Pennsylvania State University
Department of Astronomy and Astrophysics

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This report covers the period from September 1, 1997 to August 31, 1998.

1. PERSONNEL

1.1 Faculty

The regular members of the faculty during the academic year 1997-1998 were Professors Peter Mészáros (Department Head), Eric Feigelson, Gordon Garmire (Evan Pugh Professor), Lawrence Ramsey, Douglas Sampson, Peter Usher, Daniel Weedman, and Alexander Wolszczan (Evan Pugh Professor); Associate Professors Jane Charlton, Robin Ciardullo, Pablo Laguna, Donald Schneider and Richard Wade; Assistant Professors William Brandt and Louis Winkler, were joined by Michael Eracleous (formerly of the University of California-Berkeley) and Steinn Sigurdsson (formerly of the University of Cambridge, England); 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.

Research Associates in the program were Karen Camarda, George Chartas, Christopher Churchill, Audrey Garmire, Scott Horner, Eugene Moskalenko, Jerome Orosz, George Pavlov, Jorg Rachen, Frederick Ringwald, Rita Sambruna and Leisa Townsley. Joining the department as Research Associates were Steven Brandt (formerly of the Albert Einstein Institute Max-Planck-Institute for Gravitational Physics Potsdam, Germany) and Mijan Huq (formerly of the University of Texas at Austin). Joseph Pesce was a Lecturer/Research Associate. Fred Ringwald departed July 1998 to take up a visiting assistant professorship at Florida Institute of Technology.

Adjunct Associate Professor was Hans Kraus at the Oxford University Nuclear and Astrophysics Laboratory. Adjunct Assistant Professor was Matthew Bershady at the University of Wisconsin-Madison.

1.2 Visitors to the Department

Visitors to the department included William Krivan and Johannes Ruoff (from the University of Tubingen) working with Pablo Laguna; David Montes (from the Universidad Complutense de Madrid, Spain) working with Larry Ramsey; and Maciej Konacki, Grazyna Walentynowicz, Malgorzata Redmerska and Wojciech Lewandowski, (from Nicolaus Copernicus University, Centre for Astronomy, Torun, Poland), and Dr. Norbert Wex (from Max-Planck-Institut fuer Radioastronomie, Bonn, Germany) working with Alexander Wolszczan; Dr. Yoshitomo Maeda (from Koyoto University Department of Physics, Japan) working with the X-ray Astronomy Group. Dr. John Bahcall from the Institute for Advanced Study presented the 1998 Marker Lecture Series in March, with the general title of Astronomy.

2. ACADEMIC PROGRAM

2.1 Graduate and Undergraduate Majors

Eighteen graduate and sixty-one undergraduate astronomy majors were enrolled during the academic year 1997-98. During that time eight B.S. degrees, four Ph.D. degrees were awarded in Astronomy & Astrophysics. Doctoral recipients were Lee Carkner, Sally Hunsberger, Jeffrey Mendenhall and Darren Williams.

2.2 Educational Initiatives

For the third 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 1998 program, entitled Penn State Inservice Workshops in Astronomy (PSIWA), consisted of two 1-week courses on ''Stars and Planets for Science Teachers'' and ''Galaxies and Cosmology for Science Teachers.'' Both courses were offered at Penn State's main campus and included a variety of classroom, laboratory and computer activities. Over forty teachers from around Pennsylvania participated in the programs. Funding was received from the PA Space Grant Consortium. Feigelson and Weedman were the workshop instructors. Numerous department faculty, research associates and graduate students also participated in the programs.

2.3 Outreach

The department outreach effort in 1998 has been tremendous, in part, because of the recent swell in public interest. Synchronous with that 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 47 programs have been offered this year (since January of 1998) alone, and the number of students and adults attending has exceeded 2400. The programs have included planetarium shows, observing with telescopes, and public lectures. A complete listing of outreach programs offered by the Penn State Astronomy Dept. may be viewed at http://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. Members also participated in outreach programs for school children, making use of the Department's planetarium. Club officers are: President, Jane Rigby; Vice President, Andy Lonsbary; Secretary, Ken Pelman; Treasurer, Cyndi Pruss. Usher is the Club's faculty advisor.

3. RESEARCH ACTIVITIES

3.1 Instrumentation for Observing

3.1.1 Optical

3.1.1.1 The Hobby-Eberly Telescope During this entire last year the Hobby-Eberly telescope (HET) remained in the commissioning process. The most significant milestone this past year was the installation and successful testing of the final spherical aberration corrector (SAC). This complex 1/2-meter diameter corrector consists of 3 conics and a low order asphere. The last of these mirrors was delivered in late spring after an extensive fabrication delay. The SAC is part of a larger package called the prime focus instrument platform (PFIP) which delivers the image to either a prime focus low resolution spectrograph or a fiber instrument feed. The PFIP also contains the acquisition camera as well as a guider facility and an atmospheric dispersion corrector (ADC). In August 1998 we tested the basic optical system without the guide facility or ADC. Sixty six primary mirror segments that spanned the system pupil were used in these tests and showed that the SAC performed well over the center 2 arc-minutes of the 4 arc-minute science FoV. Due to a mechanical problem in the PFIP we were unable to test the outer part of the field during this run. However we are gratified with the performance we have seen to date from the SAC which was one of our high-risk systems. After rework this fall it will be re-installed for further testing.

The primary mirror always has been and remains our most critical risk area. This last year, and the last few months in particular, have seen significant improvement. As we have gone from 21 active mirrors in summer 1997 to 66 currently, our average time to stack the array in tip/tilt had decreased from 40 minutes to typical 10 minutes. All the 91 mirror segments are currently at the site and all will be installed and activated by the end of 1998. Prior experience leads us to expect that the tip/tilt stacking time will remain about 10 minutes. The major challenge with the primary mirror is maintaining the alignment of all the segments. The low- cost, high-risk approach taken with the segment alignment system was to forego edge sensors that continually provide an alignment feedback signal and operate open loop allowing 6 min/hour to tune the mirror and a thermal model to minimize drift. The mirror truss is instrumented with 50 thermal sensors. So far the thermal modeling approach has not worked and the mirror can drift out of alignment in a few tens of minutes. However, when the temperature gradients are low, we have gone several hours without alignment with arc-second images. Also we have not yet met our 6 min spec but that is not seen as a barrier as times as short as 8 minutes have been achieved with 10 being more typical. We are also accelerating our understanding of this complex system and still reserve hope that we can mitigate some of the drift with a thermal model. The current strategy is to maximize the open loop performance and begin science operations at some level in 1999 while we implement a closed loop system.

Several commissioning observing runs were conducted by the science commissioning team this last year. These tested the HET systems as a whole and highlighted areas critically needing attention. One success this last year has been the target planning software. The nature of the HET makes it challenging to use as any given object only has a limited time window in which it can be accessed. Thus, observing with the HET is more akin to HST than to a typical ground based telescope. The early planning software that has been implemented has proven to be up to the task and given the observers the tools needed to efficiently use the telescope. While the data set is very limited, the HET facility appears to meet our design goal of delivering seeing as good as the site offers.

There are three facility instruments under construction for the HET. Dr. Robert Tull at UT Austin is working on a high resolution single object spectrograph (HRS) which will commence integration on site in spring 1999. The second instrument is the MOS capable medium resolution spectrograph (MRS) that is addressed in more detail below. The schedule is captive to the procurement of calcium fluoride for the visible camera. The earliest commissioning date now appears to be late fall 1999. Both the HRS and MRS are fiber fed instruments and depend on the fiber instrument feed. This system will undergo a second commissioning run in early 1999 with test fibers and be complete by mid 1999. Dr. Gary Hill at UT Austin is leading the effort to build a prime focus low resolution spectrograph with multi-slit capability. This instrument is in the integration phase and a commissioning run is expected in late 1998 or early 1999.

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 Georg-August-Universitaet Goettingen. For current information on the HET, its science programs or partnership 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 which also has links to HET sites at UT Austin and other partner institutions. The HET is operated by the McDonald Observatory on behalf of the HET participants. The McDonald Observatory annual report contains details on staffing and infrastructure development as well as complementary materiel on telescope operations.

Weedman continued as a member of the HET Science Commissioning Team.

3.1.2 Instrumentation

3.1.2.1 Optical and Near Infrared Instrumentation 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 included professional staff Leland Engle and Ben Rhoads, Drs. Scott Horner, and L. Ramsey, graduate students Dave Andersen and Jason Harlow as well as undergraduate students and Eric Mamajek, Joe Maywalt and Kevin

McGouldrick. Dr. Horner left in spring 1998 to take a position at the US Naval Observatory. Eric Mamajek graduated with honors in spring 1998.

3.1.2.2 Medium Resolution Spectrograph As mentioned this last year 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 has 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. This last year Engel and Horner have completed at the 90% level the design of the Fiber Instrument Feed (FIF) portion of the MRS project. This complex system is described in more detail by Horner *et al.* (SPIE vol 3355, p 399) but briefly it can place either a synthetic long slit capability, 10 MOS probes, single fibers or an Integral Field Unit (IFU) in the HET 4 arc minute diameter focal plane. Initial on-telescope testing was conducted with the FIF structure and a single MOS probe with its fiber cable in August 1998 to validate routing paths and instrument lifting and installation sequences. Engel is refining the FIF structure, fiber cable and probe designs based on that experience and expects completion of all FIF mechanical components in early 1999 for a final integration test on the telescope. The electronic control system for the FIF is being assembled by Rhoads with completion expected before the end of 1998. In late spring, Ramsey finalized the basic MRS optical layout for both the visible and NIR beams. We contracted Dr. Harland Epps to produce a design for the visible beam camera. A preliminary all refracting design using 10 elements was completed by mid summer and we are now optimizing that design to the pre-production stage. Barring unusual procurement problems, we expect the full up FIF and MRS visible beam to be in integration at the telescope in late 1999.

As part of MRS testing and validation effort, REU students Mamajek, Maywalt and McGouldrick have been updating fiber evaluation hardware. Maywalt and McGouldrick constructed and characterized a test MOS cable used on the FIF test run in August 1998. The design for the HET's IFU was finalized in the past year (Andersen, Bershady, Ramsey, Horner 1997, BAAS, 188, 06.06). A single 45 fiber IFU, sampling position angles of zero, ninety, and plus and minus thirty degrees, was decided upon. This IFU pattern covers 14 by 14 square arcseconds of sky. A MOS probe will carry an additional six fibers to be used for sky subtraction. The fibers will be 200:230:260 (core:clad:buffer diameter) microns which corresponds to a core diameter of 1 arc-second in the focal plane of the HET. We are currently building a 2-m test array that will be used to characterize the optical behavior of the fibers. The final IFU is scheduled to be completed and in laboratory testing in April, 1999.

3.1.2.3 JCAM The JCAM project is a joint project with Drs. James Beatty in the Physics Department and Jane Charlton, Chris Churchill and Larry Ramsey in Astronomy & Astrophysics. It has the goal of implementing an early HET capability in the 950-1300 nm region. It uses the Upgraded Fiber Optic Echelle (UFOE) with a 31.6 l/mm echelle and a Rockwell/Boeing 1024 x1024 HgCdTe detector. Dr. Beatty has completed the design of the detector control and readout electronics and has procured most the of the required hardware. Leland Engle has designed and overseen the fabrication of the echelle grating holder. During this last year we also procured the dewar, grating and have a bare MUX from Rockwell to test the electronics. Ramsey had completed the design of a 5-element all transmitting camera that will allow resolving powers up to 13,000 to be achieved in the current system. Remaining tasks are to procure the camera fabrication and integrate and test the electronics. Our goal is to commission the system at the telescope by mid 1999.

3.1.3 *X-ray*

3.1.3.1 CCD Imaging Spectrometer on AXAF During the past year the ACIS (AXAF CCD Imaging Spectrometer) Team at PSU has concentrated on reducing the very large amount of calibration data collected at the X-ray Calibration Facility located at the Marshall Space Flight Center in Huntsville, Alabama. Preliminary results of this work was presented at the Estes Park Meeting of the High Energy Astrophysics Division of the AAS in early November of 1997. The full text of this report is available at the PSU Astronomy Web page as is the ''Final'' Report.

The ACIS instrument has been undergoing integration and testing with the remainder of the AXAF. During the Fall and Winter months the integration took place at Ball Aerospace Corp. in Boulder, CO with the Instrument Module. Then in the Spring and Summer the observatory has been assembled and tested at TRW in Redondo Beach, CA. During the final phase of the thermal vacuum test, the ACIS door, which protects the CCD's from contamination and the optical light blocking filter from acoustic loads during launch, was to be opened to check for stray-light leaks in the spacecraft. The camera body had been at -60 deg C for about one month when the attempt was made, with the result that the door failed to open and the protective shear disk in the wax actuator that opens the door was functioned to keep the actuator from exploding. A failure investigation was undertaken by the manufacturer of the door and mechanism, Lockheed Martin Astronautics, as well as Marshall Space Flight Center, MIT, PSU, and Starsys, the company that built the actuator. Several modifications to the door mechanism and procedure for opening the door were put in place, and the door was successfully opened at TRW six times after being subjected to the thermal and vacuum conditions expected during the AXAF launch sequence. The root cause for the failure of the door to open has not been determined at this time, although testing is still in progress on engineering copies of the door at Lockheed Martin Astronautics.

Townsley and Broos have implemented a Monte Carlo algorithm in order to model and predict the response of X-ray CCDs to photons and minimally-ionizing particles. This algorithm draws on empirical results and predicts the response of all basic types of X-ray CCD devices. It relies on new solutions of the diffusion equation including recombination to predict the radial charge cloud distribution in field-free regions of CCDs (Pavlov and Nousek 1998). By adjusting the size of the charge clouds, they can reproduce the grade distribution (branching ratios) seen in ACIS calibration data event lists. Using a model of the channel stops developed here and an insightful treatment of the SiO_2 layer under the gate structure developed at MIT they are able to reproduce $\sim$ 1% features in the spectrum of ACIS front-illuminated devices. They have also developed and tuned a model of charge transfer inefficiency, resulting in charge loss and the spatial redistribution of charge (trailing) in both the parallel and serial registers of ACIS back-illuminated CCDs, that is necessary to reproduce the spatially-dependent gain of these devices. Their goal is to use the simulator to predict what AXAF, with ACIS, will see in order to choose appropriate targets for observation and to configure the instrument to yield the best possible data. Used in conjunction with a model of the AXAF mirrors, an observer can predict both the spatial and spectral characteristics of a given astronomical field and prepare analysis techniques in advance of the observation. As a check on the fidelity of the response matrices and data modeling, the observer can run a model spectrum and spatial distribution of photons through the simulator and assess his or her ability to reproduce the data.

Chartas made significant contributions towards the accurate characterization of the detectors response and towards optimizing its performance. In particular using an automated event filtering software package developed at PSU, he analyzed a subset of the calibration data to investigate the dependence of the effective area and energy response of ACIS/HRMA as a function of grade selection, split event threshold, CCD and CCD amplifier, off-axis angle and region of interest on the ACIS focal plane. This work will facilitate the selection of the appropriate ACIS parameters that will lead to the enhancement of a particular scientific feature in the observed ACIS spectrum.

Sambruna and Chartas analyzed ACIS pile-up spectra based on data collected at the XRCF in 1997 during the calibration of ACIS. The primary goals of the analysis are to investigate possible trends of pile-up with source flux and grade selection, and to compare in detail the measured pile-up fraction with current theoretical models, in order to access the general validity of the latter for predicting pile-up for in flight observations.

3.1.3.2 Sounding Rocket Payloads PSU's successful sounding rocket program continued this year with a flight from White Sands, New Mexico to observe X-rays from the source Scorpius X-1. The flight was successful and produced a high quality CCD spectrum of this source, using a CCD originally acquired as a flight backup device for PSU's *CUBIC* experiment on the SAC-B satellite. More information about this launch is available from PSU's Sounding Rocket Home Page at http://www.astro.psu.edu/xray/rockets/36.176.

Burrows continues to collaborate with Dr. Hans Kraus of Oxford University on a sounding rocket payload designed to fly a cryogenic X-ray bolometer developed in his laboratory. Burrows and Roming are currently developing both X-ray mirrors and support electronics for this flight. The X-ray mirrors are being designed and built in collaboration with Marshall Space Flight Center, and feature a three-shell grazing incidence telescope fabricated from electroformed nickel mirrors. They have begun fabrication of the first mirror pair for this X-ray telescope.

3.1.3.3 CCD Detector Physics Pavlov and Nousek (1998) have made a new treatment of charge diffusion in CCD X-ray detectors. They find that previous work has ignored the velocity saturation effect, which leads to non-Gaussian profiles to the observed charge clouds. Including this effect leads to superior modeling of the observed X-ray event grade distributions.

3.1.3.4 Astro−E Nousek was named to serve as the science coordinator for selection of stellar X-ray targets for 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 meetings in the US and Japan for science working group meetings prior to launch.

3.1.3.5 Constellation X Nousek formed part of a consortium headed by Stephen Kahn (Columbia University), which was selected to carry out advanced technology development for a reflection grating-CCD instrument for the Constellation X mission. Constellation X, proposed by Harvey Tananbaum (SAO) and Nick White (GSFC), is a set of multiple X-ray telescope carrying spacecraft, designed to provide large collecting area for precision X-ray spectroscopy of astrophysical targets. The grating-CCD instrument will provide high resolution measurements on the X-ray spectrum below 2 keV, complementing the cryogenic detectors which have ideal properties above 2 keV.

Nousek is also heading the ISM panel of the Facility Science Team (FST) for Constellation X. Meetings of the FST are held twice per year, alternating between SAO and GSFC.

3.1.4 *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 was the initial chairman of the NSF Millimeter Array Oversight Committee. He was on the scientific organizing committees for IAU Symposium 194, ''Activity in Galaxies and Related Phenomena'' and the Maryland Astrophysics Conference ''After the Dark Ages, When Galaxies Were Young.''

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. He was also an initial member of the SIRTF Science Center Users Panel. SIRTF, NASA's final Great Observatory, received final authorization in 1998 and is scheduled for launch in 2001.

3.2 Observational Research

3.2.1 *Stellar Astronomy*

3.2.1.1 Halo B stars Usher has been a resource for the use of the US Survey for the detection of the Halo component of the field subdwarf B-star population by K.J. Mitchell (Astrophysical Journal 494, 256 1998) and for a new complete sample of Halo B stars, also by K.J. Mitchell (Monthly Notices of the Royal Astronomical Society 295, 225, 1998.)

3.2.1.2 Cool Stars For the 1997/98 academic year Dr. David Montes from the Dept. Astrofisica, Facultad de Fisicas, Universidad Complutense de Madrid was a visiting researcher in the department. His work focused on activity in cools stars using, in addition to his own data, the large archive accumulated at Penn State and by the Penn State Fiber Optic Echelle at KPNO to expand his research in this area.

3.2.1.3 Pre-Main Sequence Stars Montes, and Ramsey conducted a 10 night observing run at the McDonald Observatory 2.1 telescope in January 1998. Montes, and Ramsey collaborated on studies of activity in pre-main sequence stars as well as RS CVn stars. A description of this work can be found on Dr. Montes' web site at html://www.ucm.es/OTROS/Astrof/dmg.html

Feigelson continued his investigations of magnetic activity and high energy processes in young stellar objects with students and colleagues. Two results were obtained in the radio band using the NRAO Very Large Array. First, graduate student Lee Carkner, undergraduate Eric Mamajek, Feigelson and German coworkers reported a successful survey of nonthermal radio continuum emission from widely dispersed Li-rich young stars in and around the Taurus-Auriga star forming complex. With 1/3 of stars detected, it supports the argument that these stars are true pre-main sequence T Tauri stars and not foreground ZAMS stars. The origin of these stars so far from active clouds is then a serious puzzle (Feigelson 1996). Second, Feigelson, Carkner and Bruce Wilking (Univ. Missouri) detected circular polarization in the X-ray luminous, radio variable Class I protostars IRS 5 in the Corona Australis star forming cloud. This shows that protostars, like older weak-lined T Tauri stars, exhibit extremely high levels of magnetic activity and, in particular, accelerate *in situ* particles up to MeV energies.

In the X-ray band, Carkner, undergraduate Jennifer Kozak and Feigelson completed a survey of over 150 extremely young stellar objects (mostly Class 0 and I protostars) using the archived ROSAT database. Considering recent reports of X-rays from several protostars, it was surprising that only one new case was uncovered (Ced 110/IRS 6 in the Chamaeleon I cloud). They conclude that protostars may have X-ray emission similar to, but not substantially brighter than, older T Tauri stars. Feigelson also participated in a ROSAT study of more distant star forming regions, led by French colleagues Jane Gregorio-Hetem and Thierry Montmerle. They show that, at distances around 1 kpc, existing technology can locate X-ray luminous T Tauri and Herbig Ae/Be stars.

During the year, Feigelson worked on several review articles for an Italian conference, the *Protostars and Planets IV* conference, and for *Annual Reviews of Astronomy and Astrophysics*. High levels of magnetic activity characterized by powerful magnetic reconnection flares appear to be a general phenomenon for low-mass pre-main sequence stars from their protostellar phases through the ZAMS. In the older stars, the phenomena are quite similar to that seen in other magnetically active stars and is thus likely to arise from multipolar fields rooted in the stellar surface. For younger YSOs, it is possible (and has been widely theorized) that the powerful flares arise from reconnection in large-scale star-disk or disk-disk field lines. In either case, the resulting high energy radiation may have substantial effects on the cold molecular and dusty environment. Calculations indicate that YSO X-rays will ionize substantial parts of the circumstellar disk, likely inducing Balbus-Hawley instabilities and MHD turbulent viscosity resulting in accretion onto the star. X-ray ionization may also play a role in star-disk and disk-outflow magnetic coupling. MeV protons, likely to accompany the radio-observed MeV electrons in YSOs, may cause a variety of solid state and spallogenic nuclear effects on disk solids. Considerable evidence for this is independently found in meteoritic studies of the solar nebula. Thus, high energy processes may have important astrophysical roles in cool YSOs.

3.2.1.4 Interacting Binary Stars Orosz and Wade, working with C. Koen (SAAO), discovered that the hot subdwarf star KPD 0422+5421 is a single-lined spectroscopic binary with an orbital period of 2h 10m. The U and B light curves display an ellipsoidal modulation with amplitudes of ≈ 0.02 magnitudes. The sdB star contributes nearly all of the observed flux. This and the absence of any reflection effect suggest that the unseen companion star is small and therefore degenerate. Based on light curve modeling, the orbital inclination is $i = 78.05 \pm 0.50°$ and the mass ratio $q = M_{\rm comp}/M_{\rm sdB} = 0.87 \pm 0.15$. The sdB star fills 69% of its Roche lobe. The mass function of the companion is 0.126 $\pm$ 0.028 solar masses, and the individual masses are thus $M_{\rm sdB} = 0.72 \pm 0.26$ and $M_{\rm comp} = 0.62 \pm 0.18$ solar masses. A spectroscopic analysis, however, shows that the subdwarf star has a gravity consistent with membership on the Zero Age Extended Horizontal Branch, in which case its mass is expected to be near 0.50 solar masses. Further observations to improve the orbital mass determination are planned. KPD 0422+5421 has one of the shortest known orbital periods of a detached binary, evolving on a timescale of $\approx 10^8$ years by gravitational wave radiation, which should lead to a merger of the stars. If the mass estimates remain high, the total mass of the system is close to the Chandrasekhar limit for electron degenerate matter. This system is also one of only a few known binaries which contain a subdwarf B star and a white dwarf.

Orosz, Wade, Eracleous, and Harlow with J. R. Thorstensen and C. J. Taylor (Dartmouth College) made an observational study of the composite spectrum binary star PG 1224+309. Spectroscopy was obtained at both Lick and MDM Observatories, with filter photometry obtained at Kitt Peak National Observatory. The two stars are a DA white dwarf ($T_{\rm eff} = 29{,}000$ K) and a dwarf M star, the M star contributing 10 – 15 per cent of the red light in the system. The M star is irradiated by the DA star and shows a phase-modulated Hα emission line, arising from one hemisphere. The irradiation modulation is also evident in the photometry. Both of these modulations are phased correctly with respect to orbital conjunction in a binary whose orbital period is 6.1 hours. There is no eclipse, so the white dwarf's mass is uncertain but less than or equal to about 0.45 solar masses. Thus PG 1224+309 is another example of a binary star that has undergone common envelope binary evolution, probably interrupting the growth of the white dwarf prior to the helium flash.

Orosz and Wade began a spectrum analysis study of the hot subdwarf members of composite-spectrum binary systems found in the Palomar-Green catalog and other sources.

At issue is whether there is a systematic difference between hot subdwarfs in binary systems and similar stars in the field. Moderate-dispersion blue spectra were collected using telescopes at McDonald Observatory and Cerro Tololo Interamerican Observatory. Preliminary results show that it should be possible to extract approximate temperatures and surface gravities, and in some cases surface He/H ratios, even in these composite spectra. The spectra obtained to date will be used to identify a subset of the targets for intensive follow-up work with higher dispersion and ultraviolet spectra.

Orosz and Wade modified their synthetic spectrum code for accretion disks in binary star systems, to deal with the case of a disk that is partially eclipsed by the mass-losing star. As in all eclipse mapping procedures used to study disks in binaries, the known Roche geometry of the binary system permits the correspondence to be made between the spectrum observed over some phase interval and the region of the disk that contributes to the spectrum. The code can generate simulated observations corresponding to arbitrary phase intervals, with arbitrary spectral sampling and resolution. This capability clearly includes generating broad-band light curves as a limiting case. At present, the input (local, rest-frame) spectra are from non-irradiated LTE models self-consistently computed using I. Hubeny's TLUSDISK and SYNSPEC codes, and contain all relevant lines (typically thousands) from the Kurucz CD-ROM distribution. Angle-dependent specific intensities are used, so limb darkening effects are automatically taken into account. Compared with out-of-eclipse spectra of the entire disk, observations during eclipse have the advantage for diagnostic purposes of showing (1) deeper individual lines, (2) less blending of lines, and (3) an effectively smaller range of effective temperatures contributing to the observed spectrum. These advantages are especially important in analysis of the ultraviolet spectra of disks, and an analysis of archival HST observations of eclipsing cataclysmic variables will be undertaken.

Wade and I. Hubeny (AURA/NOAO) completed a large grid of far- and mid-ultraviolet spectra (850 Å to 2000 Å) of the integrated light from steady-state accretion disks in luminous cataclysmic variables. The spectra are tabulated at 0.25 Å intervals with an adopted FWHM resolution of 1.0 Å, so they are suitable for use with observed spectra from a variety of modern space-borne observatories. Twenty-six different combinations of white dwarf mass $M_{\rm wd}$ and mass accretion rate $\dot{m}$ are considered, and spectra are presented for six different disk inclinations *i*. The disk models are computed self-consistently in the plane-parallel approximation, assuming LTE and vertical hydrostatic equilibrium, by solving simultaneously the radiative transfer, hydrostatic equilibrium, and energy balance equations. Irradiation from external sources is neglected. Local spectra of disk annuli are computed taking into account line transitions from elements 1–28 (H through Ni). Limb darkening as well as Doppler broadening and blending of lines are taken into account in computing the integrated disk spectra. The models permit the radiative properties of disks to be discussed, including the dependence of ultraviolet fluxes and colors on $M_{\rm wd}, \dot{m}$, and *i*. The synthetic spectra are available as machine-readable ASCII files via *ftp*.

Orosz and C. Koen (SAAO) found (during a survey of subdwarf B stars) that the UV-bright star PG 2337+300 was a cataclysmic variable star, and not a subdwarf B star as originally supposed. This new classification was arrived at after three hours of high-speed photometric observations and moderate-resolution spectroscopic observations carried out at the McDonald Observatory. The light curve showed the ''flickering'' characteristic of cataclysmic variables and the spectrum showed emission lines of hydrogen, helium, nitrogen, and carbon.

Orosz, in collaboration with R. Jain, C. Bailyn (Yale), J. McClintock (Center for Astrophysics), and R. Remillard (MIT), established the orbital period and mass function of the soft X-ray transient 4U 1543-47. Their spectroscopic observations revealed a sinusoidal radial velocity curve with a period of $P = 1.123 \pm 0.008$ days and an amplitude of $K = 124 \pm 4$ km s^{-1}. The resulting mass function is $f(M) = 0.22 \pm 0.02\,M_\odot$ There were no emission lines seen from the accretion disk, and the measured fraction of disk light in the *B* and *V* bands was 10% and 21% respectively. The *V* and *I* light curves exhibit two waves per orbital cycle with amplitudes about 0.08 mag. Orosz *et al.* modeled the light curves as ellipsoidal variations in the secondary star, and showed that $i < 40°$ is a reasonable upper limit on the inclination of the system. The formal 3σ limits on the inclination from a simultaneous fit to the *V* and *I* light curves are $24° < i < 34°$ for $Q = M_1/M_2 > 2$. However, there are systematic effects in the data that the model does not account for, so the above constraints should be treated with caution. Orosz *et al.* also argued that the secondary star is still on the main sequence with the mass transfer being driven by expansion due to normal evolution on the main sequence. If the secondary star has a mass near the main sequence values for early A-stars ($2.3 < M_2 < 2.6\,M_\odot$), then the best fits for the 3σ inclination range ($24° < i < 34°$) and the 3σ mass function range ($0.16 < f(M) < 0.28\,M_\odot$) imply a primary mass in the range $2.9 < M_1 < 7.5\,M_\odot$. The mass of the compact object in 4U 1543-47 is likely to be in excess of about 3 solar masses, which is widely regarded as the maximum mass of a stable neutron star. Thus Orosz *et al.* concluded 4U 1543-47 contains a black hole.

C. Bailyn, R. Jain, P. Coppi (Yale), and Orosz examined the distribution of masses of the black holes in seven low-mass X-ray binaries. Using a Bayesian statistical analysis, they suggested that it is probable that six of the seven systems with measured mass functions have black hole masses clustered near 7 $M_\odot$. The remaining system, V404 Cyg, has a mass significantly larger than the others, indicating that it is probably drawn from a different distribution. Bailyn *et al.* suggested that the observed mass distribution might be explained by unknown details of supernova explosions and close binary evolution.

Maeda *et al.* 1998 report the results of three *ASCA* observations of the eclipsing Wolf-Rayet binary V444 Cyg (WN5 + O6). These observations were obtained at orbital phases 0.0, 0.25 and 0.5, with the WN5 star in front at phase 0.0 and the O6 star in front at phase 0.5. Acceptable fits of the X-ray spectra using optically thin plasma models require at least two different temperature components with a soft component at $kT_1 \approx$ 0.6 keV and a harder component at $kT_2 \approx$ 2 keV. The absorption of the hard component varies with orbital phase and is largest when the WN5 star is in front, whereas the X-ray luminosity of the hard component is at a minimum when the O6 star is in front. The high plasma temperature and variability with orbital phase suggest that the hard-component emission is due to a colliding wind shock between the WN5 and O6 stars, with the shock most likely located near the surface of the O6 star. On the other hand, the soft-component emission at $kT_1 \approx$ 0.6 keV has a nearly constant absorption and X-ray luminosity. The soft-component luminosity is $L_{x,1} = (6–11) \times 10^{32}$ ergs s^{-1} (0.2–4 keV), implying $L_{x,1}/L_{bol} \sim 10^{-6}–10^{-7}$. This luminosity ratio and the soft-component temperature are similar to those of single massive stars, leading us to attribute the soft emission to the individual O6 and WN5 components.

3.2.1.5 Galactic Center Maeda collaborating with Sakano, M., Koyama, K., and the ASCA Galactic Plane Survey Team, analyzed ASCA/GIS data from the diffuse X-ray emission around the Galactic Center region of angular size of about 10 degree. From the observed fields, they find diffuse emissions with K-shell transition lines from highly ionized silicon, sulphur, argon, calcium and/or iron. These give firm evidence for the presence of a thin thermal plasma. With the flux distribution of each observed line, they conclude that the diffuse X-ray plasma exhibits lower temperature at larger Galactic latitude than that at smaller latitude.

Maeda collaborating with Murakami, H., Koyama, K., Sakano, M., Nishiuchi, M., & Yamauchi, S., analyzed *ASCA* imaging spectroscopy data of the giant molecular cloud Sgr B2. The X-ray spectrum is found to be very peculiar; it exhibits a strong emission line at 6.4 keV, a low energy cutoff below 4 keV and a pronounced edge-structure at 7.1 keV. The X-ray image is extended and its peak position is shifted to the Galactic center direction by about 1-2 arcminute from the core of the molecular cloud. This morphology, as well as the X-ray spectrum, is well reproduced by a model in which X-rays from a source located at the Galactic center side are scattered by the molecular cloud Sgr B2, and come into our line of sight. Thus Sgr B2 may be called an *X-ray reflection nebula*.

Maeda working with Sakano, M., Koyama, K., Nishiuchi, M., & Yokogawa, J. estimated the column density distribution of X-ray binaries in the Galactic Center region using the X-ray satellite ASCA, and demonstrate a new method of the total mass determination near the Galactic Center. The column densities of these X-ray sources are given by a simple function of the angular distance from the Galactic Plane. Assuming a disk-like mass distribution of 500 pc radius and a distance to the Galactic Center to be 8.5 kpc, they estimate the total mass to be $\sim 4 \times 10^7 M_\odot$. They compare their results with previous results of other wavelength observations, and conclude that the cold interstellar matter is pressure-bounded by the hot gas or strong magnetic field in the Galactic Center region.

3.2.1.6 Pulsars Pavlov, Welty (STScI) and 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 (Kurt, Sokolov, Zharikov, Pavlov, and Komberg) 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, $R_\infty = 10R_{10}$ km is the neutron star radius as seen by a distant observer, and $d = 500d_{500}$ 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.

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.

Maeda and collaborators (Nishiuchi *et al.* 1998) report the ASCA results of the bursting X-ray pulsar GRO J1744 − 28, which was observed in February 1996 and March 1997. The source flux in the 2-10 keV band was 2.0×10^{-8} erg/sec/cm^2 (2-10 keV) in 1996 and 5.0×10^{-9} erg/sec/cm^2 in 1997. They detected 12 and 17 Type II bursts during the two observations, with mean bursting intervals of about 27 min and 37 min. Each burst is followed by an intensity dip with the depleted flux depending on the burst fluence. The energy spectra are approximated by an absorbed power law with additional structure around 6-7 keV. Constant absorption column, $(5 - 6) \times 10^{22}$ cm^{-2}, independent of the observation dates and emission phase (persistent, burst and dip) is interpreted as an interstellar absorption. The source may be actually located near the galactic center, at the distance of 8.5 kpc. The structure in the energy spectrum at 6-7 keV is most probably due to iron and maybe reproduced by the disk line model with additional broadening mechanism.

3.2.2 *Extragalactic Astronomy*

3.2.2.1 Planetary Nebulae R. Ciardullo, J. Feldmeier, and G. Jacoby (NOAO), have continued their large scale [O III] λ 5007 survey for intracluster planetary nebulae (IPN) in the Virgo Cluster. A total of 35 additional IPN candidates were found in three 14’ x 14’ fields. This new data implies that the intracluster stars in the Virgo are distributed non-uniformly, and are correlated on small angular scales ($<$ 10 arcmin). Although the amount of intracluster starlight found in Virgo may be smaller than original estimates, their latest data still suggest that the intracluster stars comprise 20-40% of the stellar mass of the cluster. In the near future, the IPN candidates will be observed spectroscopically with the WIYN telescope, and the Hobby-Eberly Telescope.

R. Ciardullo and G. Jacoby (NOAO) have begun investigating the chemical properties of M31's bulge using spectroscopy of bright planetary nebulae. One surprising result is that the mean oxygen abundance of the bright PN in M31's bulge is similar to that of the LMC, and not super-metal, as might be inferred from integrated absorption line spectroscopy. Possible explanations for this include the presence of a metallicity gradient in M31's bulge, a systematic offset in the oxygen-iron ratio of bulge stars, a selection effect in the PN chosen for study, and the option of an alternative evolutionary path for low-mass, metal rich stars. The detailed nebular analysis of PN in M31 and Magellanic Cloud PN has also revealed the reason for the invariance of the [O III] λ5007 planetary nebula luminosity function with population age. Models of stellar populations predict that young stellar systems should have a PNLF cutoff that is significantly brighter than that of old populations. Observations, however, suggest otherwise. The solution to this problem lies in a PN's circumstellar envelope. There is a steep correlation between the amount of dust surrounding a young PN and the core-mass of the object. The relation implies that PN produced by massive progenitors are extincted much more than those PN derive from low mass stars. This self-extinction is the reason why no super-luminous PN are seen in star-forming galaxies.

3.2.2.2 Distance Scale Ciardullo, Feldmeier, and Jacoby have also continued using the planetary nebulae luminosity function (PNLF) as a distance indicator to nearby galaxies. Their latest observation was of M95, a Hubble Space Telescope Distance Scale Key Project galaxy which is located in the Leo I Group. The PNLF distance to this galaxy, along with that obtained for NGC 2403 and M33, will be compared to distances found through Cepheid variables, to search for any systematic errors between the two distance methods.

3.2.2.3 UV Properties of Galaxies Weedman worked with undergraduate student Jeffrey Wolovitz, Bershady, and Schneider to compare the surface brightnesses of nearby and distant starburst galaxies. Using archival ultraviolet observations of the brightest nearby starbursts, they found that the high redshift galaxies in the Hubble Deep Field show intrinsic ultraviolet surface brightness that is 4 times brighter than the local maxima. This could be the result of either decreased dust absorption or more intense star formation at high redshift.

3.2.2.4 IR Properties of Galaxies Weedman and Wolovitz used archival spectroscopic observations of infrared galaxies from the Infrared Space Observatory to prepare simulations of spectra expected to be observed by SIRTF. Developing a simulation program that uses the various response characteristics of the SIRTF infrared spectrograph between 5 and 40 microns, they show that a luminous galaxy of flux 0.5 mJy could easily have redshift determined up to $z = 3$ if its spectrum resembles that of nearby dusty AGN or starburst.

As part of a review paper, Weedman summarized the overall characteristics of the galaxy Markarian 231 as a prototype for most phenomena observable in ultraluminous infrared galaxies.

3.2.2.5 Dwarf Galaxies and Globular Cluster Formation In June 1998, graduate student Sally Hunsberger completed her thesis entitled ''Dwarf Galaxies and Their Formation: A Study in the Compact Group Environment'' and started her position as a Lowell Observatory postdoctoral fellow. One aspect of this work, also published in the Astrophysical Journal in collaboration with Jane Charlton and Dennis Zaritsky (UCSC/Lick), was a determination of the luminosity function of dwarf galaxies in R–band images of 39 Hickson compact groups (HCGs). This luminosity function exhibits a deficit of intermediate luminosity galaxies when compared to the field luminosity function. This suggests that cannibalism is more efficient in the compact group environment and that there is either a preferential destruction of the more massive companion galaxies, a mechanism which replenishes the dwarf galaxies, or both. The luminosity function differs for groups of various subclasses, with a larger population of dwarfs in groups with tidal tails, groups with X–ray halos, and groups with a dominant elliptical or lenticular galaxy. These group categories represent successive phases of an evolutionary sequence: interaction, merger, and post–merger. This result is consistent with the prediction (from a previous paper of Hunsberger, Charlton, and Zaritsky) that tidal dwarf formation contributes significantly to the dwarf population.

3.2.2.6 Active Galaxies and Quasars Brandt, working with Th. Boller (MPE Garching), A. Comastri (Bologna), A.C. Fabian (IoA Cambridge), K. Iwasawa (IoA Cambridge) and others, has continued his studies of Narrow-Line Seyfert 1 galaxies. These galaxies often have strong and hot soft X-ray excess components, and ROSAT follow-up work has vastly increased the number of ultrasoft Narrow-Line Seyfert 1s known. Many of them show extremely rapid, large-amplitude and nonlinear X-ray variability. They lie toward one extreme of the Boroson & Green (1992) primary eigenvector, suggesting that they have extremal values of a primary physical parameter such as the fraction of the Eddington rate at which the supermassive black hole is accreting.

Brandt has collaborated with A. Comastri (Bologna) and others on analysis of the first broad-band spectrum of the bright Narrow-Line Seyfert 1 galaxy Ton S 180, obtained with the imaging instruments onboard BeppoSAX. This was the first observed source in a sample of a dozen Narrow-Line Seyfert 1 galaxies in the BeppoSAX Core Program. The X-ray spectrum shows a clear hardening above about 2 keV, where a power law with a photon index of 2.3 plus an iron line provide a good description of the data. This slope is significantly steeper than the typical one for classical Seyfert 1s and quasars. The best fit line energy is suggestive of highly ionized iron, which supports the idea that high accretion rate is the fundamental parameter characterizing the Narrow-Line Seyfert 1 phenomenon.

Brandt has also worked with K. Iwasawa (IoA Cambridge) and A.C. Fabian (IoA Cambridge) to perform spectral analysis of ASCA data for the Narrow-Line Seyfert 1 Mrk 507. This galaxy was found to have an exceptionally flat ROSAT spectrum among the Narrow-Line Seyfert 1s. The ASCA spectrum, however, shows clear absorption in the energy band below 2 keV, which largely accounts for the flat spectrum observed with the ROSAT PSPC. The absorption is mainly due to cold gas with a column density of about 2.5 $\times\ 10^{21}\ cm^{-2}$. A reanalysis of the PSPC data suggests that the absorber is slightly ionized and covers only part of the central source.

Brandt has also continued collaboration with A.C. Fabian (IoA Cambridge) and others on studies of the X-ray luminous quasar GB 1428+4217 at redshift 4.72. ASCA data for this object allow a study of its intrinsic 4–57 keV X-ray spectrum and show this spectrum to be very flat (with a photon index of 1.29). The overall spectral energy distribution of GB 1428+4217 is similar to that of lower redshift MeV blazars, and it appears likely that the Doppler beaming factor is at least 8. There may be a substantial number of high redshift blazars which must contain rapidly-formed massive black holes.

Data from the ASCA X-ray satellite have recently been used by J.J. Feldmeier (Penn State), Brandt, M. Elvis (Harvard CfA), A.C. Fabian (Cambridge IoA), K. Iwasawa (Cambridge IoA) and S. Mathur (Harvard CfA) to perform the first detailed X-ray study of Markarian 6, a bright Seyfert 1.5 galaxy with complex and variable permitted lines, an ionization cone, and remarkable radio structures. The 0.6-9.5 keV ASCA spectra penetrate to the black hole core of this Seyfert and reveal heavy and complex intrinsic X-ray absorption. Both total covering and single partial covering models fail to acceptably fit the observed absorption, and double partial covering or partial covering plus warm absorption appears to be required. The double partial covering model provides the best statistical fit to the data, and ASCA measures large column densities of $(3\ -\ 20)\ \times\ 10^{22}\ cm^{-2}$ irrespective of the particular spectral model under consideration. These X-ray columns are over an order of magnitude larger than expected based on observations at longer wavelengths. Their data suggest that most of the X-ray absorption occurs either in gas that has a relatively small amount of dust or in gas that is located within the Broad Line Region. The X-ray absorber may well be the putative 'atmosphere' above the torus that collimates the ionization cone, and free-free absorption in this atmosphere could help to explain the decapitated radio jet. A broad 6.4 keV iron K-alpha line also appears to be present, and optical spectra show that the optical emission lines of Markarian 6 were in a representative state during their ASCA observation.

Brandt has worked with K. Iwasawa (Cambridge IoA), A.C. Fabian (Cambridge IoA) and others to study an apparent 58 ks (16 hr) periodicity in the 0.5–10 keV X-ray light curve of the Seyfert galaxy IRAS 18325-5926 (Fairall 49). In a 5-day ASCA observation nearly 9 cycles of the periodic variation are seen. It shows no strong energy dependence and has an amplitude of about 15 per cent. Unlike most other well-studied Seyfert galaxies, there is no evidence for strong power-law red noise in the X-ray power spectrum of IRAS 18325-5926. Scaling from the QPOs found in Galactic black hole candidates suggests that the mass of the black hole in IRAS 18325-5926 is (6-40) million solar masses.

S. Gallagher (Penn State), Brandt and R. Sambruna (Penn State) have started a systematic ASCA study of the optically brightest Broad Absorption Line Quasi-Stellar Objects (BALQSOs). Data from ASCA are excellent for this project due to the high sensitivity of ASCA in the 2–10 keV band, and they reveal that the X-ray column densities of most BALQSOs are extremely large (provided the intrinsic X-ray properties of BALQSOs are similar to those of QSOs without BALs). The ASCA data raise the current lower limits on BALQSO column densities by about a factor of 10, and it is now clear that optical brightness is not a good predictor of X-ray brightness for BALQSOs. The currently available data empirically suggest that high optical continuum polarization may be associated with X-ray brightness for BALQSOs.

P. De Naray (Penn State) and Brandt have worked on a detailed ROSAT and ASCA study of the nearby barred spiral galaxy NGC 1672. This galaxy is thought to have a weak Seyfert nucleus in addition to its strong starburst activity. Brandt's earlier work with ROSAT showed that three X-ray sources with luminosities of $(1\text{–}2)\times\ 10^{40}\ erg\ s^{-1}$ are clearly identified with NGC 1672. The strongest X-ray source lies at the nucleus, and the other two lie near the ends of the prominent bar, locations that are also bright in Hα and near-infrared images. New ROSAT data reveal significant variability of one of the sources at the ends of the bar, suggesting that it is a highly luminous 'super-Eddington' X-ray binary. ASCA data do not show the high-energy power law emission expected from a Seyfert nucleus, and this result suggests that there may not be Seyfert activity in the center of NGC 1672 at present. Alternatively, the line of sight into the nuclear regions may be blocked by a column density that is large enough to be optically thick to Compton scattering.

Chartas has initiated a systematic study of all gravitationally lensed quasars detected in X-rays. The large magnification factors of gravitationally lens systems allows the investigation of quasar properties with X-ray luminosities that are substantially lower than those of unlensed ones. The large magnification factors also allows the study of the contribution of faint quasars to the X-ray background. Preliminary results indicate that the average spectral indices of his sample are not harder than those of bright unlensed quasars suggesting that faint quasars do not contribute significantly to the X-ray background. His preliminary results also indicate a flattening of the spectral index above 4keV (rest frame) for 2 radio loud quasars in his sample for which he has high signal to noise data.

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 strips of sky that are about 9 arc-minutes wide. In the past year they have published the catalog of objects from the Palomar Scan Grism Survey (PSGS). The PSGS covered slightly more than 1 sq deg and used slitless spectroscopy (using a grism) to identify the Lyman-alpha emission line in quasars down to approximately mag 22. The catalog contains

96 emission-line objects; the majority being compact emission-line galaxies at redshifts of a few tenths. Lyman α lines were detected in the grism data for nine objects; one has a redshift larger than four. A preliminary analysis of the PSGS results indicates that the luminosity function of $z > 3$ quasars significantly flattens as one moves to lower luminosities.

Schneider, Schmidt, and Gunn, together with Guenther Hasinger (Potsdam Observatory) and several collaborators, have identified the most distant X-ray selected object. The team has been using the Keck telescope to provide optical identifications of X-ray sources found in the ROSAT Deep Survey (RDS). The source positions in the RDS have accuracies on the order of one arc-second, with allows unambiguous identifications even a faint optical magnitudes. One of the RDS sources coincided with a 23rd magnitude optical object; Keck spectroscopy revealed that the source was a $z = 4.45$ quasar.

Rita Sambruna, in collaboration with M. Eracleous (PSU) and R.Mushotzky (GSFC), started a project involving archival and proprietary ASCA data for a large sample (34 sources) of radio-loud AGN. Among the many goals of the project is a systematic comparison of the spectral properties of radio-loud AGN to their radio-quiet counterparts, Seyfert galaxies, in order to gain insights on the origin of the radio-loud/radio-quiet AGN dichotomy. Preliminary results were presented as a poster paper at the High Energy Astrophysics Division in Estes Park, Colorado, in 1997 November. A first paper, reporting the unusual properties of the Broad Line Radio Galaxy 3C 445, was published by Sambruna *et al.* (1998).

Usher continues work on the US Survey for faint blue objects, and is presently engaged in studying the properties of the nearby quasar component with redshifts $z < 2.2$.

3.2.2.7 BL Lacertae objects and Blazars Feigelson, former Penn State scientists Ron Kollgaard and Marg Chester, former graduate student Sally Laurent-Muehleisen and German colleagues completed two aspects of an on-going investigation of radio-loud active galaxies in the ROSAT All-Sky Survey (RASS). First, a major portion of Laurent-Muehleisen's thesis work leading to a new large sample of BL Lac objects was published based on Very Large Array identifications and optical spectroscopy of a well-defined sample of RASS sources. The new BL Lacs show that the previously reported distinctions between radio- and X-ray-selected objects was largely due to selection effects. Second, a RASS-VLA study of the deep exposure around the North Ecliptic Pole revealed a number of new radio-loud AGNs, including several likely radio galaxies in poor clusters.

Rita Sambruna continued her research on multifrequency properties of blazars, with particular emphasis on their high-energy emission. Together with R.Mushotzky (GSFC), studying an archival ASCA spectrum of the X-ray bright BL Lac PKS 0548−322, she discovered the presence of ionized absorption in this source (Sambruna & Mushotzky 1998). An absorption feature was detected around 0.7 keV, modeled either with an absorption edge at a rest-frame energy 0.66 keV with an optical depth of $\tau \sim 0.3$, consistent with the K edge of OVI, or with an absorption line at rest-frame energy 0.82 keV with width 0.1 keV and covering fraction 0.1, consistent with absorption by highly ionized Fe (Fe IX-XX) or NeVII. This is the third BL Lac where high-energy absorption is discovered, reinforcing the notion that ionized absorption is common in this class of AGN previously thought to be ''featureless.'' According to current models, the most likely interpretation is absorption by a clumpy wind coming from the inner regions of the sources, perhaps clouds of ionized gas uplifted from the surface of the accretion disk by the magnetic field; high-resolution observations in soft X-rays are necessary to probe adequately the various models.

Together with G.Ghisellini (Oss. Merate, Italy), E.Hooper (CfA), R.I.Kollgaard (Fermi Lab), J.E.Pesce (PSU), and C.M.Urry (STScI), Sambruna observed with ASCA and other ground-based telescopes (operating at radio, optical/IR, and TeV frequencies) the two ''red'' BL Lacs 1749+096 and 2200+420 (BL Lac), with the goal to measure their hard X-ray continua for the first time and to study their multifrequency continuum emission (Sambruna *et al.* 1999). Red BL Lacs are characterized by a peak of their radio through X-ray synchrotron emission around IR/optical frequencies; one fundamental question is the origin of their high-energy emission, which includes a substantial fraction of their total energy budget. The authors found that the ASCA spectra of both sources can be approximated as a zero order with a power law of photon index $\Gamma \approx 2$; further spectral complexity is present, with 2200+420 exhibiting a hard tail above 2 keV (interpreted as the onset of the Compton component responsible for the emission at GeV energies) and 1749+096 possibly showing spectral flattening at low energies. The spectra from radio through γ-rays were shown to be consistent with synchrotron-self Compton emission from the relativistic jet, by explicitly fitting the data with detailed jet models. For 2200+420, comparing the spectrum to a later spectrum obtained during a γ-ray flare, the authors were able to reproduce the outburst at GeV energies with a model requiring inverse Compton scattering of photons external to the jet; interestingly, a simultaneous and similar increase of the external radiation density and the power injected in the jet is required, thus providing evidence that the jet power and the radiation ionizing the Broad Line Regions in BL Lacs are linked together. The model supports the current claim, based on independent evidence, that external Compton scattering is the dominant cooling mechanisms in blazars with strong optical emission lines.

E.Pian (TESRE, Bologna, Italy), R.Sambruna, and others, observed the blue BL Lac Mrk 501 in the X-rays with SAX in 1997 April, during a period of intense TeV flaring (Mrk 501 in one of only three extragalactic AGN reliably detected at TeV energies all the time). It was discovered that the X-ray spectrum of Mrk 501 was unusually hard, extending up to 200 keV and implying a shift of the synchrotron peak by 2–3 orders of magnitudes with respect to the normal ''quiescent'' state. This unprecedented (in this and any other blazar) spectral behavior was interpreted as a result of a large acceleration event occurring in the jet of Mrk 501 (Pian *et al.* 1998). Two new campaigns with RXTE, ASCA, EUVE and ground-based TeV and optical telescopes (PI: Sambruna) were performed during 1998 June and July; preliminary results indicate that the source faded at both X-rays and TeV, but maintaining a still high (around 20 keV) synchrotron peak.

R.Sambruna, C.M.Urry (STScI), and others have studied with RXTE the X-ray variability of the bright BL Lac object PKS 2155−304. The RXTE observations, spanning a period of ~ 2 weeks with intensive daily sampling, show complex flux variations, with short flares superposed on a longer trend. The shape of the flares is energy-dependent, in the sense that the flares become more and more symmetric at increasing energies, with larger variability amplitudes. This behavior is consistent with a model where X-rays are emitted through synchrotron, with the synchrotron losses of the injected electrons being faster than the injection time, and the light travel time effects becoming more and more important at the higher energies. The results were presented in Urry *et al.* (1997) at the first SAX/RXTE symposium in Rome, Italy, 1997 October, by Sambruna (1998) during her invited review talk at the RXTE topical session of the 192nd AAS meeting in San Diego, CA, in 1998 June, and by Sambruna (1999) during her invited review talk at the 194th IAU Symp. on AGN in Byurakan, Armenia, in 1998 August.

E.Perlman (STScI), P.Padovani (STScI), P.Giommi (CNR, Roma, Italy), R.Sambruna, and others, have undertaken a survey of archived, pointed ROSAT PSPC observations of blazars by correlating the ROSAT WGACAT database with several publicly available radio catalogs. A first paper, describing the selection criteria, data analysis, and the identification procedure, has been published (Perlman *et al.* 1998). It is shown that the survey is very efficient (~ 95%) at finding new blazars, both BL Lacs and Flat Spectrum Radio Quasars (FSRQs). One intriguing result is the discovery of a new subclass of FSRQs showing radio-to-X-ray colors similar to blue BL Lacs – this is totally unexpected in the context of current unification schemes for blazars. New ASCA AO6 (PI: Sambruna) observations of three blue FSRQs were acquired in order to study for the first time their hard X-ray spectra and compare it to blue BL Lacs. Data analysis is underway.

3.2.2.8 QSO Absorption Lines A view of galaxy evolution over all epochs is provided by the synthesis of observations in the ultra−violet (Hubble Space Telescope, first from FOS and now also STIS), the optical (first from HIRES/Keck and soon also from the Hobby Eberly Telescope (HET)), and the near−IR (soon from JCAM/HET and the near−IR beam of the MRS/HET). The gaseous components and surroundings of galaxies are as important as the stars for constructing a comprehensive view of galaxy formation and evolution. Absorption lines of different chemical and ionization species are produced in quasar spectra by these gaseous components from redshifts 5 to 0. The Penn State Quasar Absorption Line Group, led by Jane Charlton and Chris Churchill, is pursuing a multi−wavelength study of the formation, kinematic, and chemical evolution of gas in galaxies and connecting this picture to galaxies. Graduate students Rajib Ganguly and Suzanne Linder were key players in the group effort during the past year, and undergraduate students Karen Knierman, Rick Mellon, and Jane Rigby also made significant contributions. Penn State colleagues James Beatty, Michael Eracleous, Larry Ramsey, and Donald Schneider participate as collaborators in various aspects of this research effort. Work in this field is a synthesis of new and archival observations with modeling and theoretical considerations (primarily theoretical projects are listed in section 3.3.2, Theoretical Cosmology, below.)

Ganguly, Churchill, and Charlton studied the $z = 1.94$ C IV absorption line system in the spectrum of quasar Q1222 + 228. They found, through photoionization modeling, that two clouds at only a 17 km/s velocity separation have contrasting physical conditions. In the first cloud the abundance pattern resembles that of Galactic metal−poor halo stars, with Silicon enhanced and Aluminum depressed relative to solar. The second cloud has Al/Si larger than the solar abundance pattern, which is quite unusual and not characteristic of Milky Way gas. This demonstration of contrasting conditions in the same galaxy illustrates the promise of using a large sample of high resolution quasar absorption line spectra to statistically study the evolution of the dynamical ISM and gaseous halos of galaxies.

Churchill and Charlton used HIRES/Keck profiles ($R = 6$ km/s) of Mg II and Fe II in combination with FOS/HST spectra ($R = 230$ km/s) to place constraints on the physical conditions (metallicities, ionization conditions, and multiphase distribution) of absorbing gas in three galaxies at $z \sim 1$ along the line of sight to PG 1206 + 459. The multiple MgII clouds exhibit complex kinematics and the C IV, N V and O VI are exceptionally strong in absorption, far too strong to be consistent with the ionization conditions inferred for the clouds that give rise to the Mg II. In all three systems, an additional diffuse, high ionization phase is required, consistent with Galactic−like coronae surrounding the individual galaxies, as opposed to a very extended common ''halo'' encompassing all three galaxies.

Churchill, Charlton, Rigby, and Vogt (UCSC/Lick) searched for very weak Mg II absorbers in 26 HIRES/Keck QSO spectra over $0.4 < z < 1.4$. They found 30 systems which implies that weak Mg II absorbers are more than 1.5 times more abundant than those that are known to be associated with both galaxies and Lyman limit systems (LLS). This suggests that the majority of Mg II absorbers arise in sub−LLS environments. It is also found that the weak absorbers have $[Fe/H] > -1$. It is likely that some fraction of these systems arise in the so−called low surface brightness galaxies, which are more numerous than ''normal galaxies'' by a factor of two to three. If so, this would have broad implications for charting the stellar and galactic evolution around matter that cannot otherwise be charted by its luminous properties. The next step in the ongoing effort to understand the nature of these systems is to use the Mg II and Fe II in conjunction with Lyα and C IV observed in FOS/HST spectra to infer their ionization state and single vs. multiphase properties.

Churchill and Le Brun (LAS du CNRS) searched for Mg II associated with the Lyα forest clouds along the PKS 0454 + 039 line of sight. This led to a more detailed study of two of the more extreme weak Mg II absorbers. Using photoionization models, they inferred that the cloud metallicities are near−supersolar to supersolar, depending upon the assumed abundance pattern and dust depletion. Images of the QSO field and spectroscopic follow–up (by Steidel (Caltech) and collaborators) reveal no luminous candidates at the absorber redshifts. They tentatively suggest that the absorption could be arising in low surface brightness galaxies. The nature of the weak Mg II absorption systems and in particular their connection with the galaxy populations at various epochs will be a focus of the group's future efforts.

3.2.2.9 Variation of the Fine Structure Constant? An unusual application of quasar absorption line studies was implemented by Chris Churchill in collaboration with Webb, Flambaum, and Drinkwater (UNSW), and with Barrow (Sussex). They developed a method that yielded an order of magnitude sensitivity gain to investigate possible time or space variation in the fine structure constant, $\alpha\ (= e^2/hc)$. They applied the technique to a sample of 30 absorption systems spanning redshifts $0.5 < z < 1.6$ obtained with the HIRES spectrograph on the Keck I telescope and found that α was smaller at earlier epochs; for the whole sample the fractional change was $-1.5 \pm 0.3 \times 10^{-5}$. This deviation is dominated by measurements at $z > 1$. The investigators have not yet completely ruled out either a systematic error in the data, or some different physical explanation; however, they could not reliably identify any such mechanism after extensive investigations. The results are best interpreted as highly *suggestive* evidence for a time evolution in α.

3.2.2.10 Observational Cosmology Chartas continued research on constraining the Hubble parameter through X-ray observations of the lens galaxy cluster of the gravitational lens (GL) system Q0957+561. Combining several ROSAT HRI pointed observations of Q0957+561 he was able to make a 3σ detection of the lens cluster. Incorporating the observed mass of the cluster lens into a GL model for this system he provides an estimate for the Hubble constant. The current observations can only provide limited information, however future prospects are promising with the scheduled 1999 high-resolution X-ray observations of Q0957+561 with the AXAF satellite.

3.3 Theoretical Studies

3.3.1 *Theoretical Astrophysics*

3.3.1.1 Physics of Gamma-Ray Bursts Graduate student Panaitescu & Mészáros (1997a) simulated the radiation from external shock in gamma-ray bursts, calculating burst spectra and time structures arising from synchrotron and inverse Compton scattering. They investigated the effect of varying the various parameters and presented a set of correlations among the spectral and temporal features of the bursts. Multi-pulse structures were simulated using a variable magnetic field and anisotropic emission, showing that at most several subpulses can be thus generated. Another investigation (Panaitescu & Mészáros, 1997b) concerned the dynamical effects on the evolution and spectrum of GRBs from external shocks in impulsive and wind models when one includes a weak or a strong coupling between electrons and protons plus magnetic fields, and analyzed the burst features in each scenario. The spectra are generally harder in the strong coupling regime, and the various correlations were quantified in each case.

Panaitescu and Mészáros (1998d) carried out numerical simulations of the dynamics of internal shocks in GRB, using a 1-dimensional hydrodynamic code, and calculated spectra and light-curves arising from such collisions by integrating the synchrotron and inverse Compton emission of the shocked gas. The numerical results reflect the most important features observed in Gamma-Ray Bursts: the spectrum exhibits a progressive softening (its break energy decaying exponentially with the 50–300 keV photon fluence), and the pulses that form the burst appear narrower in higher energy bands. Analytical results for the most important physical parameters of the burst were obtained by solving the shock jump conditions for a pair of interacting shells, in the case when both the forward and reverse shocks are relativistic.

Mészáros & Rees (1998a) calculated the expected atomic edges and lines from ions in the internal shocks of GRB. Gamma ray burst outflows may entrain small blobs or filaments of dense, highly ionized metal rich material. Such inhomogeneities, accelerated by the flow to Lorentz factors in the range 10-100, could have a significant coverage factor, and give rise to broad features, especially due to Fe K-edges, which influence the spectrum below the MeV range, leading to a progressively decreasing hardness ratio.

Mészáros, Rees & Wijers (1998b) considered the energetics and beaming of gamma-ray burst triggers for a wide range of mechanisms proposed to supply the energy of GRB. The common misconception that some of these, notably NS-NS mergers, cannot meet the energy requirements is here dispelled. It is shown that GRB energies, even at the most distant redshifts, are compatible with current binary merger or collapse scenarios involving compact objects. This is especially so if, as expected, there is a moderate amount of beaming, since current observations constrain the energy per solid angle much more strongly and directly than the total energy. All plausible progenitors, ranging from NS-NS mergers to various hypernova-like scenarios, eventually lead to the formation of a black hole with a debris torus around it, so that the extractable energy is of the same order, 10^{54} ergs, in all cases. MHD conversion of gravitational into kinetic and radiation energy can significantly increase the probability of observing large photon fluxes, although significant collimation may achieve the same effect with neutrino annihilation in short bursts. The lifetime of the debris torus is dictated by a variety of physical processes, such as viscous accretion and various instabilities; these mechanisms dominate at different stages in the evolution of the torus and provide for a range of gamma-ray burst lifetimes

3.3.1.2 Gamma-Ray Burst Afterglows Panaitescu and Mészáros (1997b) calculated the radiative efficiency and the effects on the dynamics of the afterglow evolution of a strong or weak coupling between electrons and protons. The dynamics of the ejecta and external medium were followed into the late stages of deceleration, in order to study the hydrodynamics of the remnant and the temporal and spectral evolution of the afterglow. A comparison with the optical and radio afterglows of GRB 970228 and GRB 970508 indicates that the real situation is intermediate between these two extremes.

Panaitescu & Mészáros (1998a) derived the equation for the surface of equal arrival time of radiation from a thin relativistic shell interacting with an external medium, representing the afterglow of a gamma-ray burst produced by a fireball. Due to the deceleration, these surfaces become distorted ellipsoids and, at late times, most of the light comes from a ring-like region whose width depends only on age. They analyzed the shape of these surfaces for different dynamic and radiative regimes and homogeneous or power-law external densities. They tabulated the most relevant parameters describing the surfaces and the source brightness distribution, both for bolometric and fixed frequency observations, which are useful for more accurate analytic estimates of the afterglow evolution.

Rees & Mészáros (1998) proposed a model of ‘‘refreshed shocks’’ for afterglows. They consider fireball models where the ejecta have a range of bulk Lorentz factors, so that the inner (lower Γ) parts may carry most of the mass, or even most of the energy. The outer shock and contact discontinuity decelerate as the fireball sweeps up external matter. This deceleration allows slower ejecta to catch up, replenishing and reenergizing the reverse shock and boosting the momentum in the blast wave. In consequence, the energy available to power the afterglow may substantially exceed that of the burst itself. Such models allow a wide range of possibilities for the afterglow evolution, even in the case of spherically symmetric expansion.

Panaitescu, Mészáros & Rees (1998) calculated the multiwavelength afterglows in GRBs with refreshed shock and directional ejection effects. They presented a set of differential equations for calculating the evolution in a simplified analytical manner, and studied of the relevant parameters on the X-ray, optical and radio fluxes and the shape of the corresponding light-curves. The numerical results are compared to observed afterglows and give a quantitative description of the conditions (geometry and physical parameters) in the ejecta that are compatible with the light-curves of the 970508 afterglow, for which a large number of accurate flux measurements are available. They find that the radio, optical and X-ray light-curves of this afterglow can be explained satisfactorily within the spherically symmetric fireball model, assuming a delayed energy injection, or by an axially symmetric jet surrounded by a less energetic outflow.

Panaitescu & Mészáros (1998c) computed the evolution of spherical and conical GRB remnants by means of an analytical approach. This method leads to numerical calculations of fireball dynamics that are computationally simpler than hydrodynamic simulations. It is also a very flexible approach, that can be easily extended to include more complex situations, such as a continuous injection of energy at the reverse shock, and the sideways expansion in non-spherical ejecta. Numerical results for the dynamic evolution are discussed and compared to the analytical solutions. The light curves computed from beamed ejecta show that, due to the increased swept up matter and the time delay of the large angle emission, the sideways expansion of the remnant gas does not lead to a dimming of the afterglow, and mitigates the subsequent downturn from the transition into the non-relativistic regime.

Mészáros, Rees & Wijers (1998a) investigated the viewing angle and environment effects in GRB as a source of afterglow diversity. They discuss 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. Mészáros & Rees (1998b) discussed the formation of spectral features in the decelerating ejecta of gamma-ray bursts, including the possible effect of inhomogeneities. These should lead to blueshifted and broadened absorption edges and resonant features, especially from H and He. An external neutral ISM could produce detectable H and He, as well as Fe X-ray absorption edges and lines. Hypernova scenarios may be diagnosed by Fe K-α and H Ly-α

3.3.1.3 Cosmic Rays and Ultra-high Energy Radiation Rachen and Mészáros (1997) investigated critically the hypothesis that protons accelerated at internal shocks in GRB could be the origin of the observed 10^{20} eV cosmic rays. They find that, even though protons can be accelerated to such energies, their ejection into the ISM may lead to onerous adiabatic losses. This problem can be circumvented by neutrons produced in photohadronic interactions, which can escape unhindered. They can both be produced and escape in appreciable numbers if the photohadronic opacity is of order unity. This requirement can be fulfilled under the same condition which allows protons to reach the highest energies required. The corresponding correlation of 10^{20} eV protons and ultra-high energy neutrinos makes this a testable hypothesis.

Biermann, Kang, Rachen and Ryu (1997) investigated the cosmic structure of magnetic fields by means of cosmological large-scale structure formation simulations. Thes numerical simulations, combined with observations of rotation measures to distant radio sources give upper limits of 0.2 to 2 μGauss along the filaments and sheets that form in CDM simulations. High energy cosmic rays could be focused or strongly scattered by such fields.

Mücke, Rachen, Engel, Protheroe & Stanev (1998) developed a flexible and general numerical code to calculate photohadronic cascades for charged particles with arbitrary momentum distributions in an arbitrary radiation field. This has been tested for ultra-high energy cosmic rays in the microwave background, the main prospective use being for future applications to blazar and gamma-ray burst source models.

Rachen & Mészáros (1998) investigated the production of ultra-high energy photohadronic neutrinos ($10^{14} - 10^{18}$ eV) from transients in astrophysical sources whose physical properties are constrained by their variability, in particular jets in Active Galactic Nuclei (blazars) and Gamma-Ray Bursts (GRB). They discuss the various competing cooling processes for energetic protons, as well as the cooling of pions and muons in the hadronic cascade, which impose limits on both the efficiency of neutrino production and the maximum neutrino energy. If the proton acceleration process is of the Fermi type, they derive a model independent upper limit on the neutrino energy from the observed properties of any cosmic transient, which depends only on the assumed total energy of the transient. For standard energetic constraints, this can rule out major contributions above 10^{19} eV from current models of both blazars and GRBs; and in most models much stronger limits apply in order to produce measurable neutrino fluxes. For GRBs, they show that the cooling of pions and muons in the hadronic cascade imposes the strongest limit on the neutrino energy, leading to cutoff energies of the electron and muon neutrino spectrum at the source differing by about one order of magnitude. They also discuss the relation of maximum cosmic ray energies to maximum neutrino energies and fluxes in GRBs, and find that the production of both the highest energy cosmic rays and observable neutrino fluxes can only be realized under extreme conditions; a test implication of this joint scenario would be the existence of strong fluxes of muon neutrinos up to energies $\sim 10^{18}$ eV. Secondary particle cooling also leads to slightly revised estimates for the neutrino fluxes from (non-transient) AGN cores, which are commonly used in estimates for VHE detector event rates. Since this approach is quite general they conclude that the detection or non-detection of neutrinos above $\sim 10^{19}$ eV, eg with the Pierre Auger Observatory, correlated with blazar or GRB transients, would provide strong evidence against or in favor of current models for cosmic ray acceleration and neutrino production in these sources.

3.3.1.4 Radiation Processes in Compact Objects Zavlin (MPE, Germany), Pavlov and Trümper (MPE, Germany) analyzed X-ray data collected with the *ROSAT* and *ASCA* missions from a radio-silent isolated neutron star in the supernova remnant PKS 1209–52. They fitted the observed spectra with neutron star atmosphere models and showed that hydrogen atmosphere fits result in more realistic parameters of the neutron star than the traditional blackbody fit. In particular, they obtained a neutron star surface temperature $T_{\rm eff} = (1.4 - 1.9) \times 10^6$ K, consistent with standard cooling models.

Bezchastnov (Ioffe Institute for Physics and Technology, Russia) Pavlov and Ventura (University of Crete, Greece) 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. Similarly 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.

3.3.1.5 Globular Cluster Evolution R. Bartlett and R. Ciardullo 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 globular clusters over a Hubble time, due to destructive dynamical effects; included in the analysis is internal relaxation of a cluster resulting in the evaporation of stars, and repeated dynamical shocking caused by a cluster's orbital passages through the disk or close to the bulge of the parent galaxy. Early results have indicated that these gravitational processes are effective in selectively destroying low-mass clusters, but they are not sufficient to erode a cluster population from an ''initial'' state with a power-law luminosity function (as observed in the young compact clusters in the Antennae galaxies) to a ''final'' state with a log-Gaussian form (as observed in the Milky Way, M31, and several Virgo ellipticals). Since a system of clusters should be descended from a population of gaseous clouds, this project is now evaluating the effects of environment of cluster formation (i.e., within a forming galaxy or a merger event, for example) and the likelihood of survival of very young clusters against disruption by star formation, and against unbinding due to mass-loss from evolving stars.

3.3.1.6 Cosmology and Statistics of Gamma Ray Bursts Sources Bagoly, Mészáros, Horváth, Balázs & Mészáros (1998) carried out a principal component analysis for 625 gamma-ray bursts in the BATSE 3B catalog for which non-zero values exist for the nine measured variables. This shows 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. Thus a separate consideration of the fourth channel, and increased attention on the related hardness ratio $H43$ appears useful for future studies. The analysis gives the weights for the individual measurements needed to define a single duration, peak flux and fluence. It also shows that, in logarithmic variables, the hardness ratio $H32$ is significantly correlated with peak flux, while $H43$ is significantly anticorrelated with peak flux. The principal component analysis provides a potentially useful tool for estimating the improvement in information content to be achieved by considering alternative variables or performing various corrections on available measurements.

Horváth (1998) has analyzed the BATSE 3B bursts catalog and identified a third class of GRB. This confirms a separate and different analysis by Mukerjee, Feigelson and Babu (1998), using different methods. Two classes of Gamma Ray Bursts had been identified previously, characterized by T_{90} durations shorter and longer than approximately 2 seconds. Here it is shown that the BATSE 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 %.

Feigelson, working with several statistician colleagues at Penn State and elsewhere, completed a multivariate analysis of the 3rd BATSE catalog of gamma-ray bursts (GRBs). The purpose is to elucidate the types of GRBs and determine any relationships between their bulk properties: location, fluence, hardness and duration. Their study is based on both standard nonparametric methods (hierarchical agglomerative clustering validated with MANOVA tests) and state-of-the-art model-based (maximum-likelihood clustering validated with the Bayesian Information Criterion) techniques treating all variables simultaneously. They establish that a third class of GRBs is present in the database, in addition to the well-known short-hard and long-soft burst classes. No significant relationships between the variables are found within any class.

3.3.2 *Cosmology*

3.3.2.1 QSO Absorption Lines Graduate student, S. Linder, has determined that it is plausible that the extended HI disks of the existing population of giant, dwarf and low surface brightness galaxies can explain all Lyα absorption at low redshift. The dwarf and low surface galaxies could make a dominant contribution to absorption, but they may often be overlooked as absorber candidates in favor of more easily identified high surface brightness galaxies. These conclusions rely on a series of Monte–Carlo simulations with parameters tuned to the properties of the observed galaxy populations and to the Lyα forest observed by HST. Recent work includes incorporation of galaxy clustering and of observational selection effects into the theoretical models.

Jane Charlton and Chris Churchill constructed models of the low ionization absorbing gas in galaxies at intermediate redshifts and examined their absorption properties as seen in the high resolution spectra (HIRES/Keck) of background QSOs. They found that neither a single population of spiral disks or pure halo infall kinematics can account for the range of observed absorber properties. Either two population models or a single population of galaxies that have absorption contributions from gas in both their disks and their halos are consistent with the data. Perhaps this is not surprising in view of the multiple gaseous phases of galaxies in the Local Universe. In the future, the richness of kinematic structure in high resolution profiles of many different chemical species will be exploited in an evolutionary study of galaxies over the full range of cosmic time.

3.3.3 *History of Astronomy*

Usher continues to study the incidence of astronomical allusions in Shakespeare's plays and their relevance to the history of astronomy. The Bard's apparent lack of awareness of the Copernican hypothesis is noted in an article that has appeared in *Giornale di Astronomia* (Usher 1998a). ''Hamlet's Transformation'' is the topic of a paper delivered to the History of Astronomy Division at the Washington meeting of the AAS (Usher 1997a). The word ''transformation'' was coined by the English astronomer Thomas Digges from whose works it made its way into ''Hamlet.'' Among other conclusions Usher posits that Shakespeare eschewed Book Four of Saxo Grammaticus because to have continued the tale of Amleth's misadventures would have led him away from the allegorical fit which underlies the present interpretation of the play. The general structure of this allegory has been presented (Usher 1997b).

3.3.4 *Computational Astrophysics*

3.3.4.1 Tidal Distortions of Globular Clusters One of the external fields that influences the population of globular clusters is that due to galactic bulges. In extreme situations, perigalactic distances $r_p \leqslant 100$ pc, globular clusters could suffer total disruption in a single passage. A more common scenario is that for cluster orbits with $r_p \geqslant 200$ pc. Holly Nordquist and Robert Klinger (Penn State undergraduates), with Jane Charlton and Pablo Laguna, investigated the effects of tidal forces from a bulge on the shape of globular clusters for this type of encounters. They found distortions characterized by ''twisting isophotes'' and consider the potential for observability of this effect. In the Milky Way, a typical globular cluster must pass within several hundred pc of the center to experience substantial distortion, and it is possible that this has happened recently to one or two present day clusters. This distortion could be observed even for globulars in dense fields toward the bulge. In more extreme environments such as giant ellipticals or merger products with newly formed globulars, this effect could be more common, extending out to orbits that pass within 1 kpc of the bulge center. This would lead to a substantial shift in the eccentricity distribution of globulars in those galaxies.

3.3.4.2 Black Holes The following work by Laguna was carried out as part of the the Binary Black Hole Grand Challenge Alliance. Accurate three-dimensional numerical simulations of generic single-black-hole spacetimes have been achieved by characteristic evolution with unlimited long term stability. The simulations include distorted, moving, and spinning single black holes, with evolution times up to 60 000M. Binary black-hole interactions provide potentially the strongest source of gravitational radiation for detectors currently under development. The Alliance has developed a three-dimensional Cauchy evolution code to simulate those astrophysical events. These constitute essential steps towards modeling such interactions and predicting gravitational radiation waveforms. The Alliance has been able to carry out simulations of a black hole moving freely through a three-dimensional computational grid via a Cauchy evolution: a hole moving near 6M at 0.1c during a total evolution of duration near 60M . The Alliance also developed a method for extracting gravitational radiation from a three-dimensional numerical relativity simulation and, using the extracted data, to provide outer boundary conditions. The method treats dynamical gravitational variables as non-spherical perturbations of Schwarzschild geometry.

Laguna and collaborators Nils Andersson (Southampton, UK) and Philippos Papadopoulos (Potsdam, Germany) analyzed the amplification due to so-called superradiance from the scattering of pulses off rotating black holes as a numerical time evolution problem. They considered the case of scalar field pulses for which superradiance effects yield amplifications $< 1\%$. They showed that this small effect can be isolated by numerically evolving quasi-monochromatic, modulated pulses with a recently developed Teukolsky code. Their results showed that it is possible to study superradiance in the time domain, but only if the initial data is carefully tuned. This work illustrates the intrinsic difficulties of detecting superradiance in more general evolution scenarios.

3.3.5 Atomic Physics

Sampson and collaborators have continued their work on fully relativistic calculations of atomic properties of highly charged ions. In the current year the generalized Breit interaction between bound and free electrons was included in their code for cross sections for excitation of ions to specific magnetic sublevels by impact with directional electrons. For these detailed cross sections the Breit interaction was found to be of some significance even for iron ions. The range of nuclear charge Z for which inclusion of the Breit interaction is important for ionization from the 1s subshell of H-like, He-like, Li-like and Be-like ions was also explored. Simple fits of these ionization cross sections were made that allow one to readily obtain ionization cross sections and rate coefficients for any of these types of ions from atoms a few times ionized up to ions with Z=92. Similar work is in progress on ionization from the n=2 subshells.

3.3.6 Statistical Astronomy

3.3.6.1 Astrostatistics Feigelson's main effort in this area concerned a statistical investigation of gamma-ray bursts (see § 3.3.1.6). He also participates in the Statistical Consulting Center for Astronomy (www.stat.psu.edu/scca), maintains a Web site with statistical codes (www.astro.psu.edu/statcodes) that received about 30 hits daily, and published several talks on astrostatistical matters.

3.3.7 Numerical Relativity

3.3.7.1 Cosmological Topological Defects Symmetry-breaking phase transitions may leave behind topological defects with a density dependent on the quench rate. Laguna and Zurek (Los Alamos) investigated the dynamics of such quenches for the one-dimensional, Landau-Ginzburg case and showed that the density of kinks, n, scales differently with the quench timescale, τ_Q, depending on whether the dynamics in the vicinity of the critical point is overdamped ($n \propto \tau_Q^{-1/4}$) or underdamped ($n \propto \tau_Q^{-1/3}$). Either of these cases may be relevant to the early Universe, and they derive bounds on the initial density of topological defects in cosmological phase transitions.

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