Supercomputing Applications, Illinois) working with Pablo Laguna; Istvan Horvath (from the Central Research Institute for Physics, Budapest, Hungary) and Lajos Balazs (from the Konkoly Observatory, Budapest, Hungary) working with Peter Mészáros; Viatcheslav Zavlin (from the Max- Planck Institut fur Extraterrestrische Physik, Garching Germany) working with George Pavlov; David Montes (from the Universidad Complutense de Madrid, Spain) working with Larry Ramsey; and Maciej Konacki and Grazyna Walentynowicz (from Nicolaus Copernicus University, Poland) working with Alexander Wolszczan. Dr. Peter Goldreich from the California Institute of Technology presented the 1997 Marker Lecture Series in March, with the general title of ‘‘Thinking About Our Cosmic Environment.’’

2. ACADEMIC PROGRAM

2.1 Graduate and Undergraduate Majors

Thirty graduate and sixty undergraduate astronomy majors were enrolled during the academic year 1996-97. During that time nine B.S. degrees, four M.S. degrees and five Ph.D. degrees were awarded in Astronomy & Astrophysics. M.S. recipients were David Chuss, Donald Driscoll, Diego Janches, and Mark Shepherd. Doctoral recipients were Jason Best, Brian Cadwell, Sally Laurent-Muehleisen, Douglas O’Neal, and Craig Robinson.

2.2 Educational Initiatives

The Department received funding for the Research Experiences for Undergraduates program (Chester, PI and Ramsey, Co-PI) sponsored by the National Science Foundation. This grant provided stipend and travel support for nine Penn State undergraduates to participate in research with faculty members.

For the second summer, the Department offered summer graduate classes for high-school science teachers interested in learning more about astronomy and its potential as a medium for physical science education in secondary schools. The 1997 program, entitled *Penn State Inservice Workshops in Astronomy* (PSIWA), consisted of 1-week courses on ‘Stars and Planets for Science Teachers’ and ‘Cosmology for Science Teachers’. The former was offered at Penn State’s main campus and included a variety of classroom, laboratory and computer activities. The latter was offered at McDonald Observatory in west Texas, the site of the Hobby-Eberly Telescope, and included classroom and nighttime observing activities. Over thirty teachers from Pennsylvania and 8 other states participated in the programs. Funding was received from the PA Space Grant Consortium, Lockheed-Martin Corporation and several units within Penn State University. Feigelson, Weedman, Winkler, Townsley and several other Department faculty and researchers participated in the programs.

2.3 Public Outreach

The departmental outreach effort in 1997 has been tremendous, in part, because of the recent swell in public interest generated by the appearances of Comet Hyakutake in 1996 and Comet Hale-Bopp this spring, success of NASA missions such as HST, Galileo, and Mars Pathfinder, and the growth of the WWW. Synchronous with this rise in public

appeal has been an increase in departmental outreach awareness, support, and participation amongst graduate students and faculty members. The number of public service programs sponsored by the department, either in concert with the Penn State Astronomy club or independently, has grown to an all-time high; over 40 programs have been offered this year (since Jan. 1997) alone, and the number of students and adults attending has exceeded 1900. The programs have included planetarium shows, slide shows, demonstrations, class-room activities, observing with telescopes, and public lectures. A complete listing of outreach programs offered by the Penn State Astronomy Dept. may be viewed at http://www.astro.psu.edu/outreach/k12.html.

2.4 Astronomy Club

The Astronomy Club continued to conduct monthly public observing sessions, uninterruptedly since 1973. These Open Houses attracted hundreds of visitors to the roof of Davey Laboratory to view selected celestial objects through various telescopes. The *Nittany Observer*, a newsletter published by the Club, included articles on general astronomy and covered Club activities. Some of the activities organized for members included field trips to remote dark-sky observing locations, and weekend trips to places such as the Allegheny Observatory, Hayden Planetarium, the National Air and Space Museum, and the National Radio Astronomy Observatory at Green Bank. Members also participated in outreach programs for school children, making use of the Department's planetarium. Club officers are: President, Kevin McGouldrick; Vice President, Jane Rigby; Secretary, Cyndi Pruss; Treasurer, Chris Thiesset. Usher is the Club's faculty advisor.

3. RESEARCH ACTIVITIES

3.1 Ground- and Space-based Astronomical Instrumentation

3.1.1 Optical

3.1.1.1 The Hobby-Eberly Telescope. This last year was an extremely important one for the Hobby-Eberly telescope project (HET). After an outstanding effort by the entire project team, first light was achieved the night of December 11, 1996. However this only began a long commissioning process. After a 6-month period of system refinement calibration and debugging the telescope entered commissioning in June 1997. The commissioning phase will last a year to 18 months with the goal of bringing all telescope systems up to their expected performance levels. During this time there will be definite but limited science opportunities.

Currently 81 out of the HET's 91 segments are complete and installed on the telescope. Installation of the final segments should take place early next year. The HET has been and will continue to be utilized for tests with a partial array through the intervening period. We are utilizing a test spherical aberration corrector, which is a two-element diamond turned high order asphere system. We call this the surrogate spherical aberration corrector or SSAC. This system was meant for initial test and evaluation but will be utilized through March 1998 due to a severe slip in the final spherical aberration corrector (SAC). The final four element SAC consists of 3 conics and a low order asphere. The aspherical element and two of the conics are now complete. The vendor fabricating the conics is over 9 months behind schedule at this time. We expect to install this system in the May 1998 time frame.

Significant progress has been made in commissioning the telescope. We are delighted with the performance of the HET's unique motion system. Absolute pointing is < 30 arcseconds peak to valley. The tracking is typically better than 0.01 arcsecond/sec open loop. The primary mirror array is also turning encouraging performance with stacking lasting up to several hours open loop. However, we are delivering only arcsecond level alignments and there is clearly much room for improvement. Another significant milestone this year was testing the telescope with the UFOE, our commissioning spectrograph. This instrument was installed on the telescope in May 1997 and obtained test spectra of objects through the HET in September. We expect the pace of science commissioning to increase in coming months as test spectra are acquired and we exercise the telescope. We are very low on the learning curve on all HET systems and expect to report significant improvements next year.

The Hobby-Eberly telescope is an international collaboration between the University of Texas at Austin, The Pennsylvania State University, Stanford University, Ludwig-Maximilians-Universitaet Muenchen, and the Goerg-August-Universitaet Goettingen. For more information on the HET, its science programs or partnerships contact L. Ramsey, HET project scientist, at lwr@astro.psu.edu. The latest information and pictures can be viewed at http://www.astro.psu.edu/het.

The Penn State Optical and Near IR instrumentation team has focused this last year entirely in the design and implementation of HET instrumentation. Members of the OIR team this past year include Leland Engle, design engineer, Horner, MRS instrument scientist, Ramsey, graduate students Dave Andersen and Jason Harlow, as well as undergraduate students Lester Chou and Eric Mamajek.

The UFOE system described last year has been implemented at the HET site as the commissioning instrument. The white pupil design of the UFOE allows efficient acquisition of spectra at resolving powers between 4000 and 13000 with excellent spectral coverage. A description of this instrument can be found at http://www.astro.psu.edu/het/instrument.html.

The HET Medium Resolution Spectrograph (MRS) is now our major focus. This basic fiber fed dual beam spectrograph has been re-scoped from a blue and red beam to a visible and near IR beam. The visible beam will have complete spectral coverage over the 450-900 nm octave with capability from 390 to 950 nm. The near IR beam will go from 900 to 1600 nm. The resolving power capability will remain in the 4,000-20,000 range. In addition to the linear fiber arrays giving a synthetic long slit capability, there will be 10 MOS probes. Bershady and collaborators are also supplying an IFU unit which we anticipate will be ready a few months after MRS first light (see below). The major techni-

cal effort remains the complex fiber feed system at HET focus. Initial tests on this latter system are anticipated early next summer.

In the past year, Bershady, Andersen, and Ramsey have begun building a new, NSF-funded instrument for the HET. The instrument is a fiber-optic array, called an integral field unit (IFU), which consists of a bundle of densely packed fiber optic cables designed to spectrally image extended sources. The IFU will be fed into the Medium Resolution Spectrograph being designed and built by Ramsey and Scott Horner. Two IFUs are planned, although only one IFU will be integrated into the MRS at any one time. In recent months, Andersen and Bershady have fabricated four test arrays, and are in the process of working with Horner to develop the mechanical interface with the HET's fiber instrument feed. The arrays are optimized for studies of disk kinematics from $0.05<z<1$. They complement designs for other 10m-class telescopes which focus on higher spatial resolution but are commensurately limited to higher surface-brightness for a given spectral resolution. The IFU's for the HET should be able to measure efficiently both disk rotation as well as velocity ellipsoids for moderately distant galaxies.

Weedman continued as a member of the HET Science Commissioning Team and as the outside member of the McDonald Observatory Telescope Allocation Committee.

3.1.1.2 HET Pipeline Software. Churchill has written a first generation software package called *ufoered* for processing HET data from the UFOE spectrograph. This package is a series of IRAF scripts, or tasks. The tasks are organized into a PSU/IRAF package called *ufoe*. The purpose of the *ufoe* package is ambitious– to be a single resource for taking raw FITS images from UFOE and producing fully calibrated 1D spectra. It has been designed to provide a no–fuss pipeline reduction for PSU astronomers. The hope is to maximize the turn–around time from data acquisition to the scientific ''product'' for PSU/HET observers. This package will likey serve as a model for future pipeline software for the HET facility instruments, the MRS, LRS, and HRS.

3.1.2 X-ray

3.1.2.1 CCD Imaging Spectrometer on AXAF. This has been a big year in the Advanced X-ray Astrophysics Facility Charge Coupled Device Imaging Spectrometer, ACIS for short, program. The instrument was completed and tested at MIT just in time to be placed into the X-ray Calibration Facility at Marshall Space Flight Center with the High Resolution Mirror Assembly for overall X-ray testing. Mr Fred Wojtalik, the AXAF Program Manager at MSFC, extended the test period for about ten days so that a good sample of calibration data could be taken with the flight ACIS. The effort to get the ACIS ready for testing was troubled by many unanticipated adventures, such as flexprints that failed at low temperature, contamination of the CCDs by droplets of unknown material in the CCD calibration test chambers, optical blocking filters that cracked along their edges during acoustic testing, electronic noise discovered in thermal vacuum testing, to name just a few. All of these problems were overcome by a lot of very hard work, long hours, clever ideas, and additional funds from NASA for the MIT effort.

At Penn State, Townsley and Chartas carried out very high accuracy measurements on the optical blocking filters using the Synchrotron Light Sources at the University of Wisconsin and at the Brookhaven National Laboratory to provide well calibrated X-ray beams. Graduate students Catherine Grant and Kaori Nishikida assisted at MIT in calibrating the CCDs for the flight camera and at XRCF for calibrating the ACIS instrument. Nousek leads the calibration planning activities for the ACIS Team, working with Mark Bautz of MIT and Brian MacNamara at the AXAF Science Center to set out the detailed planning for all of the calibration activities. The software and computer support by Pat Broos, Scott Kock and Eric Cocklin kept the acquisition of data trouble free and very efficient during the 24 hours a day, seven days a week operation.

Analysis of nearly two terrabytes of calibration data has been proceeding at a high rate. The Preliminary Calibration Report was released on October 13, 1997. The final report is due in June of 1998.

Two back illuminated CCDs have been incorporated in the spectroscopic array portion of the ACIS Instrument. In order to test whether this CCD design exhibits any problems from exposure to high Z cosmic rays, one back illuminated and one front illuminated CCD (to act as a control) were placed in a sealed container and flown on the Space Shuttle in August. Moskalenko of PSU coordinated this effort. Preliminary tests following the flight show a small increase in the number of pixels above the nominal noise threshold. There was no noticeable difference between the back and front illuminated CCDs, however.

The ACIS Instrument has been integrated into the Science Instrument Module at Ball Brothers in Colorado and is about to undergo thermal vacuum testing. The instrument continues to operate flawlessly.

3.1.2.2 CUBIC. Between 1991 and 1995, the Penn State X-ray Astronomy Group built a small instrument called *CUBIC* which was launched in October 1996 on the Argentine *SAC-B* satellite. *SAC-B* was an international collaboration between Argentina (satellite fabrication), the U.S. (launch), Italy (solar panels), and Brazil (testing). The satellite carried four instruments from the U.S., Argentina, and Italy. *SAC-B* was three-axis stabilized and was launched into a 38° inclination circular orbit at 550 km altitude by a Pegasus XL rocket. Unfortunately, the rocket failed to eject the satellite into an independent orbit, resulting in the loss of the mission after about 12 hours of operation on battery power.

We are now in the process of trying to find a new opportunity to fly *CUBIC*. The *CUBIC* instrument is designed to make measurements of the spectrum of the soft X-ray diffuse background from 0.2 – 10 keV with energy resolution comparable to that of the ASCA SIS instrument. These data will provide new insights into the cosmic X-ray background above 2 keV, which is believed to be dominated by emission from distant active galactic nuclei; the 3/4 keV diffuse galactic background, which is not well understood currently; and the 1/4 keV diffuse background, which is believed to be dominated by emission from the hot interstellar medium within a few hundred parsecs of the Sun. In this lowest energy regime, it will complement the data taken by the DXS

instrument, which measured this spectrum with higher spectral resolution over a small part of the sky.

The *CUBIC* instrument consists of a pair of X-ray CCDs operated in photon-counting mode which are exposed directly to the sky through an aperture that provides a 5 x 5 degree field of view below 1 keV and a 10 x 10 degree field of view above 3 keV. The fields of view of the two CCDs overlap on the sky, and the coarse pinhole camera design provides enough position resolution to allow up to 8 spectra from adjacent regions of the sky per pointing. Although specifically designed to study the diffuse X-ray background, *CUBIC* can also study isolated point sources too bright for observation by the *ASCA* SIS instrument. Further details of the *CUBIC* instrument design are available at http://www.astro.psu.edu/xray/cubic.

CUBIC has been proposed for flight as a Spartan-Lite under the Small Explorer (SMEX) program. In the event that it is not selected for this program, we will repropose *CUBIC* as a University Explorer (UNEX) in 1998.

3.1.2.3 Sounding Rocket Payloads. Our successful sounding rocket program continued this year with a flight from White Sands, New Mexico to observe X-rays from the 3/4 keV diffuse enhancement known as the North Polar Spur. The instrument for this flight was a CCD camera utilized as non-imaging, non-dispersive X-ray spectrometers, and uses a backup *CUBIC* CCD.

Superconducting Tunnelling Junction (STJ) detectors offer an exciting alternative to bolometers for highly efficient detectors with energy resolution on order of 10 eV. In addition to a higher operating temperature, STJs have the advantage of being able to provide position resolution within the detector. A collaboration with Hans Kraus of the Technical University of Munich has been established, in which we plan to fly a detector developed in his laboratory on a sounding rocket. We are currently developing both X-ray mirrors and support electronics for this flight.

We are collaborating with Marshall Space Flight Center to build a three-shell grazing incidence telescope fabricated from electroformed nickel mirrors. We have begun fabrication of the first mirror pair for this X-ray telescope.

3.1.2.4 CCD Review. Nousek prepared an invited review article on CCD detectors for the CRC Handbook on Measurement, Instrumentation, and Sensors.

3.1.2.5 Astro-E. Nousek was one of five American scientists serving as Experiment Advisers to the Japanese Astro-E mission. Astro-E will carry US X-ray telescopes and an X-ray calorimeter from the Goddard Space Flight Center, CCD cameras from Japan and MIT, and a Hard X-ray detector from the University of Tokyo and ISAS. Launch is set for February, 2000, with annual conferences in the US and Japan for science working group meetings prior to launch.

3.1.2.6 HTXS (Constellation). Burrows, Garmire, and Nousek were members of the High Throughput X-ray Spectroscopy mission science team. This group, under the joint leadership of H. Tananbaum (Smithsonian Astrophysical Observatory) and N. White (Goddard Space Flight Center), have defined a major mission of spectroscopic discovery which has been placed on NASA's strategic plan in the timeframe after AXAF. The key concepts are large collecting area telescopes on multiple satellites and high spectral resolution detectors.

3.1.3 Future Missions

Weedman continued to serve as a regular member of the Structure and Evolution of the Universe Subcommittee, advisory to the NASA Office of Space Science. He also represented this Committee at the NASA Strategic Planning Meeting held at Breckenridge, CO. This meeting led to the preparation of the OSS plan for missions through 2004. Weedman also served as a member of the ''Origins External Review Board'' which examined the planned NGST and SIM missions within the new OSS ''Origins'' program.

Weedman continued to serve as a member of the SIRTF Infrared Spectrometer Team (P.I. is James Houck of Cornell University) and as a member of the SIRTF Science Operations Working Group. His duties included science planning for SIRTF and development of spectral simulations of extragalactic sources between 5 and 40 microns wavelength based on ISO observations of infrared galaxies. SIRTF, NASA's final Great Observatory, received its new start authorization in the FY 1998 budget for a launch in 2001.

3.2 Observational Research

3.2.1 Exoplanets

Horner, as a member of the Advanced Fiber Optic Echelle (AFOE, cf. http://cfa-www.harvard.edu/afoe) collaboration, helped discover a planet orbiting the star ρ Coronae Borealis. Near-sinusoidal radial velocity variations of this G0V star were detected, using the AFOE instrument, with a period of 39.6 days and an amplitude of 67 m s^{-1}. These variations are consistent with the existence of an orbital companion in a circular orbit. Adopting a mass of 1.0 $M_{\odot}$ for the primary, the companion has a minimum mass of about 1.1 Jupiter masses, and orbital radius of about 0.23 AU. Such an orbital radius is too large for tidal circularization of an initially eccentric orbit during the lifetime of the star, and suggests that the low eccentricity is primordial, as would be expected for a planet formed in a dissipative circumstellar disk.

Horner has also studied the plausibility that the radial velocity variations seen in the stars 51 Pegasi and τ Boötis are the result of pulsations instead of orbital companions as suggested in Gray (1997 [Nature, 385, 795]) and Gray & Hatzes (1997 [ApJ, in press]). No evidence for line profile or strength variations at the radial velocity period were found in the AFOE data for either 51 Peg or τ Boo. For 51 Peg, the upper limit for line shape variations with 4.23-day periodicity is small enough to exclude with 7σ confidence the bisector curvature signal reported by Gray & Hatzes; the bisector span and relative line depth signals reported by Gray are not seen, but with marginal (2σ) confidence. Pulsations cannot be excluded, however, as the source of 51 Peg's radial velocity variation, because the models imply that line shape variations associated with pulsations should be much smaller than those computed by Gray & Hatzes; these smaller signals are below the detection limit for 51 Peg. τ Boo's large radial velocity amplitude and $v \sin i$ make it easier to test for pulsations in this star. Again no evidence for periodic line-shape

changes were found at a level that rules out pulsations as the source of the radial velocity variability. Rejecting the planet hypothesis is unwarranted at this time; orbiting companions are still the most plausible cause of the radial velocity variations seen in these systems.

Williams, J. Kasting (Geosciences), and Wade studied the question of habitability of moons around the gaseous giant extrasolar planets that have recently been discovered in orbit around 51 Pegasi and other stars. The gas giants themselves are presumed to be uninhabitable, but if they lie in the habitable zone around the parent star, any moons they have might be habitable. Such a moon would need to be endowed with an atmosphere by one of several means, *e.g.*, accretion of volatiles from comets. To retain the atmosphere against evaporation, the moon's mass must exceed about 0.12 Earth masses, and the moon would need a magnetic field to prevent the sputtering loss of the atmosphere through bombardment by ions from the planet's magnetosphere. Additionally, habitability is threatened if the moon's rotation is tidally locked, such that large diurnal temperature excursions occur. Finally, the moon's climate must incorporate feedback mechanisms (such as the Earth's carbonate-silicate cycle) to regulate its temperature against long-term changes in stellar flux. A heat flux from the interior sufficient to drive plate tectonics is one way to ensure a C-Si cycle; this requires a mass greater than 0.23 Earth masses; but tidal heating (as in Io and Europa) may help lower this mass limit. Among the present inventory of extrasolar planets, moons in the 47 UMa and 16 Cyg B system would be the most likely abodes for extraterrestrial life.

3.2.2 Stellar Astronomy

3.1.2.1 Pre-Main Sequence Stars. Feigelson continued his research into high energy processes associated with young stars and star formation. He participated in the discoveries of X-ray emission from low-mass protostars with the ROSAT and ASCA satellites. Groups led by K. Koyama (Kyoto) and T. Montmerle (Saclay) found unusually powerful and hard X-ray emission, with occasional flares on timescales of hours, in several Class I protostars in the Corona Australis and Ophiuchi star forming clouds. The X-ray flare from YLW 15 in Ophiuchus was particularly impressive: with peak $L_x \sim 10^{33}-10^{35}$ erg/s, it was one of the strongest stellar flares ever detected. Feigelson presented two talks on potential implications of strong magnetic activity in young stars and their environments. For example, the presence of *in situ* photoionizing X-radiation in protostars may inhibit ambipolar diffusion, promote disk accretion, and enhance disk-outflow and star-disk magnetic coupling.

Graduate student Lee Carkner, working with Feigelson and German colleagues, completed a study of magnetic activity in somewhat older young stars. Their VLA survey of 91 X-ray discovered lithium-rich stars in and around the Taurus-Auriga star forming clouds detected radio continuum from 1/3 of these stars. This high detection rate implies that the stars are collectively weak-lined T Tauri stars (ages 10^6-10^7 yrs) rather than ZAMS stars (ages 10^8 yrs). The presence of so many young stars over such a dispersed region is a puzzle not yet solved. Feigelson and colleague W. Lawson (Univ. New South Wales) investigated a smaller sample of dispersed X-ray discovered stars in the Southern Cross constellation, concluding that they are probably low-mass members of the Sco-Cen OB association. Feigelson also collaborated with a group led by T. Montmerle on ROSAT observations of two star forming regions, the Rosette and Monoceros molecular clouds, lying at distances of $1-2$ kpc. They found individual Herbig Ae/Be stars, and clusters of lower mass stars, indicating that X-ray imaging can map low- and intermediate-mass star formation at considerable distances in the Galactic plane.

3.2.2.2 Astroseismology. Horner continues to study the internal structure and evolution of stars through the technique of asteroseismology as a member of the Advance Fiber Optic Echelle (AFOE) collaboration. This has included the study of Sun-like stars, in particular Procyon, as well as δ Scuti stars. Using the new technique of Doppler Deconvolution, line–profile variations can be extracted from the observed spectra in multi-periodic, rapidly rotating, δ Scuti stars. Oscillation modes can be detected of higher degree than can ordinarily be seen on unresolved stars due to the rapid rotation. Frequencies and modes of oscillation are identifiable from the variations using the technique of Fourier–Doppler Imaging and a two–dimensional least–squares cleaning algorithm. A rich mode spectrum with degrees up to $\ell = 20$ has been found for the star τ Peg.

3.2.2.3 Chromospheric Activity. G. Smith (UCO/Lick) and Churchill obtained echelle spectra of the Ca II H and K lines for a sample of metal-poor subdwarf stars as well as for a number of nearby Population I dwarfs selected from among those included in the Mount Wilson HK survey. The main result of their work is that Ca II H– and K–line emission does occur among subdwarfs. It is particularly notable among those subdwarfs with colors of $B-V>0.75$; all such stars observed exhibit chromospheric emission, although emission is observed among some subdwarfs bluer than this color. The Ca II K_2 emission profile in most subdwarfs exhibits an asymmetry of $V/R>1$, similar to that seen in the intergrated light of the solar disk. Two quantitative indicators of the contrast between the peaks in the K_2 emission profile and the neighbouring photospheric K_1 line profile were introduced to the literature. Measurements of these indicators show that the level of Ca II emission among the subdwarfs is similar to that among low–activity Population I dwarfs.

3.2.2.4 CNO Abundances: Mixing versus Primordial. Churchill, with G. Smith, M. Shetrone (UCO/Lick), R. Bell (Maryland), and M. Briley (Wisconsin), participated in a study of the carbon, nitrogen, and oxygen abundances in globular cluster stars in M5, M3, and M13. They found a CN–CH band strength anticorrelation exists among a sample of six red giant members of the globular cluster M5 having absolute magnitudes in the range $-2.0<M_V<-1.3$. Carbon and nitrogen abundances determined for five of the observed stars reveal that, for the giants exhibiting the CN–CH anticorrelation, (i) carbon is depleted ([C/Fe] <-0.5) by comparison with the [C/Fe] abundances of typical halo subdwarfs, (ii) nitrogen is greatly enhanced ($+0.5<$ [N/Fe] $<+1.2$) relative to the [N/Fe] abundances of typical subd-

warfs, and (iii) the nitrogen and carbon abundances are anti-correlated and correlated respectively with the [O/Fe] abundances. These properties are similar to the pattern of CNO abundances reported in the literature for upper−giant−branch stars in other globular clusters such as M92, M3, and M13.

There has been a long−standing debate as to whether the CN−CH band strength bi−modalities seen in globular cluster stars are due to primordial enrichment or due to internal mixing as a function of stellar age. Oxygen abundances are the key to resolving this debate. Drawing upon O line strengths from the literature for M3 and M13, Smith, Shetrone, Bell, Churchill, and Briley measured the [C/Fe], [N/Fe], and [O/Fe] abundances (using stellar models) and found the striking result that the [C+N+O/Fe] abundances are the same within uncertainties among both the CN−strong and the CN−weak giants. These observations strongly support the internal mixing hypothesis in which C→ N and O→ N processed material has been brought to the surface of the CN strong giants.

3.2.2.5 Interacting Binary Stars. Orosz, Wade, and graduate student Jason Harlow carried out a radial velocity survey of evolved binaries selected from the PG catalog. Evolved binaries are important to study because some of them will have undergone the common-envelope (CE) phase of orbital evolution. The CE phase is a way to shrink a wide binary into a much tighter binary, and can explain the existence of evolved stars (white dwarfs, neutron stars, and black holes) in short-period binaries. The goal of the survey was to classify the stars as either wide binaries (periods of order several years and never interacting) or as post-CE (periods of order hours to a few days). Out of the 12 stars sampled, only one star showed a large velocity variation, which indicates a close binary. Although the sample is small, one might have expected to find on the order of three or four tight binaries. This work will be continued on much larger samples with the Hobby-Eberly telescope.

Orosz, in collaboration with C. Bailyn (Yale), J. McClintock (Harvard-CfA), and R. Remillard (MIT), continued optical studies of Galactic black hole binaries. A black hole is defined as a compact object (i.e., an object whose radius is on the order of tens of km) whose mass exceeds the maximum mass of a stable neutron star ($\approx 3\,M_{\odot}$). The known black hole binaries are transient X-ray sources—episodic accretion of matter onto the black hole produces copious amounts of X-rays during short and infrequent time intervals. Orosz and Bailyn modelled high quality optical light curves of GRO J1655-40 which allowed them to constrain the mass of the black hole to better than 4% ($M = 7.02 \pm 0.22\,M_{\odot}$), which is by far the most precisely known black hole mass. Orosz and collaborators observed an optical precursor to a recent X-ray outburst of GRO J1655-40 (normally the X-ray outbursts are detected first). This important observation provided constraints on the theories of the outburst mechanisms for these sources.

Ringwald continued his research on cataclysmic variable binary stars, their evolution, and the physics of their accretion disks and outbursts. With Wade and Orosz, he began a program to use the Hobby-Eberly telescope to study their progenitor stars and origin in common envelope evolution, in which a star expands and engulfs a companion.

BZ Camelopardalis is the first cataclysmic variable known with an optical spectrum revealing a wind from its accretion disk. A detailed study with high-speed, high-resolution spectra from the 4.2-m William Herschel Telescope found the acceleration law in a CV wind for the first time, a linear acceleration to 1700 km s^{-1} in 6 to 8 minutes. The spectra also show an apparent subsequent linear deceleration in 30 to 40 minutes, perhaps an effect of dilution of the wind as it expands and cools.

Work with Wade and Orosz on modeling accretion disk spectra using HST observations progressed. Ringwald was also active in public outreach, giving open houses with the Penn State Astronomy Club, and publishing an article in Mercury.

3.2.2.6 Accretion Disk Models/Observations. Wade continued an investigation of the spectra of accretion disks in close binary systems, in particular cataclysmic variables (CVs). A grid of steady-state, LTE, synthetic disk spectra has been extended to the mid-ultraviolet, to supplement the far-ultraviolet spectra previously computed.

The models generated have been used to revise the map of temperature *vs* radius that was derived earlier for the dwarf nova Z Chamaeleontis in outburst by E.L. Robinson (U. Texas/Austin) and co-workers. When limb darkening effects are taken into account, using computed model atmospheres for each annulus of the disk, the eclipse mapping procedure gives best results with a disk opening angle of about 6 degrees, rather than the 8 degrees found earlier. This is more consistent with the computed opening angle of the disk. In addition, using accurate specific intensities (computed from the disk atmosphere models) to derive effective temperatures gives a flatter $T(r)$ distribution than is found using brightness temperatures (derived using the Planck function). This makes Z Cha in outburst even further from a steady-state disk than before.

Wade continued a collaboration with K. Long and C. Knigge (STScI) and others in analyzing Hubble Space Telescope spectra of cataclysmic variables. The Faint Object Spectrograph was used to obtain time-series ultraviolet and visible spectra of the eclipsing nova-like variable UX Ursae Majoris. As with other CVs, it was found that straightforward modeling of the energy distribution assuming steady-state, LTE disk atmospheres does not do a good job of matching simultaneously the absolute flux and relative energy distribution of this object. A tentative interpretation is that optically thin emission (recombination radiation) from the base of the disk wind may be responsible for the mismatch. The 29-s oscillations found in white light long ago by Warner, Nather, and Robinson have now been observed much more clearly in the ultraviolet, and the phase shift through eclipse is clearly seen.

3.2.2.7 Hubble Space Telescope Observations of Face-on Accretion Disks. Wade is leading an HST program to model the ultraviolet spectra of three high luminosity cataclysmic variables (CVs) that are oriented close to face-on. Data were collected using the Goddard High Resolution spectrograph for RW Sex, V603 Aql, and BZ Cam. Each object shows a

different behavior in the wind lines (*e.g.,* C IV, Si IV), with BZ Cam showing the most violent changes from one exposure to the next. Attempts to model the photospheric spectrum of RW Sex have had only mixed success so far, but have all been in the context of a steady-state temperature *vs* radius distribution. Relaxing this assumption may allow a better match between spectrum models and data, but would reinforce the long-standing problem that CVs thought to be in steady-state really are not.

3.2.2.8 The VOYAGER Ultraviolet Spectrometer (UVS) archive. Wade and Penn State undergraduate Kevin McGouldrick made further progress in exploring the UVS archive of observations of cataclysmic variable stars. The VOYAGER 1 and 2 spacecraft observed many of these stars, often for days or weeks at a time, and the database is unique in wavelength coverage and temporal coverage. The database was updated in May 1997, and preparation of a catalog of observations is underway, showing for each variable star the log of observations and preliminary estimates of count rates in two wavelength bands, one of which is shortward of the Lyman edge. This will allow archived observations to be identified that will be most fruitful upon further study. A bibliography of published results on UVS observations of cataclysmic variables is also being prepared.

3.2.2.9 Hot Stars. Ringwald identified a Be star at high Galactic latitude, PG 1002+506. If on the main sequence, as befits a Be star, PG 1002+506 is over 10 kpc above the Galactic plane. How did such an apparently young star get there? Was it flung out of the Galaxy? Or did it somehow form in the halo?

3.2.2.10 Novae. Ringwald cast doubt on nova hibernation theory with a detailed study of the oldest securely known nova, WY Sge (Nova 1783), and with a refutation of a claim that the suspected nova of 1667 had been recovered.

3.2.2.11 Planetary Nebulae. Ciardullo and graduate student Mike Sipior, in collaboration with H.E. Bond, L. Fullton, and K. Schaefer (STScI) have continued the analysis of Hubble Space Telescope *V* and *I*-band snapshots of Galactic Planetary Nebula Nuclei. Out of a total of 111 objects, 19 have nearby companions that have greater than a 95% probability of being physically associated. The measurement and analysis of these frames is continuing; when complete, the data will be used to obtain distances to the PN via the technique of main-sequence fitting. These new distances will recalibrate the Galactic planetary nebula distance scale and produce a Milky Way zero point to the [O III] λ5007 planetary nebula luminosity function.

3.2.2.12 Pulsars. Pavlov, A. Welty (STScI) and F. Córdova (UCSB) observed the middle-aged pulsar 0656+14 in three spectral bands with the Faint Object Camera of the Hubble Space Telescope. The results of these observations, together with those of supporting ground-based observations with the 6-m telescope show that the optical-UV spectral flux of this pulsar can be interpreted in terms of a two-component spectral model which combines a power-law spectrum (nonthermal component) with a Rayleigh-Jeans spectrum (thermal component). The nonthermal component with the power-law index $\alpha = 1.4(-0.7,+0.6)$ dominates in the optical spectrum, at $\lambda > 3000$ Å. The thermal component is characterized by the Rayleigh-Jeans parameter, $G \equiv T_6 (R_{10}/d_{500})^2$, where $T = 10^6 T_6$ K is the brightness temperature, $R_\infty = 10 R_{10}$ km is the neutron star radius as seen by a distant observer, and $d = 500 d_{500}$ pc is the distance. For a plausible extinction, $E(B-V) = 0.03$, this parameter equals $G = 3.6(+1.6,-2.0)$. There is some indication that the spectrum may have a spectral feature at $\lambda \sim 4000-5000$ Å. The observed shape of the optical-UV spectrum of PSR 0656+14 differs drastically from those of both younger pulsars (Crab, 0540–69, Vela) and of the older pulsar Geminga.

V. Zavlin (MPE, Germany) and Pavlov fitted the soft X-ray and EUV spectra and light curves observed from the nearby binary millisecond pulsar J0437–4715 with model spectra and light curves of radiation emitted from hot pulsar polar caps of pure hydrogen, helium, and iron composition. The models take into account the frequency-dependent anisotropy of the emergent radiation (limb-darkening) and the gravitational redshift and bending of the photon trajectories. The analysis of both the *EUVE* and *ROSAT* data indicates that the radiation originates from two polar caps of areas $\simeq 2-3$ km^2 covered with hydrogen and/or helium with an effective temperature of $\simeq (0.9-1.0)\times 10^6$ K.

Pavlov and Zavlin obtained constraints on the position of hot polar caps and the mass and radius of the neutron star for the nearest millisecond pulsar J0437–4715. They analyzed the soft X-ray radiation from the pulsar's polar caps with allowance for the gravitational bending of the photon trajectories. Adopting the orientations of the pulsar's magnetic and rotation axes inferred from the radio polarization measurements, they found the mass-to-radius ratio in the range $1.4 < (M/M_\odot)(R/10\text{km}) < 1.6$.

S. Anderson, S. Kulkarni, and T. Prince (Caltech) and Wolszczan have completed the timing analysis of two millisecond pulsars discovered in the globular cluster M5. No additional pulsars have been detected in this cluster in a sensitive search using the data collected with the Arecibo telescope between 1989 and 1994.

M. Kramer (MPIfR), K. Xilouris (NAIC), and collaborators, and Wolszczan have analyzed observations of 21 millisecond pulsars made with the 100–m Effelsberg radiotelescope to investigate their morphologies, spectra and polarization properties. This study represents an attempt to define global characteristics of the millisecond pulsars and compare them to the properties of ''normal'' pulsars.

B. Jacoby (PSU), Wolszczan and their collaborators at the Nicolaus Copernicus University in Toruń, Poland have begun systematic, long–term timing observations of 100 pulsars at 1.4 GHz with the 32–m Toruń radiotelescope and the Penn State Pulsar Machine–2 (PSPM–2), a 2 × 64 × 3 MHz fast–sampled radiometer designed for use with medium–sized radiotelescopes. Each pulsar is observed twice a week using a fully automated, computer–controlled scheduling procedure. The purpose of this program is to search for timing glitches, binary or multiple (planetary) companions to pulsar, and to monitor pulsar scintillations.

The PSPM–1, a 128–channel pulsar machine in operation at Arecibo since 1994 has been used by Anderson (Caltech),

Cadwell and Foster (NRL) and Wolszczan to search for fast pulsars. Several pulsar candidates have been detected. The PSPM−1 is an open access, Penn State owned pulsar backend operated and maintained by the Arecibo Observatory.

3.2.3 Extragalactic Astronomy

3.2.3.1 Dwarf Galaxies and Globular Cluster Formation. Graduate student, Sally Hunsberger, along with Charlton, and D. Zaritsky (UCSC/Lick) completed a study of the luminosity function of galaxies in 39 Hickson Compact Groups. There are larger dwarf populations in groups with X−ray halos, those with tidal dwarf candidates, and those with a dominant elliptical or lenticular galaxy. Interestingly, for groups without X−ray halos, those with higher M/L have a smaller dwarf population than those with lower M/L. These data support the picture that the dwarf population in compact groups is gradually cannibalized, but is replenished by formation of tidal dwarfs in the debris of giant galaxy interactions.

Further tests of the tidal dwarf formation hypothesis are provided by an ongoing project to measure the metallicities of the tidal dwarf candidates in the compact groups HCG 31 and 92. Long−slit data including the [O II] and [O III] emission lines were obtained at the KPNO 2.1-m telescope by undergraduate Andrew Glenn, Hunsberger, and Charlton in October 1996. The origin of the tidal clumps will be probed by comparing their metallicities to that in the outer region of the parent galaxy and by correlating metallicity with galactocentric radius.

Charlton, Hunsberger, and collaborators are awaiting the scheduling of HST optical imaging of the famous Hickson Compact Group, ''Stephan's Quintet.'' This group is particularly rich in tidal dwarf candidates and the observations in two colors and improved resolution will elucidate the nature of these objects and allow a comparison to the population of dwarf galaxies at large. In another planned HST/WFPC2 project, the group will image the tidal debris of four nearby interacting galaxy pairs. The driver of this study is the question of whether there is a continuum of structure from the rather large tidal dwarf galaxies often found at the end of a tail to the many globular clusters formed nearer the center of a merger product a result of the interaction. Using VLA HI maps provided by J. Hibbard (NRAO) the group will consider the distribution of the gas from which the clumps formed. With modelling, it may be possible to identify the physical circumstances and formation histories which can produce tidal dwarfs, star clusters, and other structures in tidal tails.

3.2.3.2 Low Surface Brightness Galaxies. Schneider, with J. Dalcanton (O.C.I.W), J. Gunn, and D. Spergel (Princeton University), and M. Schmidt (Caltech), have completed an investigation of the number density of low surface brightness galaxies (central surface brightnesses in the range $23 < \mu_0 < 25$ V mag/arcsec^2). The galaxies were found via an automated search algorithm applied to the image data of the Palomar Transit Grism Survey. This study suggests that the number density of low surface brightness galaxies is comparable to or greater than the number density of ''normal'' galaxies.

3.2.3.3 Normal Galaxies. Brandt, M.J. Ward (Leicester), A.C. Fabian (Cambridge) and P.W. Hodge (Univ. of Washington) have used pointed observations made with the ROSAT HRI to study three Local Group galaxies that have never been studied in detail in the X-ray regime: IC 10, NGC 147 and NGC 185. The most notable result is the discovery of a luminous and highly variable X-ray source in IC 10. The source is located near the center of a large, nonthermal bubble of radio emission, and is positionally coincident with an emission line star in IC 10 which has been classified as a WN-type Wolf-Rayet star. The X-ray source is probably a powerful X-ray binary in IC 10, and it may be a Wolf-Rayet + black hole binary. The source has mean and maximum isotropic luminosities of 2×10^{38} erg s^{-1} and 4×10^{38} erg s^{-1}, respectively.

3.2.3.4 Clusters and Distance Scale. Ciardullo, graduate student John Feldmeier, and G. Jacoby (NOAO) have begun a large-scale [O III] λ5007 survey of the Virgo Cluster for intergalactic planetary nebula. Their initial results are extremely encouraging: in three blank $16' \times 16'$ fields, they have discovered over 150 planetary nebula candidates. Their data imply that the surface brightness in the Virgo core due to intergalactic stars is $B \sim 27 \pm 1$ mag per sq. arcsec, and that up to ∼50% of the stellar mass of the cluster may be in intergalactic stars. Analysis of the [O III] λ5007 planetary nebula luminosity function also demonstrates that not only are the intergalactic stars are inhomogeneously distributed and non-virialized, but that they extend up to ∼4 Mpc in front of the central cD galaxy M87. Extrapolation of their results suggests that over 40,000 of the Virgo core's intergalactic planetary nebula are within reach of 4-m class telescopes. The distribution and kinematic study of these objects will provide new insights into the dynamical evolution of clusters.

Ciardullo, Feldmeier, and Jacoby have also continued using the planetary nebula luminosity function (PNLF) for distance measurements to nearby spiral galaxies, in order to improve the number of galaxies with both PNLF and Cepheid distance measurements. This year's observations focussed on NGC 2403, M33, and NGC 3627 (the latter for an improved calibration of the supernova distance scale). A preliminary distance to NGC 2403 has been found; work is continuing on the other galaxies.

3.2.3.5 Active Galaxies and Quasars. The morphological definition of a ''quasar'' has been further refined by work performed by REU student William Boos during the summer of 1996. Objects in the magnitude and redshift ranges $12.5 < B < 18.5$ and $0.07 < z < 0.3$ were selected from entries in NED and SIMBAD and their appearance examined on prints of the Palomar Sky Survey. Even though the sample comprised a mix of optical, radio and X-ray selected objects, the data confirm previous results established solely for optically selected quasars, that quasars are unresolved by telescopes of the 1.2m class for $B < 21 - (3/4z)$.

Brandt, working with S. Mathur (Harvard-CfA), C. Reynolds (JILA) and M. Elvis (Harvard-CfA), has extended the X-ray study of the prototype infrared quasar IRAS 13349 +2438 using spectra taken by the ASCA satellite. The com-

bination of the X-ray data and optical/near-infrared spectropolarimetry for this quasar strongly suggest the presence of a dusty ionized ('warm') absorber along the line of sight to the central X-ray source. The ASCA spectra allow a direct detection of the warm absorber via oxygen edge absorption, and the spectra allow the properties of the absorber to be constrained far better than before. The dusty warm absorber appears to have a density below 10^8 cm^{-3}, and it is probably located outside the broad-line region. The dust in the warm absorber does not appear to have been heavily sputtered or destroyed by other means. Based on the ASCA fitting, it appears likely that ultraviolet absorption lines from the warm absorber will be detectable. Hubble Space Telescope spectroscopy should allow a search for such lines. The steep hard X-ray power law of IRAS 13349+2438 also has relevance to some models of radiative Fe II line formation.

Brandt has also collaborated on SAX data analysis and interpretation for the ultrasoft narrow-line Seyfert 1 galaxy Ton S 180. This galaxy shows an extremely strong soft X-ray excess below 1 keV. The spectrum is seen to harden at higher energies, although the slope of the hard X-ray power law is still steeper than the 'canonical' value for a Seyfert 1 galaxy. Systematic residuals between 6–7 keV appear to be due to ionized iron K line emission, and the presence of ionized iron line emission suggests that the black hole in Ton S 180 is accreting at an unusually high fraction of the Eddington rate.

A.C. Fabian (Cambridge), Brandt, R.G. McMahon (Cambridge) and I. Hook (ESO Garching) have recently used ROSAT to detect the highest redshift radio-loud quasar known, GB 1428+4217 at $z=4.72$. This makes GB 1428+4217 the most distant X-ray detected object to date, and it is the brightest X-ray source above a redshift of 4. GB 1428+4217 appears to have an extremely large isotropic X-ray luminosity, which exceeds that at other (observed) bands. The spectral energy distribution peaks at X-ray, or even shorter, wavelengths, suggesting that the X-ray emission in this quasar is beamed toward us. Recently obtained ASCA spectra will allow a more detailed study of the X-ray properties of this quasar.

Nousek and former Penn State Research Associate, K. Weaver (JHU), collaborated on ASCA observations of MCG -5-23-16. They found a complex Fe X-ray line emission which is indicative of general relativistic effects from the black hole in MCG -5-23-16.

Nousek and others from the ASCA team studied X-ray emission from M82, the nearest starburst galaxy.

Schneider, M. Schmidt (Caltech), and J. Gunn (Princeton University) are engaged in a long-term program to identify high-redshift quasars based on surveys with the 5-m telescope on Palomar Mountain. The data are acquired with a CCD camera running in ''scan mode''; the survey areas are long strips of sky that are about 9 arcminutes wide. Two techniques are used: multicolor observations designed to detect the strong signature of the Lyman-alpha emission line/Lyman-alpha forest of $z>4$ quasars, and slitless spectroscopy (using a grism) to identify the Lyman-alpha emission line. The total area of the new surveys is approximately 65 sq degrees. In the past year the discovery of four $z>4$ quasars was announced; all are relatively faint, and two, with redshifts above 4.5, are among the most distant known quasars.

Penn State undergraduate Andrew Stephens, with Schneider, Schmidt, Gunn, and D. Weinberg (The Ohio State University), published a study of the clustering properties of quasars at redshifts larger than 2.7. The data set consisted of the quasars from the Palomar Transit Grism Survey, the previous high-redshift survey published by Schneider, Schmidt, and Gunn in 1994. There appears to be little doubt that high-redshift quasars display significant clustering; for example, the survey contains three close pairs of quasars (separations of a few Mpc), whereas not even one would be expected if the quasars were distributed randomly.

The object US 3215 is an optically variable galaxy with very broad Balmer lines and a weak ultraviolet continuum. Work by Usher and colleagues shows that the object has several unusual properties. R-band images show a galaxy with a bright starlike center and faint envelope which obeys a deVaucouleurs brightness law. The galaxy is surrounded by a swarm of lesser galaxies whose incidence out to a radial distance of 40 arcseconds is estimated to be at least of Abell Richness Class 0. US 3215 has a visible extent of about 13 arcseconds, which corresponds to a diameter of about 49 kiloparsecs at the redshift of 0.193. The object appears therefore to be an optically variable AGN whose host galaxy is a giant elliptical of type E2.

3.2.3.6 BL Lacertae Objects and Blazars. Graduate student Sally Laurent-Muehleisen, Kollgaard, and Feigelson completed the first two of a series of four papers on a new sample of BL Lac objects, with W. Brinkmann (Max-Planck Inst. Extraterr. Physik) and colleagues. These papers report VLA observations of $\simeq$2000 sources from the ROSAT All-Sky Survey, covering about 1/10 of the celestial sphere, which were known to be associated with radio sources brighter than about 20 mJy. The VLA maps provide arcsecond positions and, using the Cambridge APM catalog, optical identifications. Papers describing optical spectroscopy and identification of the BL Lac sample are in progress. The principal result is the discovery of many BL Lacs with properties intermediate to the previously bifurcated populations of X-ray and radio discovered BL Lacs.

Pesce joined PSU in August as a Lecturer. He continues his research into the environments (host galaxies and extended, Mpc-scale regions) of BL Lac objects with collaborators R. Falomo (Obs. Padua), M. O'Dowd, R. Scarpa, and C.M. Urry (STScI). He is currently working on a large dataset of HST GO and snapshot observations of BL Lacs and is submitting several papers on the analysis of low redshift BL Lacs and FRI/II radio galaxies using data from the digitized sky survey plates. His findings are somewhat surprising in that they are not what is expected. Contrary to earlier studies, the environments of low redshift FRI and II galaxies are similar, while the environments of BL Lac objects are more similar to those around FRII galaxies than those around FRI galaxies.

With M. Eracleous (Berkeley), Pesce has started an ambitious project to analyze the spectra of BL Lac objects, Flat Spectrum Radio quasars and radio galaxies. The intent is to

obtain high resolution data in order to understand how these objects fit in with other AGN and to determine the conditions near the black holes.

Sambruna recently joined the X-ray group as a member of the ACIS team. She continues her research on blazars and radio-loud AGN using X-ray data from past and current missions, as well as data at longer wavelengths. Together with C.M. Urry (STScI), L. Maraschi (Oss. Brera, Italy), and others, she investigated the multifrequency properties of PKS 0528+134, one of the brightest and most distant γ-ray blazars known, using simultaneous ASCA, CGRO, and ground-based data. It is argued that the huge power emitted at high-energies by this source is most likely originating from inverse Compton scattering of external thermal photons off the jet particles. Excess absorption over the Galactic value is also present in the ASCA spectrum.

Using data from the ROSAT archive, Sambruna investigated the spectral and timing properties of a sample of Flat Spectrum Radio Quasars. She found that the soft X-ray spectra of these sources have a wide distribution of photon indices, $0.5 \lesssim \Gamma \lesssim 2.5$, overlapping significantly with BL Lacs. This hints for the first time at the presence of a new FSRQ subclass, characterized by steep soft spectra, possibly due to the high-energy tail of the synchrotron component. The ROSAT light curves of a number of repeatedly observed FSRQs show low-amplitude (20%) flux variability, with little or no spectral variations, a different behavior from BL Lacs which have large-amplitude flux and spectral X-ray variability.

Using data from BBXRT and ASCA, Sambruna, R. Mushotzky (GSFC), C.M. Urry, and others found an X-ray absorption feature in the X-ray spectra of the BL Lacertae objects H1426+428 and PKS 0548−322. These features are seen for the first time and indicate the presence of a low-density ($N_H \sim 10^{20}$ cm^{-2}) photoionized gas around the central engine, possibly moving with subrelativistic velocities ($v \sim 0.1c$). Higher-resolution follow-ups are planned.

Sambruna is also involved in a deep X-ray, optical, and radio survey aimed at substantially expanding the current blazar samples (PI: Perlman, STScI), which is finding more and more examples of steep X-ray FSRQs. She is also collaborating with L. Maraschi and others in SAX monitoring of blazars.

Sambruna, with Mushotzky, I. George, J. Turner, K. Nandra (GSFC), investigated the X-ray properties of the Broad Line Radio Galaxy 3C 445, using ASCA and ROSAT data. The data are consistent with the presence of complex and heavy cold absorption in the inner regions of this source, and confirmed the detection of the Fe Kα line, with an EW $\sim$ 270 eV.

3.2.3.7 Quasar Absorption Lines. The rather ambitious goal of the Penn State Quasar Absorption Line Group, led by Charlton and Churchill, is to observe the formation and evolution of galaxies through their gas over all of cosmic time. Graduate students Rajib Ganguly and Suzanne Linder, and undergraduate students Lester Chou, Janet Geoffroy, and Jane Rigby are members of the group. Penn State colleagues Bershady, Ramsey, and Schneider also participate in various aspects of this research effort. The different ionization states of various chemical elements in absorbing clouds in, around, and between galaxies, provide probes of the source and intensity of ionizing radiation, and of the processes by which the chemical elements in the Universe are produced. With high resolution spectroscopy it is possible to examine the distributions and motions of gas in various phases within and in the environments of galaxies.

Churchill's Keck/HIRES data, obtained with S. Vogt (UCSC/Lick), builder or the HIRES spectrograph, provides a base for a comprehensive study of Mg II absorption systems at intermediate ($0.4 < z < 1.5$) redshift. In a recent paper in the Astrophysical Journal, Churchill, Vogt, and C. Steidel (Caltech) compared the high resolution Mg II absorption profiles to the absorbing galaxy properties. They found little correlation between various quantifications of profile shapes and spreads with the impact parameter, luminosity, or color of the absorbing galaxy. Such a large scatter in these relationships indicated that ongoing dynamical events and heterogeneous subgalactic structures give rise to large variations in the profiles.

A systematic search through twenty−six quasar spectra by Churchill, undergraduate Jane Rigby, and Charlton has yielded a new population of 30 weak Mg II absorbers ($W(MgII) < 0.3$Å). The stronger absorbers at intermediate redshifts have been found to arise mostly in the population of fairly bright ($> 0.1 L_B^*$) normal galaxies. A systematic study of this population is underway, including comparisons of Fe II to Mg II (diagnostic of the type of supernovae responsible for producing metals) and comparisons to single clouds of similar equivalent widths that are located within stronger systems.

Two of these weak Mg II absorption systems were studied in detail by Churchill and V. Le Brun (LAS du CNRS), who searched the Keck/HIRES spectrum of the quasar PKS 0454 +039 for Mg II lines associated with Lyα forest clouds in an HST/FOS spectrum of this quasar. Their detection of two Mg II doublets represent the first metals found in Lyα forest clouds at $z < 1.5$ associated with neutral Hydrogen column densities in the range $15.8 \leqslant \log N_{\rm HI} \leqslant 16.8$ cm^{-2}. From photoionization models, these clouds are inferred to have near−solar metallicities despite the relatively weak HI absorption and the lack of bright galaxies in the image of the field. These clouds also have relatively strong Fe II, indicative of enrichment by Type Ia supernovae rather than ''alpha−enhancement.'' Churchill and Le Brun suggest that the weak Mg II absorbers with strong Fe II absorption may be probing the class of ''giant'' (Malin−type) low surface brightness galaxies at intermediate redshifts.

Also underway, by Churchill, Charlton, B. Jannuzi (NOAO/KPNO), S. Kirhakos (IAS), Schneider, and C. Steidel is an archival search through HST data to study the distribution of high ionization gas and HI associated with both these new weak Mg II absorbers, and the class of stronger ones. A preliminary result is that the total equivalent width of the C IV associated with Mg II absorbers is correlated with the kinematic spread of the Mg II profiles, more so even than the total Mg II equivalent width. This suggests, tentatively, a picture in which the kinematics of the outlying Mg II clouds are governed by the same underlying potential or kinematic processes as the C IV. Incorporation of more

data and more extensive interpretations are underway.

Usually, with a deep search, a galaxy can be found associated with a strong Lyα absorber, but this is not the case with the damped absorber at $z=0.656$ along the line of sight to QSO 3C 336. Although the absorption is quite strong, and metals are present, no galaxy has been found in a very deep HST/WFPC2 image nor in a Keck/NIRC image obtained by Steidel. HST/NICMOS data, in a narrow band filter tuned to the wavelength of the redshifted Hα emission line expected from the absorbing galaxy, have just been obtained by Bershady, Charlton, Churchill, and collaborators Lowenthal (UMass) and Steidel. Analysis will either yield an absorbing galaxy or place extremely sensitive limits on its size and star formation activity. Churchill also contributed to a large study of damped Lyα systems conducted by L. Lu, W. Sargent, and T. Barlow (Caltech), and S. Vogt. The resulting paper presents spectra of multiple chemical species associated with the damped absorbers at $2<z<3$. Metallicities and abundances of these systems were studied in detail. The metallicities of the damped systems ranged from 1/10 to 1/300 solar, with a mean of 0.028 solar, and increased with decreasing redshift. Abundance patterns are typical of Type II enhancement. The authors claim little evidence for dust in these systems, an issue still under debate by the community of researchers.

Graduate student Rajib Ganguly, with Charlton and Churchill, has been comparing the distributions of high and low ionization gas in the context of a study of C IV systems in Churchill's Keck/HIRES sample. Caution is in order when studying the evolution of clustering of subcomponent clouds, since the two point clustering function statistic is often dominated by a small number of rich systems. Variations in the Si IV/C IV ratio across individual systems point toward variations in ionization parameters or abundances, and demonstrate that multiple phase models are needed. The focus of this work is to infer the physical conditions of clouds in individual systems. Ganguly has also been developing tools for a principal components analysis for quantifying the relationship between the distributions of high and low ionization gas.

As described below in the section on Theoretical Cosmology, the population of Mg II absorption line profiles at intermediate redshifts is consistent with a population of clouds in the kinematic distributions characteristic of disks and halos of local galaxies. The disk component often makes a dominant contribution to the Mg II column density in systems at $z<1$. Is this true at high redshift? The PSU QAL group is planning a survey for Mg II absorbers at $2.5<z<4.0$ using the JCAM, a near–IR, $R=10000$ spectrograph planned for the Hobby–Eberly telescope. This spectrograph is high enough resolution to search between sky lines, and thus a complete survey of Mg II absorbers will be possible. This redshift range could be a critical time when galaxies are being assembled and when their disks are settling in.

3.2.4 High Energy Astrophysics

3.2.4.1 Eridanus Enhancement. Burrows and Guo continued to work on soft X-ray emission from the ''Eridanus enhancement,'' a large diffuse feature produced by emission from the interior of the Orion-Eridanus superbubble, using ROSAT sky survey and pointed observations to obtain more detailed spectral and spatial information. ROSAT sky survey data provide a wealth of detail on small angular scales not visible in previous X-ray maps of this object, including the discovery of a number of shadows cast against the X-ray enhancement, presumably by clumps of neutral material in its shell. ROSAT PSPC pointed observations have been analyzed to investigate spectral variations across this object, and are also producing a number of unexpected shadow detections. The latter have been used to constrain the physical location of the absorbing clouds, using 21 cm observations to determine the radial velocities of the absorbing clouds and optical absorption measurements to constrain the distances to these clouds. This work constituted the thesis research of Guo and has led to improved constraints on the distance to the edge of the Local Hot Bubble surrounding the solar system.

Burrows and Guo also studied the X-ray spectrum of the supernova remnant VRO 42.05.01, using data from the ASCA satellite. The remnant was found to possess an almost featureless spectrum, in contrast to most other supernova remnants, which typically have strong emission lines in their X-ray spectra. This is suggestive of low elemental abundances for this remnant, which can be explained by its location at a galactocentric radius of about 13 kpc.

3.2.5 Observational Cosmology

The technique of using multi-band photometry to estimate galaxy redshift (photometric redshifts) continues to be improved and refined by graduate student David Andersen, Bershady, and collaborators at Johns Hopkins Univ. Bershady and Andersen have used photometric redshifts to begin a novel study of the faint end of the field galaxy luminosity function. Photometric redshifts are used to winnow down a magnitude-limited sample to an (estimated) volume-limited field galaxy sample. Confirmation and precise redshifts are then efficiently obtained using the WIYN 3.5m telescope and the Hydra multi-fiber spectrograph. In the past year they have received approximately 35 hours of time at WIYN for this survey. The spectra have been reduced and redshifts determined for approximately 500 galaxies. When the survey is completed, they expect to have substantially improved estimates of the slope of the faint end of the nearby field galaxy luminosity function, as well as the slope's dependence on color. This slope is critical for understanding the excess of faint blue galaxies seen in deep images.

Bershady continued to explore the evolution of the mass-to-light ratio of spiral galaxies. In collaboration with M. Haynes and R. Giovanelli (Cornell), rotation curves for a large sample of galaxies between $0.1<z<0.4$ are being obtained with the Palomar 200'' telescope and the double spectrograph. Bershady is also working with C. Mihos (Johns Hopkins) to use three-dimensional, kinematic models of galaxies to understand the effects of spatial sampling, spectral resolution and signal-to-noise on the derived rotation speeds of intermediate redshift galaxies.

A program to select low luminosity AGN on the basis of their variability has been completed over the past year by

Bershady and collaborators D. Trevese (U. Rome) and R. Kron (U. Chicago).

Bershady and S. Majewski (U. Virginia) have completed a systematic search of very luminous high redshift galaxies in their 4m plate fields covering over a square degree. A critical aspect of this study is the prediction of the colors of high redshift galaxies. Detailed modeling of the statistical distribution of high redshift galaxy colors is underway by Janet Geoffroy, Charlton, and Bershady. An alternative approach is also being explored by Weedman, Jeffrey Wolovitz, Bershady and Schneider: the morphology of identified high redshift galaxies in the Hubble Deep Field can plausibly be used to define selection criteria which do not require expensive U band photometry. In related research, Bershady and a large team of collaborators lead by M. Dickinson (STScI) have obtained very deep near-infrared (JHK) images of the Hubble Deep Field using 10 nights at Kitt Peak 4m telescope. These data are publicly available and have been analyzed in several recent presentations.

Graduate student Anna Jangren and Bershady have continued the analysis of HST images of blue, compact, narrow emission-line galaxies (CNELGs). The CNELGs often show a disturbed structure and have high surface brightnesses, indicating that they are undergoing bursts of star formation triggered by mergers or interactions. The photometry has shown that the CNELGs have an inverted correlation between the image concentration and color, compared to what is seen in local galaxies. The derived image structure information will be used in a future study to explore in detail the changes in surface brightness and color expected to take place over time as the starburst fades. Photometry has also been completed for a nearby galaxy sample. These well-resolved objects are used to calibrate the correlations of photometric properties, such as surface brightness, color, and image concentration, for ''normal'' galaxies. Using photometry of galaxy profile models, Jangren as attempted to understand how image concentration depends on bulge-to-total ratio and the ratio of disk/bulge scale-lengths, and also how seeing will affect the observed surface brightness.

Undergraduate student Jeffrey Wolovitz working with Weedman, Bershady, and Schneider analyzed the Hubble Deep Field in search of criteria for efficient location of high redshift galaxies. Using maximum surface brightness for selection, they found criteria for use with only the F814 and F606 filters which seem to allow 30% efficiency in locating galaxies with $z>2$ based on image characteristics.

3.3 Theoretical Studies

3.3.1 Theoretical Astrophysics

3.3.1.1 Globular Cluster Evolution. Ciardullo and graduate student Roger Barlett are continuing to study the evolution and origin of systems of globular clusters associated with present-day galaxies. The project's first objective is to model the physical changes undergone by an ensemble of globular clusters in a Hubble time; included in the analysis are mass loss from star evolution, stellar evaporation due to internal relaxation, and cluster disruption caused by the shocks associated with the clusters' passage through the disk or bulge of the parent galaxy. First results indicate that these processes are effective in selectively destroying low-mass clusters, but they are not sufficient to erode the ''initial'' power-law luminosity function (observed in the young, compact clusters of the Antennae galaxies) into the log-Gaussian form (seen in the Milky Way, M31, and several Virgo ellipticals). The project's current goal is to identify a formation spectrum of clusters that will evolve into the log-Gaussian form. Effects being investigated include the environment of cluster formation (within a forming galaxy or merger event, for example), and the survival of clusters against disruption by star formation and mass-loss from evolving stars.

3.3.1.2 Arrival-Times from Binary Pulsars with Rotating Black Hole Companions. Laguna and Wolszczan studied the gravitational time delay of arrival of signals from binary pulsar systems with rotating black hole companions. In particular, they investigated the strength of this effect (Shapiro delay) as a function of the inclination, eccentricity and period of the orbit, as well as the mass and angular momentum of the black hole. This study was based on direct numerical integration of null geodesics in a Kerr background geometry. They found that, for binaries with sufficiently high orbital inclinations ($>89^o$) and compact companion masses $>10M_\odot$, the effect arising from the rotation of the black hole in the system amounts to a microsecond–level variation of the arrival times of the pulsar pulses. If measurable, this variation could provide a unique signature for the presence of a rotating black hole in a binary pulsar system.

3.3.1.3 Radiation Processes in Compact Objects. A. Potekhin (Ioffe Institute for Physics and Technology, Russia), Pavlov, and J. Ventura (University of Crete, Greece) considered photoionization of the hydrogen atoms in strong magnetic fields, $10^{10}-10^{13}$ G, with allowance for coupling of electron states with different Landau numbers. This nonadiabatic approach enabled them to prove that the photoionization process is allowed for photons polarized perpendicular to the magnetic field at frequencies lower than the electron cyclotron frequency, contrary to the conclusion of many previous papers based on the adiabatic approximation. Coupling between closed and open channels leads to the autoionization of quasi-bound energy levels, which gives rise to Beutler-Fano resonances of the photoionization cross section. The corresponding spectral features can be observed in radiation emergent from surface layers of neutron stars with magnetic fields $10^{10}-10^{11}$ G.

Potekhin and Pavlov considered photoionization of the hydrogen atoms in strong magnetic fields, $10^{11}-10^{13}$ G, with allowance for the motion of atoms. They showed that the motion across the magnetic field substantially modifies the photoionization process: threshold energies are decreased as compared with those for an atom at rest, cross section values are changed significantly, and selection rules valid for atoms at rest are violated by the motion so that new photoionization channels become allowed. They folded the cross sections with the thermal distribution of atoms over the generalized atom's momentum and found that the bound-free opacities differ significantly from those of atoms at rest for typical conditions of neutron star atmospheres. In particular, the

photoionization edges are strongly broadened by the thermal motion of atoms, and this ''magnetic broadening'' exceeds the usual Doppler broadening by orders of magnitude. The decentered states of moving atoms give rise to the low-energy component of the opacity, which is most important in atmospheres of middle-aged neutron stars.

Bezchastnov (Ioffe Institute for Physics and Technology, Russia) Pavlov and Ventura investigated properties of the He^+ ion moving in a strong magnetic field. They developed a multichannel Hartree–Fock code with a two-particle basis set suitable for precise numerical solving of this nontrivial quantum mechanical problem and calculated the energies of discrete levels and corresponding sizes of the moving ion. Similar to the previously studied case of hydrogen, the ion is strongly deformed by the action of the motion-induced Stark forces. Unlike the case of the neutral hydrogen atom, whose transverse motion gives rise to a continuum of displaced energy states with changing transverse momentum, transverse motion of the He^+ ion gives rise to a discretely spaced energy spectrum. A quantitative understanding of this problem and related opacities is central in modeling neutron star atmospheres, and it should help in the interpretation of thermal emission from radio pulsars.

Bulik (CAMK, Poland) and Pavlov investigated polarization properties and absorption coefficients of the normal modes of radiation in a strongly magnetized hydrogen gas with allowance for the atomic motion. The main effect of the motion is that it induces new atomic transitions which substantially modify the bound-free and bound-bound absorption spectra for the ordinary and extraordinary normal modes.

Pavlov presented a review of the modern status of neutron star atmosphere models, with emphasis on the role of atomic physics in strong magnetic fields.

3.3.1.4 Physics of Gamma-Ray Bursts. Graduate student Hariklia Papathanassiou and P. Mészáros calculated the gamma-ray spectra from internal shocks in GRB, at wavelengths from optical through the TeV range, compared to the expected sensitivity of HETE and CGRO. The relative strength of the emission in these different energy bands can provide valuable information on the particle acceleration, radiation mechanisms and the possible types of models.

Mészáros and M.J. Rees (Cambridge) discussed magnetically dominated jet-like outflows from stellar mass black holes surrounded by debris tori resulting from neutron star disruption or collapse (a subsequent development of this model has come to be known as the hypernova model). These jets may have narrow cores (along the rotation axis) which are almost free of baryons and give rise to relativistic shocks producing the usual MeV bursts. Because the outflow is highly directional the properties of the observed gamma-rays would depend on the viewing angle relative to the rotation axis. Even for the most intense bursts, which under the assumption of isotropic emission and substantial redshifts would be inferred to emit $10^{52}-10^{53}$ erg, the efficiencies required are modest.

Graduate student Alin Panaitescu, L. Wen (MIT), Laguna and Mészáros numerically modelled the interaction between an expanding fireball and a stationary external medium with a homogeneous or power law density. The evolution of the ejecta and swept up gas is calculated, including shock and rarefaction wave reflections, in the adiabatic and radiative regimes. Bolometric light-curves are computed and simple scaling relationships are derived.

Panaitescu and Mészáros computed burst spectra and light curves from synchrotron and inverse Compton scattering by electrons accelerated in external shocks. They investigated the effect of varying the parameters on the burst spectra, and presented a set of correlations among the spectral and temporal features of the bursts. The spectral hardness, various spectral-temporal correlations and the spectral evolution of the simulated bursts are compared to those of observed bursts for a representative set of model parameters. Multipulse structures are simulated using a variable magnetic field and anisotropic emission, and the most important spectral and temporal properties of these pulses are compared with observations.

3.3.1.5 Long Wavelength Afterglows from Gamma Ray Bursts. Mészáros and M.J. Rees (Cambridge) discussed the afterglows from the evolution of cosmological gamma-ray burst remnants, after the gamma-ray event. Significant optical emission is predicted which should be measurable for timescales of hours after the event, and in some cases radio emission may be expected days to weeks after the event. The flux at optical, X-ray and other long wavelengths decays as a power of time, and the initial value of the flux or magnitude, as well as the value of the time-decay exponent, should help to distinguish between possible types of dissipative fireball models. These predictions have, in fact, been verified (after the paper appeared) in several bursts such 970228, 970508, etc.

Wijers, Rees, and Mészáros compared GRB model predictions of afterglows to the first observations of such an object, GRB 970228, detected by Beppo-SAX. The afterglow in X rays and optical light fades as a power law at all wavelengths. This behavior was predicted for a relativistic blast wave that radiates its energy when it decelerates by ploughing into the surrounding medium. Because the afterglow has continued with unchanged behavior for more than a month, its total energy must be of order 10^{51} erg, placing it firmly at a redshift of order 1. Further tests of the model are discussed, and implications for future observing strategies are pointed out. They discuss how the afterglow can provide a probe for the nature of the burst sources.

Papathanassiou and Mészáros calculated the time integrated spectra of internal shocks that bear the general features of the time averaged spectra of observed GRBs, taking into account the evolution of the electron energy distribution. They explore the parameter space of the physical quantities that relate to special spectral characteristics, such as low energy excess and high frequency components. They look into the late term behavior that may appear as a delayed transient source in lower wavelengths.

Mészáros, Rees, and Wijers discussed the afterglows from the evolution of both spherical and anisotropic fireballs decelerating in an inhomogeneous external medium. They consider both the radiative and adiabatic evolution regimes, and analyze the physical conditions under which these regimes

can be used. Afterglows may be expected to differ widely among themselves, depending on the angular anisotropy of the fireball and the properties of the environment. They may be entirely absent, or may be detected without a corresponding γ-ray event. A tabulation of different representative light curves is presented, covering a wide range of behaviors that resemble what is currently observed in GRB 970228, GRB 970508 and other objects.

Panaitescu and Mészáros derived the equation for the surface of the afterglow of a relativistic fireball which is decelerating in an external medium. Due to the deceleration, these surfaces become distorted ellipsoids and, at sufficiently late times, most of the light (either bolometric or in a given band) comes from a ring-like region whose width depends only on age. They analyze the shape of these surfaces and the radiation received from different angles for different dynamic and radiative regimes and homogeneous or power-law external densities. They calculate angle-integrated bolometric and fixed frequency fluxes, and tabulate the most relevant parameters that describe the equal arrival time surfaces and the source brightness distribution, quantities that are useful for more accurate analytic estimates of the afterglow evolution.

3.3.1.6 Cosmology and Statistics of Gamma Ray Burst Sources. Horváth, P. Mészáros, Bagoly, A. Mészáros, and Balázs did a principal component analysis (PCA) for gamma-ray bursts in the BATSE 3B catalog. This is the first systematic use of the PCA in gamma-ray burst problems. They show that only two out of the three basic quantities of duration, peak flux and fluence are independent, even if this relation is strongly affected by instrumental effects, and these two account for 91.6% of the total information content. The next most important variable is the fluence in the fourth energy channel (at energies above 320 keV). This has a larger variance and is less correlated with the fluences in the remaining three channels than the latter correlate among themselves. The hardness ratio $H32$ is significantly correlated with peak flux, while $H43$ is significantly anticorrelated with peak flux.

Horváth, P. Mészáros, and A. Mészáros carried out detailed chi-squared fits of cosmological number count distributions to the BATSE 2B and PVO catalogs of gamma ray bursts. This shows that both power law luminosity functions and density evolution models are well fitted by the data.

Reichart and Mészáros investigated Einstein-de Sitter cosmological models with a power-law luminosity of arbitrary slope as well and density evolution as a power of redshift. These were chi-square fitted to the number *vs.* peak flux counts in the 3B BATSE catalog, and the recently published data on time dilation and spectral softening versus peak flux. Good fits were obtained for evolving models, where the typical sources are at redshifts order unity, and the faintest at redshifts greater than 5.

A. Mészáros (Prague), Horváth, P. Mészáros and Bagoly (Budapest) investigated the hypothesis that, for GRB at cosmological distances, the fainter sources should have longer average durations due to the cosmological time dilation. They previously (Mészáros *et al.* 1996 [J. Korean Astron. Soc., 29, S43]) predicted that, if the cosmological origin is correct, there should be a *linear* anti-correlation between $\ln T$ (duration) and $\ln F$ (peak flux) of GRBs, provided one considers only the bursts with the longest durations. They have analyzed the BATSE 3B data, and show that such an anticorrelation is indeed present, with a probability higher than 90%.

Horváth and Mészáros investigated the duration distribution of the GRB in the 3B catalog. While previously two classes of GRB had been recognized on the basis of the duration, they showed that the 3B data allow a good fit with three Gaussian distributions in $\log T_{90}$. The χ^2 statistic indicates a 44% probability for two Gaussians, whereas the three Gaussian fit probability is 99%. Using another statistical method, it is argued that the probability that the third class is a random fluctuation is less than 0.01%.

3.3.1.7 AGN High Energy Radiation & Cosmic Ray-Neutrino Processes. Rachen and Biermann, Kang and Ryu (Bonn) carried out simulations of the formation of cosmological structure which allow to determine the spatial inhomogeneity of cosmic magnetic fields. Combining these with observations of the Rotation Measure to distant radio sources allows then to deduce upper limits for the strength of the magnetic field, which are of order 0.2 - 2 muG along the filaments and sheets of the galaxy distribution. In the sheet outside the Coma cluster there is a definitive estimate of the strength of the magnetic field consistent with this range. Such estimates are almost three orders of magnitude higher than hitherto assumed usually. High energy cosmic ray particles can be either focussed or strongly scattered in such magnetic filaments and sheets, depending on the initial transverse momentum. The cosmological background in radio and X-ray wavelengths will have contributions from these intergalactic filaments and sheets, should the magnetic fields really be as high as 0.2 - 2 muG.

Rachen calculated the propagation of UHE cosmic rays in a structured universe. In a gravitationally unstable universe, the structure of dark matter and galaxies, intergalactic gas and magnetic field can have severe impact on the propagation of ultra high energy cosmic rays (UHECR). The possible effects include spatial confinement and directional focusing along the supergalactic matter sheets, as well as universal re-acceleration at large scale shock fronts, and spectral modification due to energy dependent leakage into cosmic voids. As a result, the GZK-cutoff may be less pronounced and occur at a higher energy, where the stochastic nature of both acceleration and energy loss processes has to be taken into account.

Rachen and Mészáros investigated the acceleration of protons at internal shocks in GRB as the origin of the highest energy cosmic rays. Even though such energies are reached, the protons are confined to the expanding shell and may suffer considerable adiabatic losses before ejection. A way out is the production of neutrons in photohadronic interactions. The neutrons can be produced in sufficient numbers and escape without being reconverted into protons if the photohadronic ''optical depth'' of the emission region is of order 1. This can be fulfilled under the same conditions which also allow acceleration of protons to the highest energies – gamma ray bursts might be perfect ultra-high energy neutron bombs. The production of neutrons goes along with neutrino

production, which allows a tight connection between cosmic ray ejection and the neutrino flux correlated to GRBs. This makes the hypothesis of UHE cosmic ray origin in GRBs directly testable through VHE neutrino observatories.

Rachen and Mészáros investigated the spectrum of photohadronically produced neutrinos in astrophysical sources, whose physical properties are constrained by variability. Our treatment includes a detailed discussion of various competing cooling processes for energetic protons, as well as a detailed investigation of the cooling of pions and muons in the hadronic cascade. They find that in particular muon cooling limits the maximum neutrino energy in Active Galactic Nuclei and Gamma Ray Bursts, and affects strongly the expected event rates for horizontal air showers. In particular, they can rule out any major contribution from current models of these sources above 10^{19} eV, which is important for neutrino observations with the Pierre Auger Observatory. They also discuss test implications for the hypothesis that Gamma Ray Bursts are the sources of the highest energy cosmic rays.

3.3.1.8 General Relativity. Horváth and B. Lukács (Budapest) completed an investigation of all the shear-free geodesic stationary vacuum solutions of Einstein's equations, and classified them on the basis of the parameters involved.

3.3.2 Computational Astrophysics

3.3.2.1 Tidal Distortions of Globular Clusters. Undergraduates Holly Nordquist and Robert Klinger (now at UIUC), with Laguna and Charlton, conducted N–body simulations to study the distortions of globular clusters due to their passage through the bulges of galaxies. The team used an N–body, parallel, oct–tree code, developed by M. Warren (LANL), in order to represent each star in the cluster by its own particle in their largest run. The distortions are characterized by ''twisting isophotes'' and persist as the cluster passes back out into the galaxy until the outer unbound layers are dispersed. It is possible to observe these types of distortions for clusters in the Milky Way if any have recently passed within $\sim$400 pc of the Galactic Center. In more extreme environments, such as giant ellipticals or merger products with many newly formed globulars, this effect could be more common.

3.3.2.2 Double Lines of Sight Through the Lyα Forest. Charlton participated in a collaboration with P. Anninos, Y. Zhang, and M. Norman (NCSA/UIUC) to conduct cosmological N–body/hydrodynamic simulations of the Lyα forest. This study focused on an attempt to extract information on the shapes and sizes of the structures in the simulation box using quasar double lines of sight. If most of the lines seen in adjacent lines of sight match that is an indication that the structures are typically large enough to cover both lines of sight, and the velocity differences between material in these two locations can also be used to diagnose kinematics. The philosophy behind this study was that simulations, in which the structures and velocity fields can be examined in detail, can be used to develop techniques that could be used to assess the accuracy of analysis of the real data by double line of sight techniques.

3.3.3 Atomic Physics

Sampson and collaborators have continued their work on fully relativistic calculations of atomic properties of highly charged ions. In the latest work, effective (maxwellian averaged) collision strengths were calculated for several hyperfine transitions of possible astrophysical interest.

3.3.4 History of Science

Usher continues pursuit of the relevance of astronomical allusions in Shakespeare's plays and sonnets to the history of astronomy. The Bard's apparent lack of awareness of the Copernican hypothesis is pointed out in an article in Mercury. This paper has been translated and adapted for publication in the Journal of the Astronomical Society of Sofia, Bulgaria.

In a paper delivered at the Toronto Meeting of the American Astronomical Society, Usher presented the case for Shakespeare's play *Hamlet* being an allegorical recounting of competing cosmological models of the late sixteenth century, viz. those of (i) Claudius Ptolemy, (ii) Tycho Brahe, and (iii) one of the earliest advocates of the Copernican model, Thomas Digges. Merely to note that the false King Claudius has the same first name as the geocentricist Claudius Ptolemy, does not go far enough, for in the play all three models are personified by Claudius, Rosencrantz and Guildenstern, and Hamlet, respectively. There are manifold allusions to astronomy through double meanings of technical words like ''retrograde'' and ''opposition,'' while the infinite universe is brought out in Hamlet's Diggesian plaint: ''I could be bounded in a nutshell and count myself a king of infinite space....'' Moreover, while the play follows the outline of the twelfth century Amleth legend as recounted by Saxo Grammaticus, Shakespeare uses only the first part because that alone suits his dramatic purpose. There is a significant departure in the final scene when the Copernican and Diggesian hypotheses are united to give what amounts to the modern world view. A copy of the American Astronomical Society / Penn State news release may be seen at (http://www.astro.psu.edu/users/usher/Hamlet.html) and in reports in the press (*e.g.*, The Times, The Daily Telegraph, January 14, 1997).

3.3.5 Statistical Astronomy

3.3.5.1 Methodology. Feigelson continued his collaboration with G. J. Babu and M. Akritas (Dept. Statistics, Penn State) in the development of advanced statistical methods for observational astronomy. Cross-disciplinary links were emphasized with the publication of the proceedings of the *Statistical Challenges in Modern Astronomy II* conference, and talks by Feigelson at several conferences: the Interface '96 meeting at the Sydney International Statistical Congress; Data Analysis in Astronomy V workshop in Erice Italy; the IAU Symposium on multiwavelength surveys in Baltimore; Astronomical Time Series conference in Tel Aviv; and the general Session of the International Statistical Institute in Istanbul.

3.3.5.2 Consulting Center. The Statistical Consulting Center for Astronomy (http://www.stat.psu.edu/scca), led by Akritas, produced a major paper summarizing over two

dozen questions and answers on statistical matters raised by astronomers. Feigelson also created a Web matasite called StatCodes that provides hypertext links to over 200 public domain software packages, programs and services that may be useful to astronomers. StatCodes was receiving about 30 hits daily in mid-1997 and can be found at http://www.astro.psu.edu/statcodes.

3.3.6 Cosmology

3.3.6 QSO Absorption Lines. Charlton and Churchill recently completed a theoretical analysis of the kinematic composition of Mg II absorbers at $0.4<z<1$. A Monte–Carlo program was used to place clouds, with column densities and Doppler parameters consistent with those observed, in a kinematic distribution such as a rotating disk or a halo with radial infall. Synthetic spectra were generated from lines of sight through a population of model galaxies and the resulting ensembles of profiles were compared with the observed Keck/HIRES. Churchill developed a maximum likelihood least squares fitter (MINFIT) which made it possible to quantitatively describe the profiles and perform statistical tests to distinguish various models from the data. The result of these tests was that various models with rotating disk and infall/halo contributions are nearly consistent with the data. An intermediate component between halo and disk, such as material settling into the disk, is needed to explain the kinematic spread in some of the profiles. The variety of Mg II profiles at intermediate redshift can be explained by the gas in disks and halos of galaxies not much different than those in the nearby Universe.

Graduate student Suzanne Linder completed a paper that examines the expected contribution to Lyα forest absorption from the extended disks of giant, dwarf, and low surface brightness galaxies. In fact, it is easy to produce all of the Ly α absorbers observed at low redshift from the population of galaxies at present, with logical assumptions about their gaseous content and distribution. Since absorption often occurs at >200 kpc from luminous galaxies it is often hard to identify the particular galaxy that dominated the absorption. In these models a large fraction of the absorption lines originate in a plausible population of low surface brightness galaxies.

3.3.6.2 Numerical Studies of Inhomogeneous Cosmologies. In collaboration with P. Anninos (NCSA), Laguna is developing a general relativistic code for cosmology that incorporates minimally coupled real scalar fields and collisionless matter as sources. They have performed a series of code tests that include solutions from cosmological perturbations and examples of inhomogeneous cosmological spacetimes. The testbed computations also included gravitational waves propagating in expanding background cosmologies, inflationary scalar field dynamics, and matter perturbations of the FLRW models in the sub– and super–horizon scale limits. The ultimate goal is to develop a fully self–consistent code for cosmology, which include collisionless, hydrodynamic and scalar field matter sources. This code will be used to study physics of the early Universe, when general relativistic effects play an important role.

3.3.6.3 Dynamics of Perturbations of Black Holes. Laguna, Papadopoulos and graduate student William Krivan carried out a numerical study of the evolution of a massless scalar field in the background of rotating black holes. The study showed that, for rotating black holes, the late time dynamics of a massless scalar field exhibits the same power-law behavior as in the case of a Schwarzschild background independently of the angular momentum of the black hole. Krivan, Laguna and Papadopoulos also conducted the first numerical study of the time evolution of gravitational perturbations of rotating black holes. The solutions are obtained by integrating the Teukolsky equation written as a first-order in time, coupled system of equations; a form that captures its essential characteristic structure. They followed the propagation of generic initial data through the burst, quasinormal ringing and power-law tail phases. In particular, they calculated the effects due to the rotation of the black hole on the scattering of incident gravitational wave pulses, namely super-radiant scattering. These results may help clarify the role of black hole angular momentum on signals produced during the final stages of black hole coalescence.

3.3.6.4 Cosmological Topological Defects. In collaboration with Bettencourt (Imperial College) and Matzner (Texas), Laguna investigated the numerical field evolution for the collision of two Abelian type I cosmic strings. This study presented strong evidence that, for collisions at small but characteristic relative velocities and angles, these cosmic strings do not exchange ends and separate. Rather, local higher winding number bound states are formed close to the collision point, which promote multiple local scatterings at right angles and prevent intercommutation from happening. This constitutes the simplest example of the breakdown of the intercommutation rule, usually assumed in the construction of effective models for cosmic string network evolution. In collaboration with Zurek (Los Alamos), Laguna also carried out a numerical study to calculate the initial density of topological defects after a symmetry breaking phase transition. The numerical study of order parameter evolution in the course of symmetry breaking transitions dynamics showed that the density of topological defects, kinks, which form during a quench is proportional to the fourth root its rate. The simulations strongly support the analytic predictions by Zurek.

3.4 Particle Astrophysics

The particle astrophysics group consists of Associate Professor James Beatty, Postdoctoral Fellow Michael DuVernois who joined in the Fall of 1996 from the University of Chicago, and Assistant Professor Stephane Coutu who arrived in the Fall of 1997 from the University of Michigan. Graduate students include Steve Beach who began work with the group in 1996 and Georgia de Nolfo who completed her degree (at Washington University in St. Louis) in 1997.

Research work at PSU focuses on the High-Energy Antimatter Telescope (HEAT) balloon-based cosmic-ray observatory. The group, along with collaborators at UC Irvine, Chicago, Indiana, Michigan, and Eastern New Mexico, have been studying cosmic-ray electrons and positrons at the top of the atmosphere. This work has extended high-precision

determinations of the positron fraction and $e^{\pm}$ spectra from 1 to 100 GeV. Construction of a new set of instruments for the HEAT observatory is underway. Theoretical work on cosmic-ray propagation with a special focus on antimatter propagation is also being conducted by Coutu and DuVernois.

As a part of an international collaboration, the group has worked on the design of the Pierre Auger Observatory. This facility will study the highest energy cosmic rays ($> 10^{19}$ eV) with all-sky coverage. It will utilize surface water Cherenkov tanks and atmospheric nitrogen fluorescence detectors from installations in Utah and Argentina. Beatty is the surface electronics task leader and was one of two Americans on the original design committee. The science goals include studies of the origin and acceleration of the most energetic particles known, the intergalactic magnetic field, gamma-ray bursts, high-energy neutrinos, and exotic particle signatures.

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