This report covers the period from September 1, 1999 to August 31, 2000.

1. PERSONNEL

1.1 Faculty

The regular members of the faculty during the academic year 1999-2000 were Professors Peter Mészáros (Department Head and Distinguished Professor), Eric Feigelson, Gordon Garmire (Evan Pugh Professor), Pablo Laguna, Lawrence Ramsey, Douglas Sampson (Emeritus), Donald Schneider, Peter Usher (Emeritus), and Alexander Wolszczan (Evan Pugh Professor); Associate Professors Jane Charlton, Robin Ciardullo, and Richard Wade; Assistant Professors William Nielsen Brandt, Michael Eracleous, Jian Ge, Steinn Sigurdsson and Louis Winkler; 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.

Senior Research Associates in the program were George Chartas and Leisa Townsley, Research Associates were Christopher Churchill, Audrey Garmire, Joanne Hill, Mijan Huq, Shai Kaspi, Peter Roming, Rita Sambruna, Divas Sanwal, Hisa-aki Shinkai, and Deirdre Shoemaker.

Joining the department as Research Associates were Margaret Chester (formerly of Bucknell University), Keith Duclos (formerly of Cornell University), Patrick Durrell (formerly of the University of British Columbia, Canada), Vladimir Getman (formerly a Research Technologist at Penn State University), Sally Hunsberger (formerly of Lowell Observatory), Ingo Lehmann (formerly of Astrophysikalisches Institut, Potsdam, Germany), Gordon Richards (formerly of the University of Chicago), Bing Zhang (formerly of Goddard Space Flight Center).

Instructors Charles Higgins and Phillip Martell were joined by Anna Jangren (formerly a graduate student at Penn State).

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 Maciej Konacki and Wojciech Lewandowski, (from Nicolaus Copernicus University, Centre for Astronomy, Torun, Poland) working with Dr. Alex Wolszczan, Dr. Yoshitomo Maeda (from Kyoto University, Department of Physics, Japan) working with the X-ray Astronomy Group, Dr. Yohko Tsuboi (from Kyoto University, Department of Physics, Japan), Dr. Warrick Lawson (from the Australian Defence Force Academy) and Dr. Steven Pravdo (from the Jet Propulsion Laboratory) working with Dr. Eric Feigelson. Dr. Alexei Koptsevich (from Ioffe Institute, St. Petersburg, Russia, Dr. V. Zavlin (from MPE, Garching, Germany) and Dr. Marcus Teter (from Montana State University) working with Dr. George Pavlov.

2. ACADEMIC PROGRAM

2.1 Graduate and Undergraduate Majors

Twenty graduate and sixty-eight undergraduate astronomy majors were enrolled during the academic year 1999-00. During that time nine B.S. degrees and two Ph.D. degrees were awarded in Astronomy & Astrophysics. Doctoral recipients John Feldmeier and Brian Thomas.

2.2 Educational Initiatives

Once again, 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 2000 program entitled, Penn State Inservice Workshops in Astronomy (PSIWA), consisted of two 1-week courses on Stars and Planets for Science Teachers and Galaxies and Cosmology for Science Teachers. Both courses were offered at Penn State’s main campus and included a variety of classroom, laboratory and computer activities. Funding was received from the PA Space Grant Consortium. Feigelson and Brandt were the workshop instructors. Numerous department faculty, research associates and graduate students also participated in the programs.

2.3 Outreach

The Department continued for the 5th year in offering summer graduate teacher workshops for in-service middle- and high-school science teachers. Dr. Feigelson was the lead instructor for the workshop on stars and planets, and Dr. Brandt was the lead instructor for the workshop on galaxies and cosmology. Thirty-nine teachers, mainly from Pennsylvania and West Virginia, attended. Participant ratings of the experience were extremely high. This program is coordinated by Feigelson in collaboration with the NASA Pennsylvania Space Grant Consortium and Penn State’s Office of Continuing Education. The department outreach effort continued to provide stimulating and educational programs for the general public in 2000. Once again this summer, members from the department teamed up with Astronomy Club members to produce AstroFest: a program featuring astronomical activities held during the Central Pennsylvania Festival of the Arts. More than 1,200 people visited the department over the four-day event. Additional public service programs, i.e., planetarium shows, observing with tele-

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scopes, and public lectures were held throughout the year. A complete listing of outreach programs offered by the department may be viewed at http://astro.psu.edu/outreach.

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. Members also participated in outreach programs for school children, making use of the department’s planetarium. Club officers are: President, Shinji Kondo; Vice President, Scott Guzewich; Secretary, Nick Bond; Treasurer, Jenn Donley. Eracleous is the Club’s faculty advisor.

3. RESEARCH ACTIVITIES

3.1 Instrumentation for Observing

3.1.1 Optical

3.1.1.1 The Hobby-Eberly Telescope Beginning in October 1999, the Hobby - Eberly Telescope (HET) began “Early Operations.” The Early Operations phase has up to 50% of the HET time scheduled for science observations in the queue mode. The remainder of the time is taken up by instrument commissioning and telescope and facility improvements. In the period October through July, the HET was scheduled for science operations 149 nights and 1552 improvements. In the period October through July, the HET instrument commissioning and telescope and facility improvements. The remainder of the time is taken up by instrument commissioning and telescope and facility improvements. The remainder of the time is taken up by instrument commissioning and telescope and facility improvements.

3.1.2 X-ray

3.1.2.1 CCD Imaging Spectrometer on Chandra This has been a banner year for the ACIS group using the Chandra X-ray Observatory that was launched on 23 July 1999 by the Space Shuttle Columbia. A total of 67 different objects were observed during the year, resulting in six press releases and 9 publications accepted, and at least eleven more papers in various stages of preparation. After an initial scare when a build-up of radiation damage was detected in the front illuminated CCDs of the ACIS, the operational solution to place ACIS under shielding during radiation belt passages has worked very well to halt the damage, with no further damage being detected. The damage has made data analysis more difficult, since the gain and energy resolution vary over the surface of each front illuminated CCD, but gain maps and energy resolution maps have been produced by the Chandra X-ray Center that permit good quality analysis to be performed. Dr. Townsley with P. Broos has lead an effort to produce a charge transfer inefficiency corrector program to improve the performance using software tools on the data. The software increases the quantum efficiency and energy resolution for energies above a few keV. Some of the highlights of the science program are as follows: D. Burrows led an effort to characterize the image quality and considerable progress was made in understanding and improving it. Conclusions from this most recent testing effort and re-analysis of earlier data is that the current HET image quality problem is primarily driven by stacking inaccuracy and mirror array destack, and by seeing. Optical errors introduced by the SAC are likely small although further testing with better tools will be required to confirm this. Errors due to tracking alignment were not investigated, and will be the focus of the next engineering period on the telescope. Finally, Hartmann testing of individual segments indicate that a small number of individual segments probably require maintenance attention. The Segment Alignment Maintenance System (SAMS) will address the destack issue, but to get below 1 arc-second images will require improved stacking. The image quality team thanks D. O’Donohue of the South African Astronomical Observatory for his vital participation in this effort. The current facility instrument on the HET is a low resolution spectrograph (LRS). The LRS (PI Gary Hill, McDonald Observatory) was successfully commissioned this year by Hill and his team in the long slit mode and substantial progress was made in testing its Multi-Object Slitlets configuration. Current information on the LRS can be found at: http://rhea.as.utexas.edu/HET_inst.html#Lrs.

E. Feigelson and Y. Tsuboi have been studying the over
1000 X-ray sources detected in the Orion Trapezium image from CXO. All classes of young stellar objects have been detected as well as several pre-brown dwarf stars. Many of the stars show temporal variability on many timescales.

G. Chartas has been studying the properties of a number of gravitational lenses in X-rays, possible for the first time with the very high angular resolution of the Chandra X-ray Observatory. In several cases there is an indication of flaring in the X-ray signal from one of the lensed images, suggesting that time delay measurements will be possible using correctly spaced observations, thereby leading to an independent measure of the Hubble Constant and possibly new information on the Cosmological Constant.

Y. Maeda has concentrated his efforts on understanding the diffuse emission surrounding SgrA*, where it appears that a supernova went off in the past several thousand years. The very unusual environment in the Galactic Center region has produced a remnant with unique properties, which may have some bearing on the extremely low X-ray luminosity of the SgrA* black hole, which is nearly $10^{-10}$ of the Eddington luminosity.

A. Garmire has discovered that the central X-ray source of the supernova remnant RCW103 has now optical counterpart to 24 Rmag, and that when in the low state it shows a nearly sinusoidal variation with a six hour period. Just three months after the first observation the central source brightened by nearly a factor of 100, something never before seen in an object at the center of a young supernova. G. Pavlov and V. Zavlin of Max Planck, confirmed the six hour period in archival ASCA data.

N. Brandt and A. Hornschemeier have worked one of the deepest Chandra observations of the X-ray sky containing the Hubble Deep Field North. Using the Hobby Eberly Telescope and the Keck telescope in Hawaii, fifty one of the nearly 200 sources detected in this exposure have measured redshifts. The bulk of the sources are found to lie at a redshift less than one, and the slope of the log N(redshifts. The bulk of the sources are found to lie at a redshift less than one, and the slope of the log N(redshifts.

Townsley and Broos also continued work on a model of charge transfer inefficiency (CTI), an effect of charge traps resulting in charge loss and the spatial redistribution of charge among pixels (trailing) in both the parallel and serial registers of ACIS CCDs. A CTI model is necessary to reproduce the spatially-dependent gain and QE of these devices (Townsley et al. 2000). This CTI model has been used to improve astrophysical results from ACIS FI devices as well (e.g. Hornschemeier et al. 2000), since they manifest the effects of radiation damage on-orbit as pronounced parallel CTI. It has been incorporated into the Monte Carlo CCD simulator described above.

The CCD simulator, including CTI, has been tuned to reproduce the QE, spectra, and event grades (charge distributions) seen in ground-based and flight calibration data for ACIS devices.

Chartas developed the software tool LYNX that employs a forward fitting approach to infer incident astrophysical spectra. LYNX differs from conventional deterministic tools in that the mirror and detector characteristics are determined by incorporating Monte-Carlo simulators. In particular LYNX links to the standard X-ray spectral fitting package XSPEC (Arnaud 1996) to provide an initial guess, to the raytrace tool MARX (Wise et al. 1997) to simulate the mirror response and to the PSU ACIS simulator (Townsley et al. 2000, in preparation) to provide the CCD response.

3.1.2.3 Sounding Rocket Project

Roming, Burrows, and Garmire in collaboration with Rouh and Leichty, have been working on the design of a wide-field (3.1 degree-squared field-of-view), short focal length (190.5 cm), grazing incidence mirror shell set, with a desired rms image spot size of 15 arcsec. The baseline design consists of Wolter I type mirror shells with polynomial perturbations applied to the baseline design. The overall optimization technique is to efficiently optimize the polynomial coefficients that directly influence the angular resolution, without stepping through the entire multi-dimensional coefficient space.

The optimization techniques investigated include the downhill simplex method, fractional factorial, and response surface (including Box-Behnken and central composite) designs. Also investigated was the use of neural networks, such as backpropagation, general regression (GRNN), and group method of data handling (GMDH) neural networks. The preliminary results have been published (Roming et al. 2000) and the final results will be published in a forthcoming paper.

In addition to the above methods, Markov Chain Monte Carlo (MCMC) algorithms are being investigated as a method for optimizing the multi-dimensional coefficient
space. Although MCMC algorithms are traditionally used to explore probability densities that result from a particular model specification, they can be used to create irreducible algorithms for optimizing arbitrary, bounded functions. In situations where very little is known, a priori, about a function and where the function may have multiple minimums, the irreducible nature of the MCMC algorithm combined with the ability to adapt MCMC algorithms offers a promising framework for optimizing this multi-dimensional complex function.

3.1.3 Multiple Wavelength Missions

3.1.3.1 The Swift GRB Explorer On October 24, 1999, NASA announced that a collaboration headed by the Goddard Space Flight Center and the Pennsylvania State University, were selected to build the next MIDEYS-sized Explorer satellite, named the Swift Gamma-Ray Burst Explorer. The Swift mission is designed to discover a thousand gamma-ray bursts within its three year life and follow up the gamma ray detections with X-ray and optical observations starting only tens of seconds after the burst detection. All Swift data on these bursts will be immediately sent to the ground, and made available to observers on the ground to make further observations.

The Penn State role in Swift is to provide the X-ray and UV/Optical telescope instruments (supported by contributions from partners at the University of Leicester (U.K.), the Mullard Space Science Lab (U.K.) and the Osservatorio Astronomico di Brera (Italy) and technical support from the Southwest Research Institute) and to supply and operate the Swift Mission Operations Center (supported by the Omitron Corp.) at Penn State. The PSU Swift team is lead by John Nousek. The X-ray, UV/Optical and Operations teams are lead by David Burrows, Peter Roming and Margaret Chester, respectively. Thirty-five PSU faculty, staff and students are currently working on the Swift project.

3.2 Observational Research

3.2.1 Stellar Astronomy

3.2.1.1 Pre-Main Sequence Stars Feigelson, with colleagues Warrick Lawson (UNSW) and former undergraduate Eric Mamajek (Arizona), pursued their discovery of an X-ray luminous cluster of pre-main sequence stars in the southern sky centered on η Chamaeleontis. This is the nearest open cluster found this century, and provides a rare opportunity to study a coeval group of stars with age ~10 Myr. In two studies completed this year, the existence of the cluster was firmly established, the low-mass members were found to be unusually magnetically active and rapidly rotating, and masses of the eclipsing binary RS Cha components were successfully compared to theoretical pre-main sequence evolutionary calculations. Kinematically study indicates the η Cha cluster, and the similar but more dispersed TW Hya association, originated in the same giant molecular cloud as the giant Sco-Cen OB association. This supports Feigelson’s (1996) model of T Tauri dispersion inherited from molecular cloud turbulent motions.

3.2.1.2 Stellar Clusters The Chandra ACIS team initiated its intensive program to investigate X-ray emission from young stars with a study of the rich cluster illuminating the Orion Nebula. Over 1000 sources are seen in the ACIS field (a record for X-ray astronomy). These include nearly all (cluster members above ~1 M⊙), even with extinctions to up A_V=60, a decreasing fraction of lower mass stars, but very few brown dwarfs. A well-defined subsample of solar-mass stars was examined and found to show very high levels of X-rays (L_x~2×10^30 erg/s) for the first t~2 Myr, whereafter some stars maintained a high level but others decreased by 1–2 orders of magnitude. Also, for the first time, stars in the deeply embedded Becklin-Neugebauer/Kleinman-Low region of current high-mass star formation were detected in X-rays, including possibly the BN object itself. Feigelson presented these and related early Chandra results on star forming regions at three conferences.

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.

3.2.1.3 Cool Stars The wide areal coverage, sensitivity, and long wavelength bandpass of the SDSS make it an effective survey for very cool stars. The SDSS has found a number of L and T dwarfs, objects with effective temperatures lower than M stars (for recent results see Fan et al. 2000 and Schneider et al. 2000). In the past year the first “L/T transition” objects were identified (Legget et al. 2000); in March 2000 the HET obtained the first optical spectrum of a transition object.

3.2.1.4 X-ray Transients Eracleous, in collaboration with in’t Zand (SRON), Halpern (Columbia), McCollough (USRA, Huntsville), Augusteijn (INGT, La Palma), Remillard (MIT), and Heise (SRON) has identified the optical counterpart of the transient X-ray source SAX J2239.3 +6116. The X-ray source was discovered in a program of regular monitoring of the Galactic center region with the BeppoSAX wide field camera. The optical counterpart is a B0 V to B2 III star with broadened emission lines at an approximate distance of 4.4 kpc. The X-ray source varies dramatically at regular intervals, as indicated by older X-ray observations.

3.2.1.5 Novae Wade collaborated with R. Prinja (UCL), C. Knigge (Columbia U.), and F. Ringwald (Florida Inst. of Tech.) in a study of episodic absorption in the outflow from the old nova V603 Aquilae. The data used were obtained using the Goddard High Resolution Spectrometer on HST. Blueshifted absorption in the ultraviolet resonance lines is present extending to roughly -2500 km s^-1, with variability down to timescales of one minute. At least three absorption events were recorded in a five-hour period, each lasting 10-15 min. In contrast, the emission components of the lines are very stable in velocity and strength. There is no clear relation between continuum “flares” and the absorption events, although the timescales for the two phenomena are similar.

Wade, Harlow, and Ciardullo published a study of biases in the statistical estimation of expansion distances of novae.
reviewing and formalizing the method in the case of prolate spheroidal shells. Expressions were derived for the maximum line-of-sight velocity from a complete, expanding shell and for its projected major and minor axes, in terms of the intrinsic axis ratio and the inclination of the polar axis to the line of sight. For prolate shells there is no unique angular size except when the shell is seen pole-on, and several different measures of angular size have been used in the literature. For each of these, the error in distance that is introduced under the assumption of spherical symmetry (i.e., without correcting for inclination and axis ratio) was tabulated. The errors can be significant and systematic, and can affect studies of novae whether considered individually or statistically. Each method overpredicts the distance when the polar axis is close to the line of sight, and most underpredict the distance when the polar axis is close to the plane of the sky. Use of the straight mean of the projected semimajor and semiminor axes gives the least distance bias for an ensemble of randomly oriented prolate shells; this method is recommended when individual inclinations and axis ratios cannot be ascertained. The best individual expansion distances, however, result from a full spatio-kinematic modeling of the nova shell. Several practical complications were discussed that affect expansion distance measurements of real nova shells. Nova shell expansion distances should be based on velocity and angular size measurements made contemporaneously, if possible, and the same ions and transitions should be used for the imaging and velocity measurements.

3.2.1.6 Interacting Binary Stars Brandt and Schulz (MIT) have presented the first grating-resolution X-ray spectra of the X-ray binary Circinus X-1, obtained with the High Energy Transmission Grating Spectrometer on Chandra. These reveal a rich set of lines from H-like and/or He-like Ne, Mg, Si, S and Fe detected with a high signal-to-noise ratio. The lines are broad ($\pm 2000 \text{ km s}^{-1}$) and show P Cygni profiles. The absorption components of the lines extend to low velocity, and they have about the same widths and strengths as the corresponding emission components. The widths of the X-ray P Cygni lines are comparable to that of the broad component of the strong, asymmetric H$\alpha$ line from Circinus X-1, suggesting that the two phenomena may be related. Outflow models suggest that the P Cygni profiles may arise in the moderate temperature ($\sim 5 \times 10^6 \text{ K}$) region of the wind from an X-ray heated accretion disk. This basic picture strengthens the idea that the accretion disk in Circinus X-1 is viewed in a relatively edge-on manner, and it suggests that Circinus X-1 is the X-ray binary analog of a Broad Absorption Line quasar.

3.2.1.7 Galactic Center Maeda, in collaboration with T. Tanaka, K. Koyama, and T. Sonobe, have continued the analysis of the diffuse emission in a $1^\circ \times 1^\circ$ region of the Galactic center using the ASCA data. The observed spectrum contains prominent emission lines from helium-like and hydrogen-like ions of various elements, and is essentially the same all over the region. If the observed spectrum is thermal emission from hot plasmas, it requires multi-temperature plasma components, each at a different degree of ionization and with a different amount of absorption. The absence of adiabatic cooling and of systematic changes in the degree of ionization over the region is against the Galactic center origin of hot plasmas. A significant broadening of the helium-like and hydrogen-like iron K-lines is confirmed. The line width corresponds to a rms velocity of $\sim 3300 \text{ km s}^{-1}$, which far exceeds the sound velocity in a plasma of $kT \sim 14 \text{ keV}$ measured with the Ginga satellite. These facts cast doubt on a thermal origin of the observed X-ray emission.

Maeda, in collaboration with H. Murakami, K. Koyama, M. Sakano, and M. Tsujimoto, performed 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.

Maeda, in collaboration with M. Sakano and others, continue to study the column density distribution of X-ray binaries in the Galactic Center region using the X-ray satellite ASCA, and demonstrate a new method of the total mass determination near the Galactic Center. The column densities of these X-ray sources are given by a simple function of the angular distance from the Galactic Plane. Assuming a disk-like mass distribution of 500 pc radius and a distance to the Galactic Center to be 8.5 kpc, we estimate the total mass to be $\sim 4 \times 10^4 M_\odot$. We compare our results with the past results of other wavelength observations, and suggest the cold interstellar matter is pressure-bounded by the hot gas or strong magnetic field in the Galactic Center region.

3.2.1.8 Neutron Stars, Pulsars, and Central Compact Objects in Supernova Remnants Garmire, Pavlov, and Zavlin (MPE, Germany) observed 1E 161348–5055, the compact central source of the RCW 103 SNR, with the Chandra X-ray observatory. The position of the source is determined with an accuracy of 0.5". No optical counterpart (to mag $R = 24$) is seen closer than 3.95" from the source. The observed flux is $9.6 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$ in the band 0.4–10 keV, which corresponds to a luminosity of at least $1 \times 10^{33} \text{ erg s}^{-1}$ for a distance of 3.3 kpc. The light-curve is compatible with a fragment of a sinusoid with period 5.97 ($+0.47$, $-0.44$) hr and pulsed fraction of about 60%. Variations with period 6.05 ($+0.28$, $-0.35$) hr were found for this source in the ASCA archival data. The 6-hr periodicity hints that the source may be a low-mass binary with an underluminous companion and unusually low X-ray luminosity. This is the first observation of such a long periodicity of a compact remnant of a supernova explosion.

Pavlov, Zavlin, Aschenbach, Trümper (MPE, Germany), and Sanwal analyzed Chandra observations of the compact central object of Cassiopeia A. This source was discovered with Chandra and found later in the archival ROSAT and Einstein images (Pavlov & Zavlin 1999). The analysis of these data does not show statistically significant variability.
of the source. Because of the small number of photons detected, different spectral models can fit the observed spectrum. The power-law fit yields the photon index $\gamma = 2.6 - 4.1$, higher than those observed from very young pulsars. One can fit the spectrum equally well with a blackbody model with $T = 6 - 8$ MK, $R = 0.2 - 0.5$ km, and $L_{\text{bol}} = (1.4 - 1.9) \times 10^{33}$ erg s$^{-1}$. The inferred radii are too small, and the temperatures too high, for the radiation to be interpreted as emitted from the whole surface of a uniformly heated neutron star. One cannot exclude, however, the possibility that the observed emission originates from hot spots on a cooler neutron star surface. For instance, the source may be a strongly magnetized neutron star with magnetically confined neutron star surface. For example, the source may be a strongly magnetized neutron star with magnetically confined hydrogen or helium polar caps ($T_{\text{pc}} = 2.8$ MK, $R_{\text{pc}} = 1$ km) on a cooler iron surface ($T_{\text{c}} = 1.7$ MK). Such temperatures are consistent with the standard models of neutron star cooling. Alternatively, the observed radiation may be interpreted as emitted by a compact object (more likely, a black hole) accreting from a residual disk or from a late-type dwarf in a close binary.

Zavlin, Trümper (MPE, Germany) and Pavlov showed that the X-ray spectrum of the compact central object 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, $T_{\text{eff}} = 1.6 - 1.9$ 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.

Zavlin (MPE, Germany), Pavlov, Sanwal, and Trümper (MPE, Germany) observed the central source of the supernova remnant PKS 1209-51/52 with Chandra. The timing analysis of the data yields a period $P = 0.42412924 \pm 0.23 \mu s$. The detection of this short period proves that the source is a neutron star. It may be either an active pulsar with an unfavorably directed radio beam or a truly radio-silent neutron star whose X-ray pulsations are caused by a nonuniform distribution of surface temperature.

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 $\sim 10 - 30\%$, 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 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 (UCSB), Brown (Berkeley), Pavlov, and Zavlin (MPE, Germany) 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.

Pavlov and Zavlin (MPE, Germany) reviewed observations of thermal radiation from neutron stars and its interpretation in terms of neutron star atmosphere models. So far, thermal soft X-ray radiation has been certainly observed from four isolated pulsars, two radio-quiet central compact objects in supernova remnants, and two isolated radio-quiet neutron stars. Thermal optical radiation has been apparently observed from four pulsars and two isolated radio-quiet neutron stars. The spectra and luminosities of the thermal radiation from some of these objects can be fitted with hydrogen or helium atmosphere models, which shows that these neutron stars have accreted some interstellar or circumstellar matter. Emission from the other neutron stars is consistent with a hypothesis that their surface layers are comprised of heavy elements, presumably iron.

Pavlov, Sanwal, Garmire, Zavlin, Burwitz (MPE, Germany), and Dodson (Hobart Univ., Australia) reported observations of the Vela pulsar and the surrounding compact X-ray nebula with the Chandra X-ray observatory. The superb angular resolution allowed them to resolve a complex structure within 2' around the pulsar. It includes a two-sided asymmetrical jet at a position angle of 127°, coinciding with the position angle of pulsar’s proper motion. The nebula is symmetrical with respect to the jet direction (interpreted as the pulsar’s spin axis) and has a cometary shape, with a bright, narrow (<4") bow-shaped front edge, of about 40' maximum size. The pulsar is enveloped by a smaller torus-like nebula of 30' maximum size. The observations were carried out 4, 12, 36 and 105 days after the powerful glitch of 2000 January 16. A 3σ upper limit of 0.7% on the difference between the pulsar’s fluxes in the first and third observations, taken with the same instrument, corresponds to an upper limit of 0.3% on temperature change. The shape of the light curve does not show statistically significant variations. The soft X-ray pulse profile consists of at least three distinct peaks (total pulsed fraction is about 11%). Two peaks are apparently associated with those observed in hard X-rays and gamma-rays and are probably due to nonthermal radiation emitted by relativistic particles ejected from the pulsar. The lowest of the three peaks, and possibly a fourth peak shifted by half a period from the third one and merged with the two higher peaks, may be caused by periodic modulation of the thermal X-ray flux due to hot polar caps, with a temperature of 6 MK and a radius of 100 m. Alternatively, the presence of the additional peak(s) might indicate that the nonthermal radiation is generated at two distinct sites in the pulsar magnetosphere.

Sanwal, Pavlov, Kopitshev (Ioffe Inst., Russia), Zavlin (MPE, Germany), Teter, Tsuruta (Montana State) and Halpern (Columbia) analyzed Chandra observations of the middle-aged radio and gamma-ray pulsar 1055–52. The pulsar’s light curves are quite different in different energy bands, and the spectra are phase-dependent. The pulse profile is very broad and smooth for lower energies, while it is much
narrower and centered at a different phase at higher energies. The light curve is apparently composed of several (at least two) components with different spectral properties. The spectrum can be fitted with a three-component model which includes soft thermal radiation from the neutron star surface, hard thermal radiation from hot polar caps, and nonthermal radiation from the magnetosphere.

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

3.2.1.9 Galactic Structure Schneider is a member of the Hubble Space Telescope Quasar Absorption Line Key Project Team. This long-term program used the Faint Object Spectrograph of HST to obtain R=1300 ultraviolet spectra of dozens of bright quasars for the purpose of constructing a catalog of absorption lines. The primary motivation of the project was to investigate the extragalactic nature of the lines, but the data base included a wealth of information on Galactic structure, as each observation contained a number of absorption features produced by material in the Galaxy. The Key Project Team has just published their analysis of the Galactic absorption lines (Savage et al. 2000).

3.2.2 Extragalactic Astronomy

3.2.2.1 Planetary Nebulae R. Ciardullo, J. Feldmeier, and G. Jacoby (NOAO), have continued their large scale [O III] $\lambda$5007 survey for intracluster planetary nebulae (IPN) in nearby clusters. Using mosaic CCD imagers at Kitt Peak and Cerro Tololo, Ciardullo et al. have imaged over 0.97 square degrees in Virgo, and 0.7 square degrees in Fornax. In addition, smaller surveys have also been conducted in the Leo I and M81 Groups. These surveys have turned up over 500 IPN candidates. Spectroscopy of a small sample of these objects has already been performed with the European Very Large Telescope and the Anglo Australian Telescope; these data suggest that 20% of the emission lines sources are not intracluster planetary nebulae, but starburst galaxies at $z = 3.13$, where $Ly\alpha$ is redshifted into the bandpass of the [O III] filter. The analysis of a separate blank-field image confirms this level of contamination. The next step is to perform spectroscopy of the northern sample of objects with the Hobby-Eberly Telescope. When this is done, Ciardullo et al. will not only be able to study the kinematics of a significant sample of IPN to determine their origin, but will also have an extremely large sample of high-redshift starburst galaxies ready for analysis.

3.2.2.2 Dwarf Galaxies and Globular Clusters in Tidal Debris Undergraduate student Karen Knierman (now a graduate student at Arizona) discovered compact star clusters in the tidal debris of the merger NGC 3256, using WFPC2 images from the Hubble Space Telescope. With collaborators Jane Charlton, Sarah Gallagher, Sally Hunsberger, Brad Whitmore (STScI), Arunan Kundu (Virginia), John Hibbard (NRAO), and Dennis Zaritsky (Arizona), Knierman also searched for these clusters in the debris of the merger remnants NGC 4038/9, NGC 7252, and NGC 3921. Despite the great abundance of clusters in the central regions of all these mergers, they were absent in the tidal debris. The most obvious difference between the mergers is the absence of larger extended dwarf galaxies in NGC 3256 which led the group to suggest that the processes of star formation lead to smaller “packages” in this case. The group has proposed observations of the debris in additional mergers to test this hypothesis.

Large numbers of compact star clusters are also found in the Hickson Compact group known as Stephan’s Quintet. Hubble Space Telescope WFPC2 images of the Quintet have been analyzed by graduate student Sarah Gallagher (along with Charlton, Hunsberger, and Zaritsky (Arizona). The images, in the $B$, $V$, and $I$ bands facilitate rough estimates of the ages of the stellar populations. The dynamical history of this group involves the fast passage of one of the galaxies past a region rich in H I debris from a previous interaction. This apparently triggers star formation that continues past the time of interaction, but the region also contains an intermediate age population as well as an old population that must have been stripped from the galaxies. The group has proposed $U$–band images and spectra to obtain more precise ages of the young populations. Also they have recently obtained new WFPC2 images of another compact group, Hickson compact group 79, which will be used to construct the dynamical history of that group.

3.2.2.3 Low-Luminosity Active Galactic Nuclei The Chandra ACIS team is engaged in X-ray studies of starburst nuclei and low-luminosity active galactic nuclei (LLAGN) in nearby galaxies. The first two studies emerged in the past year. One is a high-resolution imaging spectroscopic study of the core of M 82, the nearest starburst (Griffiths et al.). It shows a highly structured diffuse component with iron line emission, indicating that it is mainly thermal rather than inverse Compton in origin. This gas, probably produced from many merged supernova remnants, drives the well-known galactic wind from the disk. About 20 very luminous and hard-spectrum X-ray binaries are also seen, and there is no evidence for a central LLAGN. The second study is a snapshot survey of nearby LLAGNs selected as weak Seyferts or LINERS from optical spectroscopy (Ho et al.). We see a great variety of LLAGN properties, ranging from a nuclear source that greatly outshines stellar sources to a nuclear source comparable to or much fainter than X-ray binaries. The sample extends the well-established $L_{X}$–$L_{F\alpha}$ AGN relationship, but with systematically lower $L_{X}$ values.
3.2.2.4 Active Galaxies and Quasars  Charts collaborations with a team of researchers from CFA, MIT, Bristol University, NASA, ATNF, Ohio University and JPL reported the discovery of a remarkable X-ray Jet in the Radio-Loud Quasar PKS 0637-752. By applying spatial analysis techniques to the Chandra observations of the quasar PKS 0637-752, Chartas et al. revealed the detailed X-ray morphology of an X-ray jet in the core-dominated radio-loud quasar that extends about 10 arcsec to the west of the nucleus. At least four X-ray knots were resolved along the jet, which contains about 5% of the overall X-ray luminosity of the source. Chartas et al. also tested a variety of emission models to the observed spectral distribution of the jet, and examined plausible X-ray emission mechanisms.

Collinge (Penn State) and Brandt have presented analyses of the ASCA X-ray spectra of two Seyfert galaxies, Tololo 0109–383 and ESO 138–G1. In both cases, spectral fitting reveals two statistically acceptable continuum models: Compton reflection and partial covering. Both spectra have strong iron Kα lines, with equivalent widths greater than 1.5 keV. These large equivalent widths are suggestive of heavier obscuration than that directly indicated by the partial covering models ($\approx 2 \times 10^{23}$ cm$^{-2}$), with the actual column densities being ‘Compton-thick’ (i.e., $N_{H}=1.5 \times 10^{25}$ cm$^{-2}$). The hard X-ray/O III flux correlation for Seyferts and data from the literature provide additional support for this hypothesis. Since Tololo 0109–383 is known to have optical type 1 characteristics such as broad Balmer line components and Fe II emission, this result marks it as a notable object.

Kaspi (Penn State), Brandt and Schneider have reported on a search for X-ray emission from quasars with $z > 4$ using the ROSAT public database. This search has doubled the number of $z > 4$ quasars detected in X-rays from 6 to 12. Most of those known prior to this work were radio-loud and X-ray selected sources; the new study increases the number of X-ray detected, optically selected $z > 4$ quasars from one to seven. The $z > 4$ quasars do not show any strong broadband spectral differences from quasars at lower redshifts.

Kaspi, Brandt, Netzer (Tel Aviv) and other members of the ACIS team have presented the first grating-resolution X-ray spectra of the Seyfert 1 galaxy NGC 3783, obtained with the High Energy Transmission Grating Spectrometer on Chandra. These spectra reveal many narrow absorption lines from the H-like and He-like ions of O, Ne, Mg, Si and Ar, as well as Fe xvi–Fe xxi L-shell lines. They have also identified several weak emission lines, mainly from O and Ne. The absorption lines are blueshifted by a mean velocity of $\approx 440 \pm 200$ km s$^{-1}$ and are not resolved, indicating a velocity dispersion within the absorbing gas of a few hundred km s$^{-1}$ or less. The lines’ equivalent widths have been measured and compared with the predictions of photoionization models. The best-fitting model has a microturbulence velocity of 150 km s$^{-1}$ and a hydrogen column density of $1.3 \times 10^{22}$ cm$^{-2}$. The measured blueshifts and inferred velocity dispersions of the X-ray absorption lines are consistent with those of the strongest UV absorption lines observed in this object. However, simple models that propose to strictly unify the X-ray and UV absorbers have difficulty explaining simultaneously the X-ray and UV absorption line strengths.

Donald Schneider has been using the Marcario Low Resolution Spectrograph (LRS) of the Hobby-Eberly Telescope (HET) to investigate high-redshift quasars (Fan et al. 2001a,b; Schneider et al. 2000a,b, 2001; and Zheng et al. 2000), low mass stars/brown dwarfs (Legget et al. 2000, Schneider et al. 2000b), and the 2-10 keV X-ray background (Brandt et al. 2000).

The Sloan Digital Sky Survey (SDSS) has been undergoing commissioning in the past year, and Schneider and postdoctoral scholar Gordon Richards, along with Xiaohui Fan and Michael Strauss of Princeton University and Wei Zheng of Johns Hopkins University, are leading an investigation of the properties of high-redshift ($z > 3.5$) quasars. To date the SDSS has discovered 107 high-redshift quasars (see Schneider et al. 2001 and references therein), including the most distant known quasar ($z = 5.80$, Fan et al. 2000b). Spectroscopy of the quasars was done with the HET, the Apache Point 3.5-m, and the Keck telescopes.

The quasar luminosity function was investigated using a carefully constructed sample of 39 SDSS high-redshift quasars (Fan et al. 2001a,b), a sample roughly twice as large as previous work at these redshifts. The SDSS study confirmed the finding of previous works that the number density of luminous quasars dramatically declines between redshifts of 3.5 and 4.5, and the SDSS data allowed the first probe of the $z > 4.5$ quasar number density, and finds that the decline continues. The SDSS group is currently using the SDSS, HET, APO, and Keck telescope to assemble a new high-redshift sample, covering more area and going one magnitude fainter than the Fan et al. 2001a,b studies.

In June 2000, an observation of an SDSS high-redshift quasar candidate with the HET led to a surprising result: the object was indeed a quasar ($z = 4.25$), but a fainter object located 33” from the quasar, which just happened to fall into the LRS slit, was also a $z = 4.25$ quasar! The quasars are separated by a few hundred kpc. This is the third serendipitous discovery of a $z > 4$ quasar.

One of the SDSS quasars, at a redshift of 5.0, was detected in a mm observation; this is the most distant source of mm radiation yet found, and the optical/mm/radio observations indicated that the mm radiation is produced by dust associated with the quasar (Carilli et al. 2000).

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 $z < z < 2.2$. Here the value $z = 2.2$ is the limit imposed by the ‘‘U’’ or ultraviolet selection criterion of the US survey, while the value $z_0$ is the magnitude-dependent solution of the morphology cutoff condition $B = 21 - 3/4z$ for objects unresolved on plates POSS-I of the Palomar Observatory Sky Survey. This morphology condition is the ‘‘S’’ or ‘‘starlike’’ component of the US survey. Usher & Mitchell (2000) define these and other selection conditions and present a new statistically complete sample of quasars brighter than $B = 16.95$ mag. This sample is compared to other complete samples with a sufficiently large $n$ at bright magnitudes. Like the Medium-Bright Quasar Sample (MBQS) which was also derived from the US Survey, the new sample gives surface densities higher than most other surveys. Only the Hamburg/ESO
(HES) and Edinburgh (EQS) quasar samples have comparable surface densities. Moreover, the redshift distribution of the new sample suggests that selection in the US survey is complete to $z_s \approx 0.2$ based on comparison both with data from the Hamburg/ESO survey and with semi-empirical prediction of luminosity-dependent luminosity quasar evolution, indicating that the morphology or ‘‘S’’ component of the US survey has been properly implemented. Statistical tests on the three combined samples indicate that there is about a 91% chance that an excess of quasars at redshift $\approx 0.55$ is anomalous. This combined sample has an $n = 53$ and is currently the best available sample of bright quasars.

### 3.2.2.5 Broad Absorption Line Quasars

Gallagher (Penn State), Brandt, Laor (Technion) and collaborators have presented the best hard X-ray study to date of soft X-ray weak Active Galactic Nuclei (AGN). Recent ROSAT studies have identified a significant population of AGN that are notoriously faint in soft X-rays relative to their optical fluxes. Are these objects intrinsically X-ray weak or are they just highly absorbed? Brandt, Laor & Wills have systematically examined the optical and UV spectral properties of a well-defined sample of these soft X-ray weak (SXW) AGN drawn from the Boroson & Green sample of all the Palomar Green AGN with $z < 0.5$. Gallagher et al. have now presented ASCA observations of three of these SXW AGN: PG 1011–040, PG 1535+547 (Mrk 486), and PG 2112+059. In general, these ASCA observations support the intrinsic absorption scenario for explaining soft X-ray weakness; both PG 1535+547 and PG 2112+059 show significant column densities ($N_H \approx 10^{23} - 10^{24}$ cm$^{-2}$) of absorbing gas. Interestingly, PG 1011–040 shows no spectral evidence for X-ray absorption. The weak X-ray emission may result from very strong absorption of a partially covered source, or this AGN may be intrinsically X-ray weak. PG 2112+059 is a Broad Absorption Line QSO, and the ASCA data show it to have the highest X-ray flux known of this class. It shows a typical power-law X-ray continuum above 3 keV; this is the first direct evidence that Broad Absorption Line QSOs indeed have normal X-ray continua underlying their intrinsic absorption. Finally, marked variability between the ROSAT and ASCA observations of PG 1535+547 and PG 2112+059 suggests that the soft X-ray weak designation may be transient, and multi-epoch 0.1–10.0 keV X-ray observations are required to constrain variability of the absorber and continuum.

### 3.2.2.6 Intrinsic Quasar Absorption Lines

Ganguly, for his Ph.D. thesis, is focusing on the study of intrinsic narrow absorption lines (NALs). Faculty members Jane Charlton, Michael Eracleous, Chris Churchill, and Niel Brandt are involved in these efforts. The group has completed a study of $z < 1$ NALs from the FOS/HST archive, and is beginning to collect STIS spectra from an HST snapshot program in order to analyze the variability of these narrow absorption lines, about two-thirds of which are likely to be intrinsic. They are also collecting low resolution spectra in a synoptic program with the Hobby–Eberly Telescope (HET) of a large sample of high redshift quasars. A detailed study of the physical conditions in the absorbers that are found to be intrinsic will be undertaken with the HRS on the HET.

A paper by Ganguly, Bond, Charlton, Eracleous, Brandt, and Churchill, has recently been accepted. The paper presents analysis of HST/FOS archival spectra to find NALs in $z < 1$ quasars. The quasars from the HST Quasar Absorption Line Key Project were reanalyzed in order with the goal of determining the difference between quasars that host intrinsic narrow absorption line systems and those that do not. Statistically, Ganguly et al. found that about 15% of quasars at low redshift host intrinsic NALs. Although the host QSOs of NALs have varied radio, optical, and emission line properties, they did find an area in parameter space that seems to prohibit the presence of NAL in quasars. This region includes radio–loud QSOs which have flat radio spectra ($\alpha (5\text{GHz}) > -0.5$) and normal C IV FWHM ($\approx 3500$ km/s). They also found that BALQSOs have an enhanced probability of hosting detectable NAL gas. They interpreted these trends in the context of the Murray–Chiang wind model. Intrinsic NALs may be rare along lines of sight toward quasars with relatively low accretion rates which are viewed face–on.

### 3.2.2.7 Gamma-Ray Sources

Eracleous has collaborated with Halpern, Uglesich, Mirabal (Columbia), Halpern (Columbia), and Becker (U.C. Davis) have been searching for the optical counterpart of the high-Galactic latitude $\gamma$-ray source 3EG J1835+5918 through an exhaustive multiwavelength study of the region around it. This study includes including X-ray, radio, and optical imaging surveys, as well as optical spectroscopic classification of most of the active objects in this area. The identified X-ray sources in or near the EGRET error ellipse are radio-quiet QSOs, a galaxy cluster, and coronal emitting stars. The radio sources inside the error ellipse are all fainter than 4 mJy at 1.4 GHz. In addition there are no flat-spectrum radio sources in the vicinity. Since no blazar-like or pulsar-like candidate has been found as a result of these searches, 3EG J1835+5918 must be lacking one or more of the physically essential attributes of these known classes of gamma-ray emitters. If it is an AGN it lacks the beamed radio emission of blazars by at least a factor of 100 relative to identified EGRET blazars. If it is an isolated neutron star, it lacks the steady thermal X-rays from a cooling surface and the magnetospheric non-thermal X-ray emission that is characteristic of all EGRET pulsars. If a pulsar, 3EG J1835+5918 must be either older or more distant than Geminga, and probably an even more efficient or beamed gamma-ray engine.

### 3.2.2.8 Gamma-Ray Sources

Eracleous has collaborated with Halpern, Uglesich, Mirabal (Columbia), Kassin (Ohio State), Thorstensen (Dartmouth), Keel (Alabama), Diercks, Bloom, Harrison (CalTech), and Mattox (Boston U.) to study the optical afterglow of GRB 991216. The optical light curve of this $\gamma$-ray burst consists with jet-like behavior in which a power-law decay steepens gradually from an index of -1.22 at early times to an index of -1.53 after 2 days. Thus GRB 991216 is the third good example of a jet-like afterglow (following GRB 990123 and GRB 990510), supporting a trend in which the apparently most energetic gamma-ray events have the narrowest collimation and a uniform ISM environment.

### 3.2.2.9 LINERS

Eracleous, in collaboration with Ho (OCIW), Rudnick (Arizona), Rix (MPIA), Shields (Ohio U.), McIntosh (Arizona), Filippenko (U.C. Berkeley), and Sar-
gent (CalTech) has studied the double-peaked Balmer lines of NGC 4450 discovered by the Hubble Space Telescope. This characteristic line profile, previously seen in a few nearby LINERs and in a small fraction of broad-line radio galaxies, can be interpreted as a kinematic signature of a relativistic accretion disk. A number of LINERs are now known to host double-peaked emission lines and their properties are very similar to those of the broad-line radio galaxies previously known to host such lines.

3.2.2.9 Quasar Absorption Lines and Galaxy Evolution

The Quasar Absorption Line (QAL) team at Penn State continued their efforts to analyze quasar spectra in order to study the distribution of gas in all sorts of galaxies and intergalactic structures. The group, led by Chris Churchill and Jane Charlton, included graduate students Rajib Ganguly and Jie Ding, and undergraduate students Jane Rigby (now a graduate student at Arizona), Rick Mellon, Nick Bond, and Stephanie Zonak. Local faculty collaborators include Niel Brandt, Michael Eracleous, and Donald Schneider. Environments probed by QAL’s included small (~10 pc) metal–enriched pockets separate from giant galaxies, a damped Ly $\alpha$ absorber that is invisible despite its huge column density of gas, and coronae of other galaxies which seem to be maintained by star formation in their disks. The Hubble Space Telescope component of the program has grown with Churchill’s successful Cycle 9 program to study the multiple phases of gas in 19 $z \sim 1$ Mg II absorbers with high resolution Space Telescope Imaging Spectrograph (STIS) data. Observations for that program are planned to begin in December 2000. The group also anticipates surveys and detailed studies in the next year, using the High Resolution Spectrograph and the JCAM near–IR spectrograph on the Hobby–Eberly Telescope.

For redshift 0.4 to 1.4, a complete study of a large variety of chemical species is facilitated by a combination of optical and UV spectroscopy. Churchill, Mellon, Charlton, B. Januzzi (NOAO), S. Kirhakos (Princeton), C. Steidel (Caltech) and Schneider complete a study of 45 Mg II absorbers using low resolution HST Faint Object Spectrograph (FOS) data in conjunction with high resolution HIRES/Keck spectra. The first paper in the series presents spectra of all the transitions covered for each system and looks for trends between absorption strengths of the different transitions. Analysis yields the result that the Mg II absorbing galaxies have multiple phases, not unlike the interstellar medium and halo/coronae of the Milky Way and local galaxies. In the second paper of the series, the focus was on the equivalent widths of the Mg II, Fe II, Ly$\alpha$, and C IV lines, and the kinematics of the Mg II. A multi–variate clustering analysis was applied to the data in order to identify five categories of absorbers: “Classic,” “CIV–deficient,” “Single/Weak,” “Double,” and “DLA/H I–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. For 16 of the absorbers, galaxy properties were compared to the gas properties. It is significant that there were no strong correlations, but there is a hint that early type galaxies may tend to be C IV–deficient.

Rigby, Charlton, and Churchill investigated the physical properties of single–cloud, narrow, weak Mg II absorbers (those with equivalent widths $W_r(2796)<0.3$ Å). These sub–Lyman limit systems comprise a population distinct from strong Mg II absorption systems and are not closely associated with bright (L$^*$) galaxies. Rigby, Charlton, and Churchill found column densities and Doppler parameters for Mg II and Fe II from HIRES/Keck spectra at resolution $R=6.6$ km/s. Using these fits and FOS/HST ($R\sim230$ km/s) ultraviolet spectra as constraints, they modeled the absorbers with the photoionization code Cloudy to infer metallicities and ionization parameters. They found that: 1) weak Mg II systems account for a significant fraction of the $N$(H I) $\sim 10^{16}$ cm$^{-2}$ Ly$\alpha$ forest; 2) at least 7 of 15 absorbers contain at least two phases of gas: a low–ionization, narrow component which contains the bulk of the Mg II and Fe II gas; and a broader, high–ionization phase which is responsible for most of the C IV and Ly$\alpha$ absorption; 3) weak Mg II absorbers can be divided into two subclasses, those with and without $N$(Fe II) $\sim N$(Mg II). The sizes of the iron–rich clouds are constrained as $\sim 10$ pc. At this size, if the clouds are spherical, then to produce the observed cross–section, they should outnumber bright (L$^*$) galaxies by approximately six orders of magnitude. The iron–rich weak Mg II absorbers require enrichment by Type Ia supernovae. We discuss how star clusters or supernova remnants in dwarf galaxies might give rise to such absorption. The clouds with relatively less Fe II are less well constrained. They may be $\alpha$–enhanced, but similar in nature to the iron–rich class, and they may be associated with sub–Lyman limit high velocity clouds in galaxy groups.

Based upon those studies of intermediate redshift Mg II absorbers Charlton, Churchill, and Rigby have contributed to the heated debate on the nature of high velocity clouds (HVC) around the Milky Way. Evidence from the work of Blitz/Spergel et al. and from Braun and Burton strongly suggest that a significant fraction of these clouds have an extragalactic origin. In that model, the HVC are clouds originating as cold dark matter mini–halos that are falling toward the barycenter of the Local Group, rather than toward any particular galaxy. The typical Milky Way HVC would be at a distance of 700 kpc. However, the statistics of Mg II absorbers show that redshift 0.5 groups cannot contain such a population of intragroup clouds. This work constrains the intragroup HVCs to have extremely clumpy structure or to be within 100–200 kpc of the luminous group galaxies.

In many ways, “satellite” subsystems of strong Mg II absorbers are similar to weak Mg II absorbers. Churchill and S. Vogt (UCSC) submitted a paper that presents a kinematic survey of 23 $z \sim 1$ strong ($W_r(2796)>0.3$ Å) absorbers. The most common kinematic structure in this sample consists of a dominant system (velocity spreads 10–50 km/s) with weaker subsystems out to $\sim 400$ km/s. The subsystems are asymmetrically distributed in the sense that they are either all redshifted or all blueshifted, but not both. This can be explained with a model in which the dominant system results from absorption in a rotating disk, and the subsystems from clouds in a halo that are offset kinematically from the disk. The “satellite” subsystems are not consistent with being the
anals of high velocity clouds; they are inferred to have sub–Lyman limit column densities.

Both the weakest and the strongest Mg II absorbers can be associated with gas that is far from bright galaxies. N. Bouché (U. Mass), J. Lowenthal (U. Mass), M. Bershady (Wisconsin), Charlton, Churchill, and C. Steidel (Caltech) completed they analysis of an HST/NICMOS image of the field of an elusive damped Lyα cloud at \( z = 0.6 \). Narrow–band images were obtained that cover the redshifted H–α line for this damped Lyα absorber towards the quasar 3C336. Even in these deep images, there is no trace of the galaxy responsible for the strong absorption, that is the star formation rate must be small despite the large amount of neutral gas. We found that this DLA has a small C IV equivalent width. Churchill and Charlton have in previous papers hypothesized that there is a relationship between C IV and star formation. The small C IV equivalent width for this DLA is consistent with this hypothesis. We propose that lines of sight through pockets of high density material in low luminosity galaxies or gas clouds are responsible for many damped Lyα absorbers. Most other lines of sight through the lower density surrounding medium in the proposed, highly structured objects would not even commonly give rise to Lyman limit breaks.

Up until this year there were no high resolution spectra covering the Lyman series and the high ionization transitions for intermediate redshift Mg II absorbers. However, this year the quasar PG 1634+706 has been observed with STIS/HST at high resolution (\( R = 30,000 \)), and those data became public in June 2000. In anticipation of these data becoming public, Charlton, Mellon, Rigby, and Churchill wrote a paper that used previously available low resolution (\( R = 1,300 \)) FOS/HST data (in conjunction with HIRES/Keck spectra covering low ionization transitions at higher resolution) to constrain the physical conditions in the four Mg II absorbers along this line of sight. In general, it is possible to constrain the low ionization Mg II phase and to infer the presence of an additional high ionization phase, but not to infer the detailed properties of the latter. Using some examples of consistent models, STIS high resolution profiles of the key transitions that are covered by the new observations were simulated at the expected signal–to–noise. This study serves as a fair test of the applicability of the photoionization modeling of a combination of low and high resolution profiles.

The QAL team (Charlton, Churchill, Ding, and Zonak) will soon submit a paper analyzing the new high resolution STIS/HST spectrum for three single cloud weak Mg II absorbers along the PG 1634+706 line of sight. One of these absorbers was newly discovered because of the C IV doublet observed in the newly spectrum; the Mg II doublet had been missed in a previous survey using the HIRES/Keck data because it was just below the detection threshold. Photo–ionization models show conclusively that the low and high ionization absorption arise in different phases/clouds. In the \( z = 0.81 \) absorber a phase that produced the broader C IV profile is centered kinematically on the low ionization phase. In the \( z = 0.90 \) the C IV phase is offset in velocity, or there are two C IV clouds that produce a structure that is asymmetric relative to the Mg II. Both of those systems have close to solar metallicity, but the \( z = 0.65 \) may have a considerably lower metallicity. It is distinctive because of its series of C IV clouds, only the bluest of which has a low enough ionization parameter to show detectable Mg II absorption. Preliminary analysis of the two stronger Mg II absorbers along the same line of sight show reasonable agreement with the inferences from our previous modeling effort.

Bond, Churchill, and Charlton have done a case study of a kinematically complex absorption profile in a \( z = 0.7 \) Mg II absorber observed toward Q1331+170. The regular patterns in the profile suggest that organized processes might be responsible. A bright spiral galaxy is seen at an impact parameter of \( \sim 20 \) kpc from the quasar, and the line of sight passes a few kpc above the disk of the galaxy. An analysis of the brightnesses and colors of the galaxies in the field indicates that two other less luminous galaxies could also be at this redshift. Bond, Churchill, and Charlton determined, using Cloudy photoionization models, that bubbles with the appropriate velocity separations and MgII column densities arise from a reasonable part of the parameter space describing superbubbles from O/B associations. They also consider the possibility that usual ISM structure in a pair or group of galaxies gives rise to the profile, but find that it would be quite rare to intercept by chance such a regular pattern.

### 3.2.2.11 Extragalactic X-ray Background

Brandt (Penn State), Hornschemeier (Penn State), Schneider (Penn State), Garmire (Penn State) and other members of the ACIS team presented some of the first results on the X-ray background from Chandra. They studied 2–8 keV X-ray sources detected by ACIS in the field of the \( z = 0.516 \) cluster CRSS J0030.5+2618. In the 63.5 arcmin² search area, they detected 10 sources with 2–8 keV fluxes down to \( \sim 4 \times 10^{-15} \) erg cm⁻² s⁻¹; the lowest flux sources were \( \sim 10 \) times fainter than those previously available for study in this band. Their derived source density was about an order of magnitude larger than previous source counts above 2 keV. The Low Resolution Spectrograph on the Hobby–Eberly Telescope was used to obtain optical spectra for several of the detected sources; combining these spectra with archival data showed that the sources appear to be active galaxies, often with narrow permitted lines, red optical continua or hard X-ray spectra. Four of the X-ray sources are undetected at \( R = 21.7 \); if they reside in \( L^* \) galaxies they must have \( z > 0.55–0.75 \) and hard X-ray luminosities of \( L_{2–8} \approx 4 \times 10^{39} \) erg s⁻¹. All but one of the 2–8 keV sources was detected in the 0.2–2 keV band as well. This result extends to significantly lower fluxes the constraints on any large, completely new population of X-ray sources that appears above 2–3 keV.

Hornschemeier, Brandt, Garmire, Schneider and other members of the ACIS team presented first results from an X-ray study of the Hubble Deep Field North (HDF-N) and its environs obtained using 166 ks of data collected by Chandra ACIS. This is the deepest X-ray observation ever reported, and in the HDF-N itself six X-ray sources were detected down to a 0.5–8 keV flux limit of \( \sim 4 \times 10^{-16} \) erg cm⁻² s⁻¹. Comparing these sources with objects seen in multiwavelength HDF-N studies showed positional coincidences with the extremely red object NICMOS J123651.74 +621221.4, an active galactic nucleus, three elliptical galaxy...
ies, and one nearby spiral galaxy. The X-ray emission from the ellipticals is consistent with that expected from a hot interstellar medium, and the spiral galaxy emission may arise from a 'super-Eddington' X-ray binary or ultraluminous supernova remnant. Four of the X-ray sources have been detected at radio wavelengths. The ACIS data were also used to place X-ray upper limits on active galaxy candidates found in the HDF-N, and they provided the tightest constraints yet on X-ray emission from the SCUBA submillimeter source population. None of the 10 high-significance submillimeter sources reported in the HDF-N and its vicinity were detected. These sources appear to be dominated by star formation or have active galactic nuclei with Compton-thick tori and little circumnuclear X-ray scattering.

3.2.2.12 Extragalactic H II Star Forming Regions Townsley is leading an effort to analyze the ACIS data on 30 Doradus in the Large Magellanic Cloud, the nearest giant extragalactic H II region. Other group members are Broos, Burrows, Feigelson, Garmire, and Tsuboi. The group has presented the first high-spatial-resolution X-ray images of the 30 Dor star-forming region (January 1999 AAS Meeting, #53.01). The central cluster of young high-mass stars, R136, is resolved at the arcsecond level. Spatially-resolved spectra and enhanced images have been generated for N157B, the plerion SNR recently shown by X-ray observations to contain a 16-msec pulsar (Marshall et al., ApJ 499, L179). The spectrally soft superbubble structures seen by ROSAT are visible in the Chandra image, as is SN 1987A and the Honeycomb Nebula (both imaged ~20 arcmin off-axis).

3.2.2.13 Clusters of Galaxies Chartas, Bautz (MIT), Garmire (PSU), Jones (CFA), and Schneider (PSU) resolve a mystery regarding the proposed presence of a dark matter object in the lens plane of the gravitationally lensed system 2016+112. The Chandra ACIS observation of 2016+112 has clearly detected the lensed images of 2016+112 with positions in good agreement with those reported in the optical and also detects 13 additional X-ray sources within a radius of 3.5 arcmin. Previous X-ray observations in the direction of 2016+112 with the ROSAT HRI and ASCA SIS have interpreted the X-ray data as arising from extended emission from a dark cluster. However, the present Chandra observation can account for all the X-ray emission as originating from the lensed images and additional point X-ray sources in the field. Thus cluster parameters based on previous X-ray observations are unreliable. Chartas et al. estimate an upper limit on the mass-to-light ratio within a radius of 800 h_0^{-1} kpc of M/L_V < 190 h_0^{-1} (M/L_V)_{⊙}. The hypothesis of the presence of a dark matter lens in 2016+112 is not supported with these recent observations.

3.3 Theoretical Studies

3.3.1 Planets

3.3.1.1 Planetary and Proto-Planetary Systems Sigurdsson in collaboration with Debes, have been exploring the dynamical evolution of planetary and proto-planetary systems in a variety of settings.

3.3.2 Theoretical Astrophysics

3.3.2.1 Physics of Gamma-Ray Bursts Mészáros and A. Gruzinov (IAS, Princeton) investigated the photon acceleration in variable ultra-relativistic outflows and the generation of high-energy spectra in Gamma-Ray Bursts. MeV seed photons produced in shocks in a variable ultra-relativistic outflow gain energy by the Fermi mechanism, because the photons Compton scatter off relativistically colliding shells. The Fermi-modified high-energy photon spectrum has a non-universal slope and a universal cutoff. A significant increase in the total radiative efficiency is possible. In some gamma ray bursts, most of the power might be emitted at the high-energy cutoff for this mechanism, which would be close to 100 MeV for outflows with a mean bulk Lorentz factor of 100.

Mészáros and J. Bahcall (IAS, Princeton) studied the production of 5-10 GeV Neutrinos from Gamma-Ray Burst Fireballs. A gamma-ray burst fireball is likely to contain an admixture of neutrons, in addition to protons, in essentially all progenitor scenarios. Inelastic collisions between differentially streaming protons and neutrons in the fireball produce muon neutrinos and antineutrinos of about 10 GeV as well as electron neutrinos and antineutrinos of about 5 GeV, which could produce about 7 events/year in cubic kilometer detectors, if the neutron abundance is comparable to that of protons. Photons of about 10 GeV from pi-zero decay and electron antineutrinos of about 100 MeV from neutron decay are also produced, but will be difficult to detect. Photons with energies near 1 MeV from shocks following neutron decay produce a characteristic signal which may be distinguishable from the proton-related MeV photons.

Mészáros and M.J. Rees (Cambridge University) extended this to consider Multi-GeV Neutrinos from Internal Dissipation in GRB Fireballs. Sub-photospheric internal shocks and transverse differences of the bulk Lorentz factor in relativistic fireball models of GRB lead to neutron diffusion relative to protons, resulting in inelastic nuclear collisions. This results in significant fluxes of muon neutrinos and antineutrinos of about 3 GeV and electron neutrinos and antineutrinos of about 2 GeV, scaling with the flow Lorentz factor below 400. This extends significantly the parameter space for which neutrinos from inelastic collisions are expected, which in the absence of the above effects requires values in excess of 400. A model with sideways diffusion of neutrons from a slower wind into a fast jet can lead to production of muon and electron neutrinos and antineutrinos in the 2-25 GeV or higher range, depending on the value of the Lorentz factor. The emission from either of these mechanisms from GRB at redshifts about 1 may be detectable in suitably densely spaced detectors.

A. Paneiucscu (Princeton) and Mészáros considered a GRB model where the MeV spectrum is produced by Up-Scattered Self-Absorbed Synchrotron Emission. They calculated the synchrotron self-Compton emission from internal shocks occurring in relativistic winds as a source of gamma-ray bursts, with allowance for self-absorption. For plausible model parameters most pulses within a GRB are optically thick to synchrotron self-absorption at the frequency at which most electrons radiate. Up-scattering of photon num-
ber spectra harder than flat (such as the self-absorbed emission) yields inverse Compton photon number spectra that are flat, therefore our model has the potential of explaining the low-energy indices harder than frequency to the -2/3 power (the optically thin synchrotron limit) that have been observed in some bursts. The optical counterparts of the model bursts are sufficiently bright to be detected by such experiments as LOTIS, unless the magnetic field is well below equipartition.

L. Balazs, Z. Bagoly, Z. Horvath, A. Mészáros (Konkoly Observatory and Eotvos University, Budapest) and P. Mészáros performed a study of the Observable Constraints on the Energetics of Gamma-Ray Bursts. They studied the correlation between the fluences and the measured durations for the long and short subgroups of gamma-ray bursts collected in the BATSE Catalog. Using Cramer’s theorem we show that this correlation reflects the correlation between the total emitted energies and the intrinsic durations of gamma-ray bursts. This result also implies a power law relation between these two quantities, where the exponents are different for the two subgroups. For the short bursts the total emitted energies are roughly proportional to the intrinsic duration, while for the long ones the energies are roughly proportional to the square of intrinsic durations. This difference in the energy-duration relationship provides an interesting constraint on models aiming to explain the short and long gamma-ray bursts.

3.3.2.2 Gamma-Ray Burst Afterglows Mészáros and R. Sari (California Inst. Technology) investigated the effects of Impulsive and Varying Injection in GRB Afterglows The standard model of Gamma-Ray Bursts afterglows is based on synchrotron radiation from a blast wave produced when the relativistic ejecta encounters the surrounding medium. We reanalyze the refreshed shock scenario, in which slower material catches up with the decelerating ejecta and reenergizes it. This energization can be done either continuously or in discrete episodes. We show that such scenario has two important implications. First there is an additional component coming from the reverse shock that goes into the energizing ejecta. This persists for as long as the re-energization itself, which could extend for up to days or longer. We find that during this time the overall spectral peak is found at the characteristic frequency of the reverse shock. Second, if the injection is continuous, the dynamics will be different from that in constant energy evolution, and will cause a slower decline of the observed fluxes. A simple test of the continuously refreshed scenario is that it predicts a spectral maximum in the far IR or mm range after a few days. Mészáros and A. Gruzinov (IAS, Princeton) studied the Delayed X-Ray Afterglows from Obscured Gamma-Ray Bursts in Star-Forming Regions. For Gamma-Ray Bursts occurring in dense star-forming regions, the X-ray afterglow behavior minutes to days after the trigger may be dominated by the small-angle scattering of the prompt X-ray emission off dust grains. We give a simple illustrative model for the X-ray light curves at different X-ray energies, and discuss possible implications. A bump followed by a steeper decay in soft X-rays is predicted for bursts which are heavily obscured in the optical.

L. Piro (U. Rome), G. Garmire, P. Mészáros and colleagues published a paper on the Detection of Moving Ejecta from the Progenitor of a Gamma-Ray Burst. This is based on Chandra observations of GRB 991216, in which about 1.5 days after the GRB trigger the X-ray spectrum shows a (cosmologically redshifted) Fe K-alpha and K-edge feature at the 4.7 sigma level significance. This can be used to derive a lower limit on the mass of Iron needed to explain this if the features are produced by a shell (e.g. a supernova remnant) at about a light day distance, which is about 1/10 of a solar mass. This gives support to the idea that GRB progenitors are massive stars, and possibly also the association with a pre-ejected supernova remnant.

M.J. Rees and Mészáros considered the Fe K-alpha Emission from a decaying Magnetar Model of Gamma-Ray Bursts. The starting point is the above report of X-ray Fe features in the afterglow of the gamma-ray burst GRB 991216, which may provide important clues for identifying the nature of its progenitor and constraining the burst mechanism. Here it was argued that the strong line emission can be attributed to the interaction of a continuing (but decaying) post-burst relativistic outflow from the central engine with the progenitor stellar envelope at distances less than a light-hour. Only a small mass of Fe (1E-4 to 1E-8 solar masses) is then required, which could have been readily produced by the star itself.

3.3.2.3 N-body Modeling of Dynamical Systems Sigurdsson continued N-body modeling of dynamical systems, in particular the effects of stellar evolution on stellar clusters.

3.3.2.4 Young Stellar Clusters Sigurdsson continued work on a large HST project. In particular, in collaboration with Elson, Gilmore, Santiago, Aarseth and Davies, they are studying young stellar clusters in the LMC.

3.3.2.5 Galaxies Sigurdsson in collaboration with Mihos, Hernquist and Holley-Bockelmann, he continued characterization and study of models of triaxial galaxies.

3.3.2.6 Black Holes Natarajan and Sigurdsson continued some speculative study of the effects of very high mass black holes on their surroundings.

Sigurdsson and Sipior worked on a a small project to examine the rate of black hole mergers in the local universe as possible sources for gravitational radiation for LIGO, and Sigurdsson continued previous work on possible sources of gravitational radiation for the proposed LISA mission.

3.3.3 Computational Astrophysics

3.3.3.1 Black Holes Pablo Laguna, Jorge Pullin (Penn State/Physics), Deirdre Shoemaker and collaborators from the Universities of Texas and Pittsburgh carried out the first numerical simulations of non-headon (grazing) collisions of binary black holes in which the black hole singularities have been excised from the computational domain. The results show that, as long suspected, black hole mergers are one of the very strongest possible source of gravitational radiation, and these events may dominate the signals in the new LIGO gravitational wave detector coming on line in the US (and other international detectors). The simulations consist initially of two equal mass black holes $m$ are separated a distance $\sim 10m$ and with impact parameter $\sim 2m$. Initial data are based on superposed, boosted (velocity $\sim 0.5c$), spinning
solutions of single black holes. The excised regions containing the singularities are specified by following the dynamics of apparent horizons. Evolutions of up to $t \approx 35m$ are obtained in which two initially separate apparent horizons are present for $t \approx 3.8m$. At that time a single enveloping apparent horizon forms, indicating that the holes have merged. Apparent horizon area estimates suggest gravitational radiation of about 2.6% of the total mass. The evolutions end after a moderate amount of time because of numerical instabilities. Laguna, Pullin, Shoemaker and graduate student Erik Schnetter are working on the next generation code to simulate inspiral collisions of black holes.

Taking the research to a new level, Shoemaker and Schnetter are working with members of the Penn State Center for Gravitational Physics and Geometry to numerical detect isolated horizons. This work, inspired by Abhay Ashtekar, will determine the mass and spin of the black holes leading to better numerical simulations. Isolated horizons also have a natural coordiniztion associated with them. Numerical solutions to Einstein equations could then have a framework for comparison.

3.3.4 History of Astronomy

William Shakespeare lived at a time of great change, yet there is general agreement that he was 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 that appeared recently (Usher 1999) has been reprinted in the journal of the Shakespeare Society of the Open University, England (Usher 2000). This paper contends that Shakespeare’s Hamlet is a cosmic allegory which dramatizes the competition between the chief World models at the turn of the sixteenth century. In particular, Usher concludes that the Bard was fully aware of the New Science and correctly foresaw the model of an infinite universe of stars. The reprinted version (Usher 2000a) differs from the original (Usher 1999) in that the direction of Wittenberg, Germany (and not of Wittenberge, Germany) is used to interpret the famous passage (II.2.347-8), that when the wind is southerly Hamlet knows a hawk from a handsaw. The original interpretation is unchanged in essence, but is now rendered more precise, since Wittenberg is almost exactly due south of the island of Ven (now part of Sweden) where in the late sixteenth century the Danish astronomer Tycho Brahe had established his observatories, whereas Wittenberge is slightly west of south.

3.3.5 Atomic Physics

Sampson and collaborators have continued their work on fully relativistic calculations of atomic properties of highly charged ions. In the current year calculations of the effect of resonances on the rates for excitation to the upper levels of hyperfine structure transitions of possible astrophysical interest in several H-like and Li-like ions were made. The effect of resonances was found to be very large for the Li-like ions, but rather unimportant for the H-like ions. The latter occurs because relatively high impact electron energies are required for resonances to occur for H-like ions. Our relativistic code for ionization was extended to treat ionization to specific magnetic sublevels by an electron beam. In contrast to excitation by an electron beam, the ionization cross sections were found to be almost independent of magnetic sublevel.

3.3.6 Statistical Astronomy

Feigelson continued his collaboration with Penn State statisticians in furthering the use of advanced statistical methods in observational astronomy. The StatCodes Web site (www.astro.psu.edu/statcodes) received over a thousand hits. With Jogesh Babu (Statistics, PSU), he is organizing the third in a series of astrostatistical conferences “Statistical Challenges in Modern Astronomy III,” to be held in July 2001 (www.astro.psu.edu/SCMA).

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PUBLICATIONS

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