

Pennsylvania State University
Astronomy and Astrophysics
University Park, Pennsylvania 16802-6305

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This report covers the period from September 1, 1998 to August 31, 1999.

1. PERSONNEL

1.1 Faculty

The regular members of the faculty during the academic year 1998-1999 were Professors Peter Mészáros (Department Head), Eric Feigelson, Gordon Garmire (Evan Pugh Professor), Lawrence Ramsey, Douglas Sampson (Emeritus), Donald Schneider, Peter Usher, Daniel Weedman, and Alexander Wolszczan (Evan Pugh Professor); Associate Professors Jane Charlton, Robin Ciardullo, Pablo Laguna, and Richard Wade; Assistant Professors William Nielsen Brandt, Michael Eracleous, Steinn Sigurdsson and Louis Winkler; and Senior Scientist/Professors David Burrows and John Nousek, and Senior Scientist George Pavlov.

James Beatty and Lee Samuel Finn, Associate Professors of Physics, hold joint appointments as Associate Professors in Astronomy & Astrophysics. Professor Peter D. Usher retired with emeritus status after 31 years of service to the department. Daniel Weedman left the department to assume a position at NSF last July.

Research Associates in the program were Steven Brandt, Karen Camarda, George Chartas, Christopher Churchill, Audrey Garmire, Mijian Huq, Rita Sambruna, and Leisa Townsley. Joining the department as Research Associates were Joanne Hill (formerly of Leicester University, England), Shai Kaspi (formerly of Tel Aviv University), Kaori Nishikida (formerly a graduate student at Penn State), Peter Roming (formerly of Brigham Young University), Divas Sanwal (formerly of the University of Texas at Austin), Hisa-aki Shinkai (formerly of Washington University in St. Louis) and Deirdre Shoemaker (formerly of the University of Texas at Austin). Charles Higgins (formerly of NASA-Goddard Space Flight Center) and Phillip Martell (formerly of Bowling Green State University) joined the department as Instructors.

Research Associate Jerome A. Orosz departed July 1999 to take up an appointment at the Sterrekundig Instituut, Universiteit Utrecht, Netherlands.

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 Drs. Maciej Konacki, Malgorzata Redmerska and Wojciech Lewandowski (from Nicolaus Copernicus University, Centre for Astronomy, Torun, Poland) working with Dr. Wolszczan, Dr. Charles Lawrence (from the Jet Propulsion Laboratory) working with Dr. Donald Schneider, Dr. Lars Hernquist (from Harvard

and Dr. Stephen Vine (from Ohio State University) working with Dr. Steinn Sigurdsson, Dr. Yoshitomo Maeda (from Koyoto University Department of Physics, Japan) working with the X-ray Astronomy Group and Dr. Yohko Tsuboi (from Kyoto University Department of Physics, Japan) working with Dr. Eric Feigelson, and Dr. Christopher Reynolds (Univ. of Colorado) working with Dr. Niel Brandt. Dr. Frank Shu from the University of California-Berkeley presented the 1999 Marker Lecture Series in April, with the general title of Astronomical Origins.

2. ACADEMIC PROGRAM

2.1 Graduate and Undergraduate Majors

Nineteen graduate and sixty-seven undergraduate astronomy majors were enrolled during the academic year 1998-99. During that time ten B.S. degrees and five Ph.D. degrees were awarded in Astronomy & Astrophysics. Doctoral recipients were Laura Cawley, Catherine Grant, Suzanne Linder, Kaori Nishikida, and Alin Panaitescu.

2.2 Educational Activities

For the fourth 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 1999 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 main campus and included a variety of classroom, laboratory and computer activities. Over 20 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 continued to provide stimulating and educational programs for the general public in 1999. This summer members from the department and the Astronomy Club produced AstroFest: a program featuring astronomical activities and a space art exhibit held during the Central Pennsylvania Festival of the Arts. More than 1,600 people visited the department over the four-day event. Additional public service programs, i.e., planetarium shows, observing with telescopes, and public lectures were held throughout the year. 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, uninterrupted 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: Club officers are: President, Nahks Tr'Ehnl; Vice President, Karen Knierman; Secretary, Ken Pelman; Treasurer: Jenn Donley.

3. RESEARCH ACTIVITIES

3.1 Instrumentation for Observing

3.1.1 Optical

3.1.1.1 The Hobby-Eberly Telescope. 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 view 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 material on telescope operations.

During the past twelve months the HET has passed its most significant milestones on the path to meeting its performance specification and science productivity goals. These include successful installation and testing of the complex four mirror spherical aberration corrector system, installation of the first HET facility instrument, dramatic improvement of in both the performance and understanding of the 91 segment primary mirror array and multi-axis tracking system and most importantly, beginning the transition from telescope commissioning to science operations.

In early February 1999, the final Prime Focus Instrument Platform (PFIP) was installed and tested. The PFIP contains the spherical aberration corrector, acquisition and guide system and the prime focus Low Resolution Spectrometer (LRS, PI Gary Hill, McDonald Observatory). It also holds the Fiber instrument feed (FIF). The LRS is described by Hill *et al.* (SPIE, 3355-20, 1998), Cobos D. *et al.* (SPIE, 3355-71, 1998) and Hill *et al.* (SPIE, 3355-74, 1998). It is a grism spectrometer with imaging, long-slit, and multi-object capability. The FIF positions fiber feeds in the focal plane for the High Resolution Spectrometer (HRS, PI Robert Tull, McDonald Observatory, SPIE 3355-21, 1998), and the multi-object Medium Resolution Spectrometer (MRS, PI Larry Ramsey, Pennsylvania State University, SPIE 3355-22, 1998). During a March 1999 science commissioning run, the FIF was installed by Engel, and Ramsey successfully tested

it with the HET commissioning spectrograph, the Penn State Upgraded Fiber Optics Echelle. In April Gary Hill and his team began commissioning of the LRS, which is the first delivered HET facility instrument. For the past year a tremendous engineering and commissioning effort has led to much improved tracking and guiding performance so that we are now approaching very closely the design specifications. During the same period the mirror alignment quality and time improved dramatically. We are now routinely obtaining 1 arc-sec stacks for all 91 mirrors with stacking times typically 10-12 minutes after the first stack of the night. The stack time in very near specification however we are still a factor of 2.5 away on the stack image quality.

The most gratifying milestone for the HET is the beginning of early operations in early October 1999. The early operations phase is a transition phase between commissioning and full operations where at least two weeks per month are spent in science observing. The long commissioning time for the HET has been necessitated in major part by the radical departure of the HET design from classical all sky telescopes divorcing us for a large body of experience. This has been extended by a parsimonious operating budget, which limits the amount of manpower that can be expended. While many technical and operational problems remain to be solved, their burden will be offset by the increasing science production. Indeed the first science paper from HET is already in press (see Schneider *et al.* elsewhere in this report).

This most disappointing, but not surprising, aspect of the HET is the necessity to re-stack the primary mirror often. The length of time that the image quality remains good depends on the temperature gradient. For gradient less than half a degree per hour, images remain good for times up to several hours. However a large fraction of observing time is lost in less ideal conditions. We are taking aggressive steps to correct this problem and increase our efficiency. A contract is in negotiation (October 1999) with Marshall Space Flight Center / Blue Line Engineering to design, fabricate, and install a Segment Alignment and Maintenance System (SAMS) on the primary mirror array. SAMS will provide closed loop control of the 91 segments and their global radius of curvature. We expect SAMS to reduce the need to align the segments using the CCAS from hourly to twice monthly. The nominal schedule for SAMS calls for completion in January 2001 and for minimal impact upon research operation during installation. By that time we expect a full complement of facility instruments to be in full-up operations.

3.1.1.2 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 Engel, Ben Rhoads and L. Ramsey, graduate students Dave Andersen as well as undergraduate students Joe Maywalt and Kevin McGouldrick. Ben Rhoads left in March 1999 to take a position as a telescope operator at the Hobby-Eberly telescope. Kevin McGouldrick graduated with honors in spring 1999.

3.1.1.3 Medium Resolution Spectrograph Initial on-telescope testing conducted with the MRS Fiber Instrument

Feed (FIF) in August 1998 illuminated some design deficiencies in the fiber cable design as well as the mechanical housing. Engel completed the design upgrades and a new system was installed and successfully tested in March 1999. The March 1999 integration at the HET included the final electronic control system assembled and tested by Rhoads. In March 1999 Engel worked with McDonald physical plant personnel to install the MRS optical benches and enclosure at the site. In early spring 1999, Dr. Harland Epps delivered the final pre-production design for the visible beam camera. All the glass for this all-refracting design using 10 elements has been ordered and all but three large Calcium Fluoride elements have been delivered. Bids for camera fabrication will be solicited by the end of the year. The delivery of the Calcium Fluoride is expected to set the schedule for instrument delivery which is now expected to be no earlier than fall 2000.

MRS fiber testing and validation efforts have continued at Penn State with REU students Maywalt and McGouldrick. Their major efforts this past year have been to utilize a HET exit pupil simulator to explore the Focal Ratio Degradation and how well the pupil is scrambled during short and long exposures. With the input ratio of 4.6 the total throughput of fibers into the MRS collimator solid angle is measured at 90%. The scrambling in the worst case is 93% and typically 98%.

3.1.1.4 JCAM The JCAM project is a joint project with Drs. James Beatty in the Physics Department and Jane Charlton, Chris Churchill, Leland Engel and Larry Ramsey in Astronomy & Astrophysics. Graduate student Rajib Ganguly and undergraduate honors student Jane Rigby are also participating. It has the goal of implementing an early HET capability into 950-1300 nm region. It uses the UFOE with a 31.6 line/mm echelle and a Rockwell/Boeing 1024 x1024 HgCdTe detector. Engel has completed the design of the echelle grating holder and will soon be working on the cross disperser and camera mechanical mountings. With Dr. Beatty's supervision Rigby has completed testing of the computer control interface concept. In addition, this past summer Dr. Beatty supervised Ganguly's breadboard testing of the detector analog readout electronics. After this testing Beatty designed a multilayer PC board that has since been fabricated and is now in test. This last summer all the optical glass needed to fabricate the camera had been received. Recently Janos optics was selected as the fabricator and Ramsey re-optimized the design for the as-delivered glass Janos test plates.

Delivery of the completed optical elements is expected by the end of the calendar year. Integration and test in the lab is expected in December 1999-January 2000 with telescope commissioning soon after.

3.1.2 X-ray

3.1.2.1 The Chandra X-ray Observatory The Chandra X-ray Observatory was launched into orbit on July 23rd by the Space Shuttle Columbia. Twenty days later the final protective cover was opened and the Chandra X-ray Observatory began recording data from the cosmos. The Advanced

CCD Imaging Spectrometer (ACIS) had begun taking calibration data over two weeks earlier, when power was applied to the ACIS electronics and the temperature of the focal plane was stabilized at -118C. Prior to opening the ACIS door the temperature of the CCDs was raised to -90C to prevent water escaping from the carbon fiber optical bench from condensing onto the CCDs in the focal plane. The very first image showed that the mirrors were forming image that was close to the specified performance of arcsecond quality. The background in the ACIS CCDs was very close to that estimated prior to launch, and that the expected sensitivity for long exposures would be realized. Occasional elevated levels of background were observed, especially in the Back Illuminated (BI) CCD at the focal location of the mirrors, but the amount of time of elevated background did not appear to exceed about 20 percent. For point source observations, this background was not a serious problem except for sources near the detection limit for very long exposures. For faint extended sources the background poses a more serious limit to low surface brightness measurements. The overall performance of the ACIS instrument was verified to be working up to specifications.

After the Observatory began to take calibration data on celestial sources, no further instrument calibration data were taken until ACIS was moved out of the telescope focus and over to its External Calibration Source over three weeks into the observation/calibration phase of the mission. In this position it was possible to obtain X-ray calibration lines from Manganese $K\alpha$, Titanium $K\alpha$ and Aluminum $K\alpha$ radiation excited by a radioactive Iron 55 sources. Much to the horror of the ACIS Team, the calibration lines in the Front Illuminated CCDs (FI) appeared very broad, as though something had happened to the charge transfer efficiency of the FI CCDs. The BI CCDs appeared unchanged. After a series of tests, the electronics and software were found to be functioning normally. The temperature dependence of the charge transfer inefficiency (CTI) was very similar to that induced by radiation damage, although no large solar flares had occurred during this period. It was found that the rate of change of the CTI could be stopped by placing ACIS in the Next In Line (NIL) position where about two grams per centimeter squared of shield covered the CCDs. Even the insertion of the High Energy Transmission Grating assembly was enough to arrest the CTI increase. These facts have lead the ACIS team to suspect that low energy protons (100 to 200 keV protons in the Outer Radiation Belts) are the causative agent. Attempts are being made to reproduce the effect in the laboratory, so that possible amelioration of the CTI increase can be affected by modifying the instrument operating conditions. So far this process is ongoing without a conclusion. The net result of the CTI increase is that the FI CCDs have much degraded energy resolution in the portion of the image far from the framestore area, but energy resolution nearly as good as on the ground next to the framestore area. The imaging properties are unaffected as are the quantum detection efficiency and background.

A calibration report for the ACIS instrument is available at the PSU website (http://www.astro.psu.edu/xray/docs/cal_report.html). A more complete description of the ACIS

FI CCD problem is available at the docs site also.

3.1.2. CCD Imaging Spectrometer on Chandra Pavlov and Nousek (1999) 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 modelling of the observed X-ray event grade distributions.

Townsley and Broos continued refining their Monte Carlo algorithm 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. Recent improvements include a complete revamping of the code, necessary to incorporate a sensible model of the gate structure in front-illuminated (FI) devices. The gate structure acts as an X-ray filter and affects the quantum efficiency (QE) of the device. It also provides a source of fluorescent photons, so its incorporation in the model allows us to reproduce the spectral redistribution function more accurately. The model has been tuned to reproduce the QE, spectra, and grade distributions seen in ground-based calibration data for ACIS FI devices. Work is ongoing for ACIS back-illuminated devices.

We continue work on a model of charge transfer inefficiency (CTI), 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. This CTI model will be used to improve astrophysical results from ACIS front-illuminated devices as well, since they show the effects of radiation damage on-orbit.

3.2 Hardware and Software Development

3.2.1 *Swift*

The period of this report includes the Phase A development work performed for our instruments on the Swift satellite, which has been selected for launch in 2003 under NASA's MIDEX program. Swift is a three telescope observatory designed to study gamma ray bursts and afterglows at gamma ray, X-ray, and optical/UV wavelengths. The Penn State Swift team, under the direction of Prof. John Nousek, is responsible for building/integrating/testing two of the three instruments (the X-ray and UV/Optical telescopes), operating the mission control center after launch, and directing the education/outreach program. Each of these activities is described briefly here; complete details on the Penn State contributions to Swift can be found on the Web at <http://www.astro.psu.edu/xray/swift/>.

The X-ray Telescope is a collaboration between the Penn State Department of Astronomy & Astrophysics, the Leicester University Space Research Centre, and the Osservatorio Astronomico di Brera. The XRT Lead is Prof. David Burrows. The XRT is a 3.5 m focal length X-ray telescope, utilizing a 12 shell electroformed nickel mirror made by the Brera observatory as a spare mirror for the JET-X instrument on the Russian Spectrum-X satellite. The focal plane detector will be an EEV CCD-22 detector made available from a pool of spare CCDs from the XMM/EPIC MOS camera program

at Leicester, providing a 22 arcminute field of view. Penn State will provide the telescope tube and most of the supporting electronics and software. The XRT will measure the position, spectrum, and lightcurve of gamma ray bursts and afterglows. Position determinations with accuracy of 3 arcseconds will be transmitted to the ground within 100 seconds of the burst for world-wide distribution through the Gamma-ray burst Coordinates Network (GCN). X-ray spectra will permit determination of red-shifts for some bursts/afterglows. For more details, see <http://www.astro.psu.edu/xray/swift/xrt/>.

The UV/Optical Telescope is a collaboration between the Penn State Department of Astronomy & Astrophysics and the Mullard Space Science Laboratory of the University College London. It is a copy of the XMM Optical Monitor, which was built by the same team. The Penn State team is responsible for the digital processing unit hardware and software, with MSSL responsible for the rest of the instrument. The UVOT will obtain high resolution optical and UV images of the burst/afterglow with a 17 arcminute field of view and sensitivity of 24th magnitude in 1000 seconds. Postage stamp finding charts will be transmitted to the ground within five minutes of the burst onset for use by ground-based telescopes for spectroscopic followup. Bursts with optical counterparts will provide positions accurate to 0.3 arcseconds. For bright optical bursts, a grism will provide on-board spectroscopy. Fainter bursts will be observed through a series of filters to provide six colors. For more details, see <http://www.astro.psu.edu/xray/swift/uvot/>.

The education/public outreach program is a collaboration between Penn State, Goddard Space Flight Center, and Sonoma State, under the direction of Prof. Eric Feigelson. This program includes Web pages on Swift, gamma ray bursts, and astrophysics; development of curricular materials for use by K-12 teachers; teacher training workshops in astronomy and astrophysics; and television programs produced by Penn State's public television station for distribution to millions of school children.

3.2.2 *Sounding Rocket Payloads*

Our successful sounding rocket program continued this year with analysis of data from our last rocket flight from White Sands, New Mexico, which observed X-rays from the source Scorpius X-1. The flight produced a high quality CCD spectrum of this source. More information about this launch is available from our Sounding Rocket Home Page at <http://www.astro.psu.edu/xray/rockets/36.176>.

We are collaborating with Prof. Hans Kraus of Oxford University, Dr. Simon Labov of Livermore, and Dr. Ian Hutchinson of MSSL on a sounding rocket payload designed to fly a cryogenic X-ray detector (either an STJ or a bolometer). We 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. Progress during the past year includes optimization of the mirror figure to provide good angular resolution over a wide field, and production and testing of some sample mirror flats

to evaluate our proposed production techniques. This work is being carried out under the direction of Prof. David Burrows and Dr. Peter Roming.

3.2.3 Laboratory CCD Cameras

Mike Zuger and undergraduate Jason Shoemaker have designed a new set of CCD camera control electronics that will serve as the basis for both our laboratory cameras and the Swift XRT flight camera. The new design includes a DSP-based clock generator, new clock drivers, and a new high speed digital I/O circuit. This represents a major upgrade to our lab camera design of about 10 years ago, and will permit us to operate our CCD cameras at much higher readout rates.

3.2.4 Current and Future Missions

3.2.4.1 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.

3.2.4.1 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 for Constellation-X. Meetings of the FST are held twice per year, alternating between SAO and GSFC.

3.3 Observational Research

3.3.1 Stellar Astronomy

3.3.1.1 Pre-Main Sequence Stars Feigelson continued his studies into magnetic activity and high energy processes in young stellar objects. A comprehensive review of the field was prepared for the 1999 issue of *Annual Reviews of Astronomy & Astrophysics* with Thierry Montmerle (Saclay). It covers multiwavelength evidence for intense magnetic fields and violent reconnection events in low-mass pre-main sequence stellar systems, incorporation of these findings into models of protostars and T Tauri stars, astrophysical influence of the energetic radiation and particles on the circumstellar environment and disks, and the utility of X-ray surveys for the discovery of older pre-main sequence stellar populations. Aspects of the field were also reviewed by Alfred Glassgold (NYU), Feigelson & Montmerle for the Protostars

and Planets IV volume. The principal research accomplishment by the group was the discovery of an isolated 10 Myr-old cluster of pre-main sequence stars at a remarkably close distance of 97 pc from the Sun. Eric Mamajek (PSU Class of 1997, Fulbright Fellow at UNSW), Warrick Lawson (UNSW) and Feigelson uncovered this cluster around eta Chamaeleontis, the closest open cluster found this century and the first discovered by X-ray techniques. They believe the eta Cha cluster is an outlying group of the Sco-Cen OB association, which must be considerably larger than previously recognized.

3.3.1.2 Interacting Binary Stars R. Ciardullo and M. Sipiør, along with H. Bond (STScI) completed their analysis of a *Hubble Space Telescope* “snapshot” survey aimed at finding resolved binary companions of the central stars of Galactic planetary nebulae (PNe). In all, they found 10 binary nuclei that are very likely to be physically associated and another six that are possible binary associations. By correcting for interstellar extinction and placing the central stars’ companions on the main sequence (or, in one case, on the white dwarf cooling curve), they derived the distances to the objects, and thereby significantly increase the number of PNe with reliable distances. A comparison of the derived distances with those obtained from various statistical methods shows that all of the latter are systematically too large, by factors ranging up to a factor of 2 or more. This is most likely due to the fact that the properties of the wide-binary PNe are different from those of PNe used heretofore to calibrate the statistical methods; specifically, the binary PNe tend to have lower surface brightness at the same physical radius than the traditional calibration objects. This difference may arise from a selection effect: the PNe in the survey are typically nearby, old nebulae, whereas most of the objects that calibrate statistical techniques are low-latitude, high surface brightness, and more distant nebulae. As a result, the statistical methods that seem to work well with samples of distant PNe may not be applicable to the more diverse population of local PNe.

Maeda, Koyama, Yokogawa (Kyoto U.), & Skinner (JILA), reported 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 lumi-

osity 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.

J. Orosz and R. Wade continued a study of the remarkable short-period binary star KPD 0422+5421, which was discovered last year to consist of a subdwarf B star and a white dwarf star in a 2.16-hour orbit. New precise photometry has revealed that the white dwarf is eclipsed by the larger subdwarf star, and in turn makes a transit across the face of that star. The data have been used to refine the inclination of the orbit and the mass ratio of the binary, as well as to establish the temperature of the white dwarf. Using the white dwarf mass-radius relation, it was also possible to put much tighter limits on the masses of the two stars; these are 0.51 solar masses for the subdwarf (error 0.05 solar masses) and 0.53 solar masses (error 0.03) for the white dwarf. In addition to the ellipsoidal variation of the subdwarf star and the eclipses, the new photometry shows a 7.8-hour modulation of the light which is non-sinusoidal with a peak-to-peak amplitude of 2 percent; this modulation was present on all four nights of photometry. The origin of this modulation, or its persistence over long timescales, is unknown.

Wade, in collaboration with Penn State undergraduate J. Donley, R. Fried (Braeside Obs.), R. E. White (U. Arizona) and A. Saha (NOAO), completed a long-term study of the RR Lyr variable star TU Ursae Majoris, which is a member of a binary system. Photoelectric timings of maximum light, obtained by the authors over the past decade, were combined with older timings from the literature to establish the light-time orbit of the RR Lyr star, with residuals of only 2.4 minutes rms for the modern data. In addition, several measurements of the center-of-mass radial velocity of the star were shown to be consistent with the inferred orbit. There is now very little doubt of the reality of the orbit, which is characterized by a period about 23 years and an eccentricity of about 0.8, with a minimum mass of the companion object of about 0.4 solar masses. The binary is presently near its widest orbital and angular separation. TU UMa is the only RR Lyr star that can be considered with high probability to be a member of a relatively short-period binary system, and as such the only RR Lyr star for which there is a prospect for direct measurement of the mass.

3.3.1.3 Cataclysmic variables Orosz and Wade made a preliminary exploration of the spectral energy distributions of accretion disks in cataclysmic variables (CVs), in the case that the radial temperature profile $T_{\text{eff}}(r)$ deviates from the usual steady-state formula. This was motivated by the long-known problem of simultaneously accounting for the flux and the ultraviolet colors of the disk: models constructed using the steady-state formula and with realistic vertical structures are unable to match the observations. Orosz and Wade modified the usual $T_{\text{eff}}(r)$ prescription to incorporate a flatter power-law profile, as suggested by observations of some eclipsing CVs. Compared with a standard model, such disks are brighter (because they are at least as hot at each radius) and redder (provided the power-law is not too shallow). This combination of changes is of the type that is needed to better match the data, as shown by a comparison

of the new models with observations of the novalike CVs V603 Aquilae and RW Sextantis.

Wade and Ringwald collaborated with R. Prinja (UCL) and C. Knigge (Columbia U.) in a study of the rapid variability of the accretion disk wind of the cataclysmic variable star BZ Cam. The data used were obtained using the Goddard High Resolution Spectrometer on HST. Extensive changes were found in the absorption troughs of the ultraviolet resonance line profiles, suggesting a very unsteady outflow. The character of the wind can vary on timescales down to as little as 100 seconds. Correlated behavior was seen in lines of low and high ionization, possibly in reflection of localized density changes in the wind. The disk in BZ Cam, although likely viewed nearly face-on, shows simultaneously very strong absorption and well-developed emission components in the Si IV, C III, and C IV lines. This poses a problem for modeling the lines using pure scattering and sets constraints for alternative thermal emission sources.

3.3.1.4 Cool Stars Schneider and various collaborators are working on the stellar content of the Sloan Digital Sky Survey (SDSS). The high photometric accuracy and near-infrared filters of the SDSS have proven quite effective at detecting cool stars (spectral types later than M). The first field methane dwarf (spectral class T, temperature lower than 1300 K) was identified in SDSS commissioning data in the winter of 1998/9; a second field T dwarf was found shortly thereafter.

3.3.1.4 Neutron Stars and Pulsars Pavlov, Zavlin and Trümper (MPE, Germany) applied a new method, correlated periodicity search, for timing analysis of two *ROSAT* observations of the compact central source in the Puppis A supernova remnant. They found a statistically significant period, $P \approx 75.3$ ms and its derivative $\dot{P} \approx 1.49 \times 10^{-13} \text{ s s}^{-1}$, which suggest that the source is a neutron star. The corresponding characteristic parameters of the neutron star, age $\tau = P/(2\dot{P}) = 8.0$ kyr, magnetic field $B = 3.4 \times 10^{12}$ G, and rotational energy loss $\dot{E} = 1.4 \times 10^{37} \text{ erg s}^{-1}$, are typical for young radio pulsars.

Zavlin, Trümper (MPE, Germany) and Pavlov showed that the X-ray spectrum of the putative pulsar in Puppis A can be interpreted as thermal radiation from a hydrogen or helium neutron star atmosphere. Fitting the observed X-ray spectra with the atmosphere models gives more realistic values for the effective temperatures and emitting areas than the commonly used blackbody model. The temperature obtained, $T_{\text{eff}}^{\infty} = 1.6\text{--}1.9$ MK, is consistent with the standard neutron star cooling models. The corresponding distance and hydrogen column density are in good agreement with those obtained from independent estimates.

Pavlov and Zavlin (MPE, Germany) calculated linear polarization of radiation emitted from a photosphere of a strongly magnetized neutron star. They showed that the degree of linear polarization, typically $\sim 10\text{--}30\%$, depends on photon energy, effective temperature and magnetic field. The spectrum of polarization is more sensitive to the magnetic field than the spectrum of intensity. Both the degree of polarization and the position angle vary with the period of rotation so that the shape of polarization pulse profiles de-

depends on the orientation of the neutron star's rotational and magnetic axes. Moreover, as the polarization is substantially modified by the general relativistic effects, observations of polarization of X-ray radiation from isolated neutron stars provide a new method for evaluating the mass-to-radius ratio of these objects, which is particularly important for elucidating the properties of the superdense matter in the neutron star interiors.

Rutledge (CalTech), Bildsten, Brown (Berkeley), Pavlov and Zavlin (MPE, Germany) reanalyzed the available spectral data on the type I bursting neutron star transients, Aql X-1, Cent X-4 and 4U 1608-522, using realistic hydrogen atmosphere models. They showed that a substantial fraction of the quiescent luminosity of these objects may be thermal emission from the surface of a neutron star with the canonical 10 km radius. The same authors suggested a novel method for distinguishing between transiently accreting neutron stars and black holes. The method is based upon fitting the spectra of the X-ray transients in quiescence with hydrogen atmosphere models — the resulting fitting parameters are quite different for the two classes of X-ray transients.

Wolszczan and Hoffman (PSU), Anderson (Caltech), Konacki (TCfA) and Xilouris (NAIC) have conducted a one-month campaign of multifrequency timing observations of the planet pulsar, PSR B1257+12, to verify a 1997 hypothesis by Scherer and collaborators that a 25.3-day period planet A in this system is an artifact caused by signal propagation in the heliospheric plasma. Measurements were made with the 305-m Arecibo radiotelescope and the Penn State Pulsar Machine. The results clearly show that the periodicity in question is radio frequency independent and cannot be a propagation effect. Consequently, the existence of a Moon-mass planet in orbit around the pulsar remains to be the most plausible explanation of a 25.3-day period residual in the timing data. A detailed discussion of this program will be presented in an upcoming paper.

Konacki, Lewandowski (TCfA), Wolszczan (PSU) and Kramer and Doroshenko (MPIfR) have combined the archival JPL pulse timing data for the pulsar PSR B0329+54 with new observations made with the 32-m TCfA and the 100-m Effelsberg radiotelescopes to show that the two planets suggested to orbit this object cannot be real.

Konacki and Maciejewski (TCfA) and Wolszczan (PSU) have worked out a semi-analytical description of the perturbations between planets B and C in the PSR B1257+12 system. This has allowed them to measure true orbital inclinations and masses of the two planets. The orbits turn out to be coplanar to within a few degrees with inclinations close to 50 degrees. This makes the planetary masses to be around 5 and 4 Earth masses, respectively. Continuing timing measurements of the pulsar at Arecibo will further improve the accuracy of these results. Furthermore, when combined with modeling of the pulsar rotational geometry from polarization measurements, these new data will provide interesting constraints on planet formation around neutron stars. The results of this study are being prepared for publication.

Wolszczan (PSU), Doroshenko, Jessner, Kramer and Wielebinski (MPIfR), Konacki (TCfA), Camilo (NRAL) and Nice and Taylor (Princeton) have completed a timing analy-

sis of millisecond pulsar observations conducted with the Arecibo and the Effelsberg radiotelescopes. Observations at Effelsberg were made in 1994-97, during the Arecibo upgrade period. Combining the pre-upgrade Arecibo data and the Effelsberg measurements for four millisecond pulsars has resulted in proper motion measurements for PSR J1640+22, PSR B1953+29 and PSR J2229+26 and in the establishment of useful limits on the variation of the gravitational constant G for PSR J1640+22 and PSR J2229+26.

3.3.1.5 Galactic Sources C. Grant and D. Burrows completed work on determination of distances to two galactic neutral hydrogen clouds (Grant & Burrows 1999) that cast shadows against the diffuse X-ray background. The cometary cloud G192-67 has a well determined distance of 109 ± 14 pc. The high latitude molecular cloud complex MBM23-24 has a less well constrained distance of 139 ± 33 pc.

3.3.1.6 Galactic Center The X-ray satellite ASCA observed the Galactic Center Region Sgr A* three times in a time-span of 4 years. Maeda (PSU), Koyama, & Sakano (Kyoto U.), reported the results of X-ray emissions from a close vicinity of Sgr A*, the dynamical center of our Galaxy. Within a few arcmin from Sgr A*, two persistent X-ray sources have been always found; one is an eclipsing burster AX J1745.6 - 2901 located $1'.3$ away from Sgr A*, while the other is an extended source with the X-ray peak at the radio position of Sgr A*.

AX J1745.6 - 2901 is found to exhibit long-term variabilities of flux and spectrum. In a short-time scale, they found an eclipsing dip in the third observation, hence confirm the discovery reported with the second observation. Then they give a tighter constraint on the binary period. No X-ray burst was found other than one event in the second observation. The extended source has a spectrum of a thin thermal plasma with time-constant temperature, luminosity and absorption column of ~ 8 keV, 3×10^{35} ergs s^{-1} , and $\sim 7 \times 10^{22}$ H cm^{-2} , respectively. No point source at Sgr A* was found with an upper-limit of 3×10^{35} erg s^{-1} . They suggest that the Galactic center variabilities reported in the past observations are mostly due to the variable low mass binary AX J1745.6 - 2901.

Murakami, Koyama, Sakano, Tsujimoto (Kyoto U.) and Maeda (PSU) presented results of the ASCA imaging spectroscopy 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*. Possible implications of the Galactic center activity related to this unique source are presented.

Sakano, Imanishi, Tsujimoto, Koyama (Kyoto U.), and Maeda (PSU), reported the ASCA results of the Great Anni-

hilator 1E 1740.7 – 2942 obtained with five pointing observations spanning 3.5 years. The X-ray spectra are fitted with a single power-law absorbed by a high column of gas. The spectral shape did not change much but the flux showed significant variability in the 3.5 years. The photon index was flat, $\Gamma = 0.9\text{--}1.3$, which implies that 1E 1740.7 – 2942 was in the “hard state.” The hydrogen column density has been constant for more than 3.5 yr and was $N_{\text{H}} \sim 1.0 \times 10^{23} \text{ Hcm}^{-2}$. The constant and large column density is consistent with the source to be at near the Galactic Center. The column density of iron determined from the edge structure is $N_{\text{Fe}} \sim 10^{19} \text{ Fecm}^{-2}$. This means that the iron abundance is about 2 times larger than the other elements in terms of the solar ratio. The equivalent width of the $K\alpha$ -line from the neutral iron is less than 8 eV in 90% confidence. This implies that the iron column density within several parsecs from 1E 1740.7 – 2942 is less than $3 \times 10^{17} \text{ Fecm}^{-2}$.

They thus conclude that 1E 1740.7 – 2942 is not in a giant molecular cloud; 1E 1740.7 – 2942 is not powered by the accretion from the molecular cloud, but from the companion star like ordinary X-ray binaries.

3.3.1.8 Galactic Superluminal Sources Nishiuchi, Koyama (Kyoto U.), Maeda (PSU), Asai, Dotani, Inoue, Mitsuda, Nagase, Ueda (ISAS), and Kouveliotou (MSFC) reported the ASCA results of the bursting X-ray pulsar GRO J1744 – 28, which was observed in February 1996 and March 1997 with ASCA. The source flux in the 2–10 keV band was $2.0 \times 10^{-8} \text{ erg/sec/cm}^2$ (2–10 keV) in 1996 and $5.0 \times 10^{-9} \text{ erg/sec/cm}^2$ 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, $(5 - 6) \times 10^{22} \text{ cm}^{-2}$, 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.

3.3.1.9 Software Graduate student J. Feldmeier and undergraduate student K. Krelove have developed a software package for use with the IRAF system that detects point-sources that appear in one frame, but disappear in another. Although this package was originally designed to detect intracluster planetary nebulae, it has possible applications in supernovae searches, and in Lyman-break galaxy searches. After the software has been thoroughly tested, it will be released to the astronomical community.

3.3.2 Extragalactic Astronomy

3.3.2.1 Dwarf Galaxies and Globular Clusters in Tidal Debris A Penn State program, led by Jane Charlton, has been ramping up with acquisition of a number of WFPC2 images of various colors and sizes of star formation regions in tidal debris associated with interacting galaxies. The

group, which consists of graduate student Sarah Gallagher, Sally Hunsberger (former PhD student now at Lowell), and undergraduate student Karen Knierman, has in December 1998 and June 1999 obtained an incredibly stunning image of Stephan’s quintet. The quintet is of particular interest because it is the site of star formation triggered by a rapid passage of a giant galaxy through the intergroup medium. The WFPC2 images enable the investigators to date the various regions of star formation in the tidal debris and intergroup medium. Knierman is writing her honors thesis on the range of structures to form in the debris of a series of four different interacting pairs, NGC 4038/4039 (“The Antennae”), NGC 3256, NGC3921, and NGC 7252. The goal of this project is to gain clues as to the process that forms such structure by relating their sizes, colors, and metallicities to the location in the debris, to the similar properties of nuclear young globulars, and to the H I environment. The group is preparing for an extensive HET program in this area, and for additional HST observations.

3.3.2.2 Active Galaxies and Quasars W.N. Brandt (Penn State), A. Laor (Technion) and B.J. Wills (UT Austin) have recently completed a systematic study of soft X-ray weak Quasi-Stellar Objects (QSOs). The soft X-ray flux from these QSOs is $\sim 10\text{--}30$ times smaller than in typical QSOs. Soft X-ray weak QSOs comprise $\approx 11\%$ of optically selected QSOs, and we find soft X-ray weakness in both radio-quiet and radio-loud QSOs. From an analysis of C IV absorption in 55 QSOs with available C IV data, we find evidence that absorption is the primary cause of soft X-ray weakness in QSOs. We also find a continuum of absorption properties connecting unabsorbed QSOs, X-ray warm absorber QSOs, soft X-ray weak QSOs, and Broad Absorption Line QSOs. From a practical point of view, our study demonstrates that selection by soft X-ray weakness is an effective ($> 80\%$ successful) and observationally inexpensive way to find low-redshift QSOs with strong and interesting ultraviolet absorption. We have also identified several notable differences between the optical emission-line properties of soft X-ray weak QSOs and those of more typical QSOs. Soft X-ray weak QSOs show systematically low [O III] luminosities and equivalent widths as well as distinctive $H\beta$ -line profiles. They tend to lie toward the weak-[O III] end of Boroson & Green (1992) eigenvector 1, suggesting that they have extreme values of a primary physical parameter, perhaps mass accretion rate relative to the Eddington rate. B.J. Wills, W.N. Brandt, and A. Laor have also found evidence that PKS 1004+13 is the first radio-loud Broad Absorption Line QSO at low redshift ($z = 0.24$). It appears to show broad absorption troughs of O VI, N V, Si IV, and C IV, indicating high-ionization outflows up to about $10\,000 \text{ km s}^{-1}$. There are also two strong, broad ($\sim 500 \text{ km s}^{-1}$), high-ionization, associated absorption systems that show partial covering of the continuum source. The large radio-lobe dominance for PKS 1004+13 indicates Broad Absorption Line and associated gas at high inclinations to the central engine axis, perhaps in a line of sight that passes through an accretion disk wind.

W.N. Brandt has continued his X-ray studies of ultrasoft Narrow-Line Seyfert 1 galaxies (NLS1). These galaxies ap-

pear to have extreme values of a primary physical parameter, perhaps the fraction of the Eddington rate at which the supermassive black hole is accreting. A recent result of note has come from an 18-day ROSAT HRI monitoring campaign on the ultrasoft NLS1-class quasar PHL 1092. Brandt, Th. Boller (MPE), A.C. Fabian (Cambridge IoA), and M. Ruzsowski (Cambridge IoA) find extremely rapid and large-amplitude X-ray variability throughout the monitoring campaign. The maximum observed variability amplitude is a factor of ≈ 14 , and in the most rapid variability event the HRI count rate increases by a factor of ≈ 3.8 in a rest-frame time interval of < 3580 s. The most rapid event has a rate change of luminosity of $> 1.3 \times 10^{42}$ erg s $^{-2}$, making it the most extreme such event known from a radio-quiet quasar. Standard ‘radiative efficiency limit’ arguments imply a radiative efficiency larger than can be achieved by accretion onto a Kerr black hole rotating at the maximum plausible rate, although such arguments depend upon the geometry of initial radiation release. Relativistic motions of the X-ray source are probably causing the radiative efficiency limit to break down; such relativistic motions have also been inferred in the similar NLS1-class quasar PKS 0558–504.

W.N. Brandt has collaborated with a team led by A.C. Fabian to study the X-ray and radio variability of the radio-loud $z = 4.72$ quasar GB 1428+4217. The strong observed variability at both X-ray and radio wavelengths supports the blazar nature of this object. A detailed comparison of the broad-band spectral properties of GB 1428+4217 with those of nearby blazars shows it to be extreme, but nevertheless consistent with the trend found for nearby sources. S. Kaspi (Penn State), W.N. Brandt, and D.P. Schneider (Penn State) have started additional studies of high redshift quasars of particular interest.

W.N. Brandt and M.C. Eracleous (Penn State) have worked as editors on the conference proceedings for the ‘Structure and Kinematics of Quasar Broad Line Regions’ conference held in Lincoln, Nebraska. The primary editor for the proceedings is C.M. Gaskell (UN Lincoln). W.N. Brandt also served on the scientific organizing committees for the ‘X-ray Astronomy 1999: Stellar Endpoints, AGN and the Diffuse X-ray Background’ and ‘Observational and Theoretical Progress in the Study of Narrow-Line Seyfert 1 Galaxies’ international conferences.

Chartas has studied the properties of gravitationally lensed broad absorption line (BAL) quasars and found that approximately 35% of radio-quiet gravitationally lensed (GL) quasars contain BAL features which is significantly larger than the 10% fraction of BAL quasars presently found in optically selected flux limited quasar samples. He has developed a model that estimates the effects of attenuation and lens magnification on the luminosity function of quasars and that explains the observed fraction of GL BAL quasars. This analysis suggests that a large fraction of BAL quasars are missed from flux limited optical surveys.

Chartas has performed timing analysis of the mini-BAL GL quasar PG1115+080 and finds strong variability on time-scales of months down to a few hours. Spectral modeling suggests that the variability can be explained in part with a variable BAL absorber. The X-ray variability in PG1115

+080 is consistent with the FAR - UV variability of the BAL absorption troughs observed with IUE. The observed large X-ray flux variations in PG1115+080 on short time-scales offer the prospect of considerably reducing errors in determining the time delay with future X-ray monitoring of this system and hence constraining the Hubble constant.

Eracleous in collaboration with Pogge (OSU), Maoz (Tel Aviv), and Ho (OCIW) has been studying the morphology of the emission-line regions of LINERs using narrow-band images obtained with the *HST*/WFPC2. These regions, which have a typical angular size of $1''$, are resolved. The bulk of the $H\alpha$ and [O iii] emission comes from regions with sizes of tens to hundreds of parsecs, consisting of combinations of knots, filaments and diffuse gas. The exact morphology differs from galaxy to galaxy. Most of the 14 galaxies studied do not show linear structures or ionization cones similar to what is seen in Seyfert galaxies. The only exceptions are NGC 1052 and possibly M84. The data suggest that the line-emitting gas in most LINERs is photoionized by a UV source which may be stellar or non-stellar in origin, and which is often hidden from direct view by dust in the host galaxy. There are no obvious differences in morphology between LINERs of different types (i.e., objects with or without broad $H\alpha$ lines or objects with or without hot-star features in their UV spectra).

Eracleous, in collaboration with Sambruna (PSU) and Mushotzky (NASA/GSFC) have obtained hard X-ray spectra of broad-line radio galaxies (BLRGs) with the *Ross X-Ray Timing Explorer*. The goal of the observations is to look for systematic differences in the X-ray spectra of radio-loud and radio-quiet AGNs, which can shed light on the origin of the radio-loud/radio-quiet AGN dichotomy. The X-ray spectra of BLRGs are found to have systematically weaker Fe $K\alpha$ lines and Compton reflection humps compared to those of Seyfert galaxies. The most plausible interpretation of this difference is that the structure and geometry of the inner accretion disks of BLRGs is different from that of Seyferts. This would be the case if the inner disks BLRGs were ion-supported torii (also known as advection-dominated accretion flows).

Eracleous, in collaboration with Sambruna (PSU), Remillard (MIT) and Halpern (Columbia U.) and with the help of undergraduated student Chou (PSU), have been analyzing multiple X-ray observations of the broad-line radio galaxies 3C 390.3 and 3C 120 taken with the *Ross X-Ray Timing Explorer*. The observations will be used to study the X-ray variability of these two objects and to constrain models for the structure of the central engine and the origin of the Fe $K\alpha$ line.

Eracleous and Halpern (Columbia U.) have been monitoring the variability of the Balmer lines of the quasar OX 169. The unusual Balmer emission line profiles of the quasar OX 169, frequently described as either self-absorbed or double peaked, are actually neither. The effect is an illusion resulting from two coincidences. First, the forbidden lines are quite strong and broad. Consequently, the [N II] λ 6583 line and the associated narrow-line component of $H\alpha$ present the appearance of twin $H\alpha$ peaks. Second, the redshift of 0.2110 brings $H\beta$ into coincidence with Na I D at zero redshift, and ISM absorption in Na I D divides the $H\beta$ emission line. In

spectra obtained over the past decade, we see no substantial change in the character of the line profiles, and no indication of intrinsic double-peaked structure. The H γ , Mg II, and Ly α emission lines are single peaked.

Eracleous, in collaboration with Kaaret (CfA) and Piraino have searched for the optical counterpart of the Gamma-ray source in Monoceros. A hard X-ray source in the error box of the Gamma-ray source has been identified optically with a V=12.8 B star, whose spectrum shows broad Balmer emission lines. If this is the correct identification of the Gamma-ray source then this object is a Gamma-ray emitting X-ray binary.

Eracleous in collaboration with Goodrich (Keck Observatory) and Koratkar (STScI) have obtained UV spectra of Seyfert 1.9 galaxies with the *HST*. These spectra will be used along with optical spectra of the same objects, obtained from the ground, to diagnose the physical conditions in the broad-line regions of the target objects. In particular the data will be used to distinguish between reddening and an unusually high density gas as the cause of the weakness of the Balmer lines in these objects.

P.J. de Naray (Penn State), W.N. Brandt, J.P. Halpern (Columbia) and K. Iwasawa (Cambridge IoA) have completed an X-ray study of the nearby barred spiral galaxy NGC 1672. This galaxy shows dramatic starburst activity, and it may also host a Seyfert 2 nucleus. Using data from ROSAT and ASCA they have found large-amplitude X-ray variability from a luminous off-nuclear source located near an end of the galactic bar, and argued that this source is a powerful X-ray binary or young supernova remnant. They do not observe soft X-ray variability of the nuclear source, and also do not detect hard X-ray emission from this source. If there is a luminous Seyfert 2 nucleus in NGC 1672, it must be obscured by a 'Compton-thick' torus with a column density of $> 2 \times 10^{24} \text{ cm}^{-2}$. The analyses also reveal two new off-nuclear sources, one of which is associated with a bright region along a spiral arm, and evidence for large-scale diffuse X-ray emission throughout part of the disk of NGC 1672.

S.C. Gallagher (Penn State), W.N. Brandt, R.M. Sambruna (Penn State) and collaborators have studied a sample of ASCA and BeppoSAX observations of Broad Absorption Line Quasi-Stellar Objects (BALQSOs). This is the first moderate-sized sample of sensitive BALQSO observations above 2 keV, and the BALQSOs in our sample are among the optically brightest known. Despite the ability of 2–10 keV X-rays to penetrate large column densities, it is found that BALQSOs are extremely weak sources above 2 keV. By comparison with non-BALQSOs of similar optical continuum magnitudes, the authors derive the column densities needed to suppress the expected X-ray fluxes of our BALQSOs. In several cases they derive column densities $> 5 \times 10^{23} \text{ cm}^{-2}$ for a neutral absorber with solar abundances. These are the largest X-ray column densities yet inferred for BALQSOs, and they exceed ROSAT lower limits by about an order of magnitude. Optical brightness does not appear to be a good predictor of 2–10 keV brightness for BALQSOs, but the data do suggest that the BALQSOs with high optical continuum polarization *may* be the X-ray brighter members

of the class. For example, the highly polarized object PHL 5200 appears to be unusually X-ray bright for a BALQSO given its optical magnitude. The highest redshift and highest luminosity BAL QSO detected in X-rays is CSO 755 ($z = 2.88$; $M_V = -27.4$). It has high optical continuum polarization and its observed-frame 2–10 keV flux from BeppoSAX ($1.3 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$) is large enough to allow XMM spectroscopy. Studies of iron K line emission from CSO 755 should prove of particular interest if a large amount of scattered X-ray flux is present.

Rajib Ganguly (graduate student), Michael Eracleous, Jane Charlton, and Chris Churchill have initiated a program to study the narrow intrinsic absorption lines which serve as constraints on models of accretion disk winds in active galaxies and quasars. Their recent paper presents a first step toward understanding the incidence of narrow absorption lines (NALs) intrinsic to quasars, by evaluating how common NALs are and by relating this to other quasar properties. The authors studied six quasars and found associated C IV absorption (within 5000 km/s of the quasar emission line) in four cases. In three of these there is evidence that the light source (continuum source and broad emission line region) is only partially covered by the absorbing material, and in two cases the continuum source is shown to be partially covered. The latter was established through a formalism developed for the paper, in order to constrain separately the continuum and the BEL partial covering. It is clear that NALs occur in both radio quiet and radio loud quasars, and Ganguly's small statistical sample implies that they may be quite common.

Chris Churchill, Donald Schneider, Martin Schmidt (Caltech), and James Gunn (Princeton) have published a paper entitled "An Unusual 'Mini-BAL' Quasar at $z = 4.59$ ". They discovered an associated absorption system, spanning the 5000 km/s blueward of the quasar emission lines, but with several separate components. The N V is very unusual in that it is exceptional strong for a "mini-BAL" quasar such as this. In this case, the continuum source is fully covered; perhaps this quasar is viewed from a preferred location or has an unusual geometry compared with other BAL quasars.

A.E. Hornschemeier (Penn State), W.N. Brandt, G.P. Garmire (Penn State), and collaborators have performed source searching analyses of initial data from the Chandra X-ray Observatory. They have detected 2–10 keV X-ray sources about an order of magnitude fainter than ever seen before, and it is likely that these sources make a major contribution to the X-ray background. The precise ($\sim 1''$) positions allow definite identification of optical counterparts; the group plans to obtain spectra of the optical sources with the Hobby-Eberly Telescope. This work serves as preparation for an upcoming deep Chandra observation of the Hubble Deep Field area. Hornschemeier and collaborators have also performed simulations of Chandra deep field observations, and these are being used to test the effectiveness of different source searching methods, including a powerful method being developed by S. Koch (Penn State) and collaborators. Furthermore, Hornschemeier is working with members of the ACIS team to study the effects that instru-

mental background will have on Chandra deep field observations.

Together with collaborators Michael Eracleous (PSU) and Richard Mushotzky (GSFC), Rita Sambruna continued her study of X-ray emission from a sample of radio-loud AGN, including Broad and Narrow Line Radio Galaxies (BLRGs and NLRGs), Quasars (QSRs), and Radio Galaxies (RGs), using archival and proprietary ASCA and RXTE data (Sambruna, Eracleous, & Mushotzky 1999; Eracleous, Sambruna, & Mushotzky 1999). The results support directly unification models for radio-loud AGN which purport that the same intrinsic object is hosted by the different types of AGNs, observed at different orientations with respect to the axis of the pc-scale molecular torus. Indeed, the authors find that the X-ray emission of BLRGs, QSRs, and NLRGs can be described by a power law component at energies > 2 keV, with similar photon index ($\Gamma = 1.7 - 1.8$) and 2-10 keV intrinsic luminosities. Large amounts of cold gas are detected at soft X-rays in NLRGs, as expected due to obscuration by the torus in these type-2 AGNs. However, similar columns are detected also in a fraction of BLRGs and QSRs, while in these type-1 sources the line of sight is expected to be devoid of cold gas. The excess X-ray columns are similar to those observed in higher-redshift radio-loud QSRs by other groups, indicating that the X-ray absorber is an important constituent of the central engines of these sources.

Sambruna and collaborators also observed and detected with ASCA for the first time a subclass of RGs, the so-called Weak Line Radio Galaxies (WLRGs). The nuclear emission is described by a very hard power law ($\Gamma \sim 1.5$) or a very hot bremsstrahlung ($kT \sim 100$ keV), with very low intrinsic X-ray luminosity. Based on the case study of 3C270, the authors concluded that the observed X-ray and optical properties of WLRGs are better explained in terms of sub-Eddington accretion in their central engines. In the brightest BLRGs, an emission line due to fluorescent iron was detected with RXTE and ASCA at 6.4 keV (rest-frame). This feature is very common in Seyfert 1s, the radio-quiet counterparts of BLRGs, where it is strong and with an asymmetric profile to the red. They find that BLRGs have weaker and narrower lines than Seyferts. They also find that BLRGs lack the reflection hump which is prominent in Seyferts above 10 keV. These properties strongly suggest that the structure of the accretion flow in the two AGN types is different. In order to clarify this issue, additional ASCA, RXTE, and SAX data were acquired on a BLRG (3C382) and a QSR (4C+74.14). The data analysis is in progress.

3.3.2.3 BL Lacertae objects and Blazars Feigelson, working with former student Sally Laurent-Muehleisen (LLNL), former postdoctoral scholar Ronald Kollgaard and colleagues at MPE in Garching Germany completed a series of papers on a new sample of BL Lac objects obtained from the ROSAT All-Sky Survey and the Green Bank 5 GHz sky survey. After extensive VLA radio and optical spectroscopic observations, a sample of 119 BL Lacs was collected; this RGB BL Lac sample is the largest ever obtained from a single survey technique. Their spectral energy distributions smoothly bridge the gap between the previously distinct subclasses of radio-selected and X-ray-selected BL Lacs, indi-

cating that there is no true paucity of BL Lacs with intermediate properties.

Together with undergraduate student Lester Chou and collaborator Meg Urry (STScI), Rita Sambruna performed an ASCA spectral survey of 4 blazars characterized by strong optical emission lines and unusually steep soft X-ray spectra. These objects are unexpected in the context of the current unification paradigm of blazars where sources with strong optical lines have flat X-ray spectra as a result of the dominance of the inverse Compton component peaking at γ -rays. The new ASCA data show that an upturn is present in the X-ray spectra above 1–2 keV, most likely the Compton tail, and suggest the presence of a soft excess at lower energies. A paper has been submitted to ApJ.

Together with Meg Urry, Laura Maraschi (Oss. Brera, Italy), Felix Aharonian and Henric Krawczynski (MPIK, Heidelberg, Germany), and Paolo Coppi (Yale), Sambruna studied the correlated X-ray and TeV emission of the BL Lacertae objects Mrk 501 and PKS 2155–304. Two papers were submitted to ApJ Letters. For Mrk 501, a campaign performed in June 1998 detected a strong TeV and X-ray flare after a period of very low flux, with a dramatic change of the X-ray and TeV spectra on timescales of one day. The data are interpreted in the context of a synchrotron-self Compton model which also allows the source parameters (magnetic field, electron energy) to be constrained. For PKS 2155–304, a monitoring campaign performed in 1996 May with RXTE is presented. The primary result is the detection of complex flux and spectral variability at X-rays, with both positive and negative time lags observed between the soft (2–4 keV) and hard (10–20 keV) energies. This implies strong acceleration and cooling of the synchrotron emitting electrons at the source, and greatly constrains models for the high-energy emission in BL Lacs.

3.3.2.4 Dynamics of Galaxy Nuclei Roming, Moody (BYU), and Hintz (BYU) continue their study of the dynamics of the gas in the nuclear region of nearby galaxies. Using long-slit spectra centered in wavelength about $H\alpha$, velocity, temperature, density, and shock heating maps of the nuclear regions of M101 and M33 were published. The M101 data indicate that the motion of the gas is consistent with gas infalling toward the nucleus as part of streaming motions. However, there appears to be a local instability in which gas of opposing motions are colliding in a region of relatively high density and temperature. A blue arc emanating from an unresolved source on or near the nucleus, shows evidence of collision in this same high-density, high-temperature region. Analysis of M33 data continues.

3.3.2.5 High-redshift Quasars and Galaxies Matthew Bershady (Wisc/Penn State), J. Charlton, and J. Geoffrey (Penn State undergraduate) published an Astrophysical Journal article reporting their simulations on the colors of high redshift galaxies. In Monte-Carlo simulations, they explored the consequence of realistic distributions of Ly α forest clouds and Lyman limit systems, along the lines of sight toward distant galaxies, on the observed colors of these galaxies. The colors could, in some cases, be affected enough that a galaxy would no longer fall in a color selection box

designated for selection of galaxies at a certain redshift. The paper cautions that in order to accurately derive the high redshift ($z > 3$) luminosity function from color-selected samples is to consider for each galaxy (with a given spectral energy distribution and redshift) the variation due to attenuation from the intervening Ly α absorbers.

Schneider is engaged in a long-term program to identify high-redshift quasars based on surveys with the 5-m telescope on Palomar Mountain as well as the newly-commissioned 2.5-m Sloan Digital Sky Survey (SDSS) telescope at Apache Point Observatory. In the past year the SDSS has discovered dozens of quasars with redshifts larger than 3.6, including the first two quasars with $z \geq 5$. Objects of particular interest include two $z = 4.6$ quasars; one displays the characteristics of the “mini-BAL” class, the other is completely lacking in emission lines (the redshift was determined by the presence of the Lyman α forest).

3.3.2.6 Faint Blue Objects 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 $z < 2.2$.

3.3.2.7 QSO Absorption Lines and Galaxy Evolution The theme of the Penn State Quasar Absorption Line (QAL) Team effort is to learn about the phases of gas in galaxies and in their surrounding environments. Undergraduates Nick Bond, Karen Knierman, Jane Rigby, and Rick Mellon were members of the team this year, along with graduate students Rajib Ganguly and Suzanne Linder (who completed her PhD in August 1999). Chris Churchill and Jane Charlton managed the team effort, and Penn State faculty Jim Beatty (Physics), Michael Eracleous, Larry Ramsey, and Donald Schneider collaborated on various aspects.

The power of the tool of quasar absorption lines is the ease, at least in principle, at which we can observe different chemical transitions and sample the multiple phases of gas in galaxies at both low and high redshifts. It is important, in such studies, to observe as many chemical species as possible, with a wide range of ionization states. However, the rest wavelengths of the key doublet transitions O VI and Mg II are 1038 Å and 2796 Å, respectively, and the Lyman limit break which is a key constraint is at 912 Å. Often, a comprehensive study of the absorption lines associated with a galaxy at a certain redshift rely on a combination of observations from different wavelength regimes, UV and optical, or optical and near-IR.

With information on many different chemical species, it is possible to apply photoionization models and infer the metallicities and densities in the absorbing medium. The QAL team is therefore collecting information about the physical conditions in the galaxies at different epochs in the history of the universe. The work in the past year has focused on an intermediate redshift interval, $0.4 < z < 1.4$, using ground based quasar spectra that Chris Churchill obtained at the High Resolution Spectrograph (HIRES) at the Keck I Telescope, in conjunction with ultraviolet Faint Object Spectrograph (FOS) observations from the Hubble Space Telescope (HST) archive. The next year promises an overwhelming advance, with data from the High Resolution

Spectrograph (HRS) on the Hobby–Eberly Telescope and from the JCAM near-IR spectrograph on the Hobby–Eberly Telescope (HET). With these instruments, the high redshift universe can be thoroughly explored in absorption and the process of assembly of proto-galactic clumps can be constrained by QAL profiles.

A series of papers was submitted by Churchill, R. Mellon (PSU undergrad), Charlton, and Schneider, in collaboration with B. Jannuzi (NOAO), S. Kirhakos (IAS), and C. Steidel (Caltech). These papers were the culmination of a large study of Mg II absorption systems at $0.4 < z < 1.4$, including both the strong systems which are associated with bright galaxies, and the population of weak Mg II absorbers. This was the first time that the high ionization gas, the Ly α and Lyman series absorption, the absorbing galaxy properties, and the kinematics and absorption strengths of the Mg II transition were simultaneously studied. The first result, presented in a letter to the *Astrophysical Journal*, was the discovery of a strong correlation between the kinematic spread of Mg II absorption and the equivalent width of C IV absorption. This implies a physical connection between the processes that produce “outlying velocity” Mg II clouds and high-ionization galactic/halo gas. Churchill and his colleagues hypothesize that the link could be the level of star formation activity, and indeed the absorption systems which are deficient in C IV are associated with galaxies that are among the reddest in the sample.

The next paper in the series is a data paper which presents “family portraits” of the Mg II absorbers drawn from the FOS archive and from Churchill’s HIRES/Keck sample. The equivalent widths of all detected transitions are presented and compared in a bi-variate analysis. The final interpretation paper focuses on the equivalent widths of the Mg II, Fe II, Ly α , and C IV lines, and the kinematics of the Mg II, since these properties were available for 30 of the 45 $0.4 < z < 1.4$ Mg II absorbers studied. A multi-variate clustering analysis was applied to the data in order to identify five categories of absorbers: “Classic,” “C IV-deficient,” “Single/Weak,” “Double,” and “DLA/Hi-rich.” These “classes” of absorbers occupy different locations in the C IV vs. Mg II plane. Within each class the systems have similar Mg II kinematics, which provide a clue as to the processes and/or types of structures that give rise to the gas. The paper discusses evolution of the gas in galaxies in this multi-parameter space in the context of ideas about star formation rates, interaction rates, and evolution of the galaxy population.

Another focus of the QAL effort in the past year has been on developing techniques to constrain the physical conditions of the multiple phases of galactic gas using the absorption line data of many chemical transitions. The method was first presented in the paper “The Multiple Phases of Interstellar and Halo Gas in Galaxies at $z \sim 1$ ” which was published in the *Astronomical Journal* by Churchill and Charlton. For a grouping of Mg II absorption systems toward the quasar PG 1206 + 459, they used HIRES/Keck profiles ($R = 6$ km/s) of Mg II and Fe II in combination with FOS/HST spectra ($R = 230$ km/s) (particularly the Ly α) to first place constraints on the metallicities and ionization pa-

rameters of the low ionization gas phase. The modelling technique relied on Gary Ferland's CLOUDY code, and on a code that generates synthetic spectra based on the model cloud components by convolving with the instrumental response function. It is not possible to account for the strong C IV and O VI absorption in the same clouds as the Mg II. A broad, high ionization component is added to the model and it is also constrained by generating a synthetic spectrum containing all model component and fitting it to the FOS data. In the three kinematically separate groupings of Mg II lines, 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.

Based upon the same strategy for photoionization modeling, Jane Rigby (undergraduate) has been writing an honors thesis in which she places constraints on the metallicities and ionization parameters of single cloud, weak Mg II absorbers. As Churchill, Charlton, and Rigby found (in their survey paper published in the *Astrophysical Journal Supplement*), this type of system is very common and does not appear to represent the same type of object that gives rise to strong Mg II absorption. In order to explain the rarity of double cloud weak systems, we come to the conclusion that the covering factor of this population must be significantly less than unity. Rigby, Charlton, and Churchill infer that the metallicities are high, greater than 10% solar and that sometimes a separate high ionization phase is required to explain the observed C IV. However, for some clouds the limit on C IV is strict and the second phase is constrained to be less substantial. Several of these systems have Lyman limit systems and/or known associated galaxies, but most are definitely sub-Lyman limit. This is a diverse population with many possible relationships to the galaxy population, but one popular and consistent idea is that some are related to the intra-group high velocity clouds proposed to populate the Local Group, an idea developed by Blitz and Spergel.

In anticipation of the release of a high resolution STIS spectrum of the quasar, PG 1634 + 706, Charlton, Mellon (PSU undergrad), Rigby, and Churchill have nearly completed a photoionization analysis of the low resolution FOS/HST and high resolution HIRES/Keck spectra. The four systems along this line of sight include two single cloud, weak Mg II absorbers, one unusual kinematically complex Mg II absorber, with a broad C IV phase that is kinematically offset, and a C IV-deficient strong Mg II absorber. Once the physical parameters of a consistent model are derived, the group simulated the expected STIS spectrum, applying the appropriate signal-to-noise ratio based upon the exposure times listed in the archive. This will be a definitive test of their technique of analysis of low resolution data, which can be applied to numerous systems for which high resolution UV spectroscopy is not feasible.

3.3.2.8 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, α ($= e^2/hc$). 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 .

3.4 Theoretical Studies

3.4.1 Theoretical Astrophysics

3.4.1.1 Physics of Gamma-Ray Bursts Graduate students Alin Panaitescu and Maddalena Spada and Mészáros (1999) simulated Gamma-Ray Bursts arising from internal shocks in relativistic winds, calculated their power density spectra (PDS), and identified the factors to which the PDS are most sensitive: the wind ejection features, which determine the wind dynamics and its optical thickness, and the energy release parameters, which give the pulse 50–300 keV radiative efficiency. For certain combinations of ejection features and wind parameters the resulting PDS exhibits the features found for the observed bursts. The upper limit on the efficiency of conversion of wind kinetic energy into 50–300 keV photons is $\sim 1\%$. Winds with a modulated Lorentz factor distribution of the ejecta which yield PDSs in accord with current observations have efficiencies closer to 10^{-3} , while winds with a random, uniform Lorentz factor ejection must be optically thick to the short duration pulses to produce correct PDSs, and have an overall efficiency around 10^{-4} . The power spectra of individual bursts have a distribution around the averaged PDS that is consistent with the observed distribution.

Graduate students Maddalena Spada and Alin Panaitescu, and Mészáros calculated a more refined model of the power density spectrum of Gamma-Ray Bursts arising from multiple shocks in a relativistic wind. The wind optical thickness is one of the factors to which the power spectrum is most sensitive, and they further developed their model by taking in account the photon down-scattering on the cold electrons in the wind. For an almost optically thick wind they identified a combination of ejection features and wind parameters that yield bursts with an average power spectrum in agreement with the observations of Beloborodov *et al.* (1998), giving an efficiency of conversion of the wind kinetic energy in 50–300 keV emission of order 1%. For the same set of model features the interval time between peaks and pulse fluences have distributions consistent with the log-normal distribution observed in real bursts.

Mészáros and Rees (1999) investigated the role of a photospheric component and of pair breakdown in the internal shock model of gamma-ray bursts. They discuss some of the mechanisms by which they would produce anomalously steep low energy slopes, X-ray excesses and preferred energy breaks. Sub-relativistic comptonization should domi-

nate in high comoving luminosity bursts with high baryon load, while synchrotron radiation dominates the power law component in bursts which have lower comoving luminosity or have moderate to low baryon loads. A photosphere leading to steep low energy spectral slopes should be prominent in the lowest baryon load cases. This may provide the explanation for the steep slopes encountered in about a third of GRB spectra, and may explain the presence of spectral breaks in the 100-400 keV range without resorting to observational selection effects.

3.4.1.2 Gamma-Ray Burst Afterglows Graduate student Christopher Weth, Mészáros, Kallman and Rees (1999) calculated the X-ray/UV spectral line signatures expected from the interaction of a gamma-ray burst afterglow and a dense pre-burst environment produced by the progenitor. They explored the conditions under which Fe line and edge equivalent widths of ~ 1 keV can arise, and discussed the possibility of gaining information about possible progenitor scenarios using X-ray metal line spectra in the first few days of a burst. A wind or supernova shell around the burst produces an X-ray absorption line spectrum and later emission lines, while a hypernova funnel model produces mainly emission lines. A detectable solar composition wind would require more mass and would produce stronger 0.5-2 keV absorption lines than a metal-enriched supernova remnant. The bound-free Fe edge equivalent widths are stronger and easier to detect than the Fe K- α line in shell models, while the opposite holds for hypernova funnel models.

Mészáros and Rees (1999) showed that the prompt ($t \leq 0.16$ days) light curve and initial 9-th magnitude optical flash from GRB 990123 can be attributed to a reverse external shock, or possibly to internal shocks. They discussed the time decay laws and spectral slopes expected under various dynamical regimes, and discuss the constraints imposed on the model by the observations, arguing that they provide strongly suggestive evidence for features beyond those in the simple standard model. The longer term afterglow behavior was discussed in the context of the forward shock, and it was argued that, if the steepening after three days is due to a jet geometry, this is likely to be due to jet-edge effects, rather than sideways expansion.

3.4.2 Cosmology

3.4.2.1 QSO Absorption Lines Graduate student S. Linder completed her thesis work at Penn State and began a postdoctoral position at the INAOE in September 1999. The final paper of her thesis makes the point that a substantial cross-section for Lyman-alpha absorption could come from low surface brightness galaxies. Through Monte-Carlo simulations, Linder demonstrated that a well-defined sample of ~ 100 galaxies would be sufficient to distinguish if absorbers arise in particular galaxies or whether they trace the large scale galaxy distribution. This would be accomplished by using tests that compare simulated and observed plots of the unidentified absorber fraction and the absorbing galaxy fraction versus the impact parameter. There is some evidence that the weakest absorbers arise gas that is around or between galaxies that are often not detected in surveys. The bulk of

the Lyman-alpha forest lines trace the surroundings of faint galaxies, not the central portions of the brightest ones.

3.4.3 Computational Astrophysics

3.4.3.1 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 $r_p \leq 100$ pc, globular clusters could suffer total disruption in a single passage. A more common scenario is that for cluster orbits with $r_p \geq 200$ pc. Holly Nordquist and Robert Klinger (Penn State undergraduates), with Jane Charlton and Pablo Laguna, published a paper exploring 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.

3.4.3.2 Black Hole Collisions Using several approximations, Laguna, Jorge Pullin (Penn State/Physics) and collaborators calculated an estimate of the gravitational radiation emitted when two equal mass black holes coalesce at the end of their binary inspiral. They found that about 1% of the mass energy of the pair will emerge as gravitational waves during the final ringdown and a negligible fraction of the angular momentum will be radiated.

3.4.3.3 Computational Simulations of Binary Black Hole Coalescence Huq, Laguna, Shoemaker and collaborators at the University of Texas at Austin and the University of Pittsburgh are making strides in the development and application of a computational solution of the Einstein field equations to the problem of the coalescence of binary black holes. The AGAVE code, developed at Penn State (Huq, S.Brandt), is being used to study the first set of grazing collisions of binary black holes using black hole excision techniques. These preliminary studies focus on the time evolution of binary black hole pairs that merge to form a single black hole. They have followed the evolution for a short time following this merger and are working to improve on the results. These results depend on appropriate choices of the outer boundary conditions, initial data and the choice of the gauge which determines how we slice spacetime into a series of space-like slices. In addition, they depend on the efficacy of black hole excision techniques for single or multiple black holes. Towards the improvement of such techniques, Huq and collaborators have been studying the stability properties of single black hole spacetimes in relation to the application of gauge conditions, study of finite difference stability (choices of spatial differencing and time update schemes), and choice of

outer boundary conditions. They have found that one of the sources of instabilities comes not purely from finite differencing but rather from the approach taken to enforce gauge conditions. Huq and Laguna have devised a scheme to enforce these gauge conditions.

3.4.3.4 The Close-limit Approximation to Neutron Star Collisions Laguna and collaborators Nils Andersson (Southampton, UK), Philippos Papadopoulos (Potsdam, Germany), Jorge Pullin (Penn State/Physics) and Kostas Kokkotas (Thessaloniki, Greece) developed a close-limit approximation to the head-on collision of two neutron stars similar to that used to treat the merger of black hole binaries. This approximation can serve as a useful benchmark test for future fully non-linear studies. For neutron star binaries, the close-limit approximation involves assuming that the merged object can be approximated as a perturbed, stable neutron star during the ring-down phase of the coalescence. They introduced a prescription for the construction of initial data sets, discuss the physical plausibility of the various assumptions involved, and briefly investigate the character of the gravitational radiation produced during the merger. The numerical results show that several of the merged objects fluid pulsation modes are excited to a significant level.

In collaboration with graduate student Michael Sipiior, Papadopoulos, Kokkotas and Andersson, Laguna developed a framework for constructing initial data sets for perturbations about spherically symmetric matter distributions. This framework facilitates setting initial data representing sources of gravitational radiation involving relativistic stars. The procedure is based on Lichnerowicz-York's conformal approach to solve the constraints in Einstein's equations. The correspondence of these initial data sets in terms of the standard gauge perturbation variables in the Regge-Wheeler perturbation variables is established, and examples of initial data sets of merging neutron stars under the close-limit approximation are presented.

3.4.3.5 N-body Modeling of Dynamical Systems Sigurdsson continued N-body modeling of dynamical systems, in particular the effects of tidal shocking on stellar clusters, and the interaction of disks with galactic halos. In collaboration with Mihos, Hernquist and Norman he continued characterization and study of models of triaxial galaxies. Natarajan and Sigurdsson continued some speculative study of the effects of very high mass black holes on their surroundings. Bloom, Sigurdsson and Pols completed a study of the spatial distribution of possible gamma-ray burst progenitors. This may provide ways of discriminating between the different engines proposed to power gamma-ray bursts, given large enough a sample of X-ray and optical counterparts. Sigurdsson continued work on two large HST projects. One, in collaboration with Elson, Gilmore, Santiago, Aarseth and Davies, is a study of young stellar clusters in the LMC; the other is in collaboration with Gilliland *et al.*, and is a search for "hot jovians" in the cluster 47 Tuc.

3.4.4 Atomic Physics

Sampson and collaborators have continued their work on fully relativistic calculations of atomic properties of highly

charged ions. In the current year fully relativistic distorted wave calculations were made of a very large number of cross sections for electron impact ionization from all the subshells with $n = 1$ and 2 of ions with $Z - N > 3$, where N is the initial number of bound electrons per ion and Z is the nuclear charge. The generalized Breit interaction between bound and free electrons was included when important. The results were expressed in a convenient way and fits made that allow one to readily obtain cross sections and rate coefficients. Relativistic distorted wave collision strengths and oscillator strengths were calculated for all the transitions with no change in n value when $n = 2$ in all N -like ions with Z between 12 and 92. The effective collision strengths with inclusion of resonance effects were calculated for hyperfine transitions of possible astrophysical interest in H-like N14 and Li-like Fe57.

3.5 History of Astronomy

Usher continued his study of history of Astronomy. Further progress can be reported on the discovery of astronomical allusions in Shakespeare's plays and their relevance to the history of science. The Bard lived at a time of great change, but was apparently unaware of the Copernican Revolution. His seeming ignorance of the changing cosmic world view must rank as a major mystery of the Renaissance. A solution to this problem has been reprinted in *Giornale di Astronomia* (Usher 1998a). A more detailed theory is contained in the paper "Hamlet's Transformation" published in *The Elizabethan Review* (Usher 1999a). The word "transformation" in *Hamlet* derives originally from the mathematical works of the English astronomer Thomas Digges, whence its use became central to the cosmic allegorical interpretation of the play. Further advances are reported by Usher (1998b; 1999b).

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Rita Sambruna
Larry Ramsey

