Columbia University
Department of Astronomy/Department of Physics
New York, New York 10027

This report covers the period September 1995 through August 1996 and comprises an account of astronomical and astrophysical research carried out in the Departmant of Astronomy and the Department of Physics.

Faculty and Research Associates were James Applegate, Elena Aprile, Norman Baker, Kaiyou Chen, William Craig, Arlin Crotts, Isadore Epstein (Emeritus), Peter Friedman, Charles Hailey, Jules Halpern, Carole Haswell, David Helfand, Philip Kaaret, Stephen Kahn, Marc Kamionkowski, Laura Kay (Barnard), Kenneth Mighell, Lloyd Motz (Emeritus), Robert Novick (Emeritus), Frederik Paerels, Joseph Patterson, Kevin Prendergast, Andrew Rasmussen, R. Michael Rich, Malvin Ruderman, Daniel Savin, Edward Spiegel, Marco Tavani, Wilhelmus van der Veen, and Jacqueline van Gorkom.

Graduate students participating in research were Elizabeth Blanton, Ari Buchalter, Alex Casti, Sandra Castro, Andrew Chen, Ping Chen, Xuelei Chen, Xinzhong Chen, Jean Cottam, Catherine Cress, Saswato Das, Deepa Majmudar, Yihu Fang, Judith Fleischman, Eric Ford, Karl Forster, Mario Jimenez-Garate, Ming Feng Gu, Ilana Harrus, JaeSub Hong, John Keck, Robert Olling, Ravi Pilla, Alex Refregier, Hayley Richman, David Schiminovich, Adrianne Slyz, Edgar Smith, Joshua Spodek, Johannes Spreeuw, Gino Thomas, John Tomsick, Robert Uglesich, Orkan Umurhan, Frank Wang, Fang Xu, Jun Xu, and Tianhua Zhu.

Undergraduates participating in research were Kerry Billingham, Scott Brown, Rano Chaterjee, Ali Kinkhabwala, Jonathan Kemp, Michael Malin, Shani Offen, Jason Scanlin, Justin Shubow, Charles Silver, Pauline Tabibian, Nicolaos Toumbas, Beth Willman, and Jessica Zimmerman.

Yihu Fang, Robert Olling, Hayley Richman and Jun Xu received Ph.D. degrees.

Appointments during 1995–96 were held by Adjunct Professor Michael Allison, Visiting Research Scientist Tatiana Lozinskaya, and Postdoctoral Research Scientists Valeri Egorov, Nobumichi Ishida, Frank Summers, Austin Tomaney, Monica Vallluri, and Ming Zhao.

We regret to report that Emeritus Professor I. Epstein died in September 1996.

Helfand continued as chair of the Astronomy Department. Kahn was appointed as Director of the Columbia Astrophysics Laboratory.

1. STARS & STELLAR EVOLUTION

Haswell's research concentrated on *HST* observations of interacting binary stars. A paper on the magnetically accreting CV YY Draconis is in press (Haswell *et al.* 1997). The UV pulse fraction was found to be very high, implying a color temperature in excess of 10^5K. Constraints on the mass of the white dwarf and the accretion geometry were derived. Preliminary results on the quiescent UV optical spectrum of the black hole X-ray transient (BHXRT) GROJ 0422+32 were presented at the Aspen Meeting in January. Analysis underway is expected to constrain the models for the dramatically variable accretion flux in these systems. The May 1996 outburst of the BHXRT GRO J1655-40 was intensively monitored with a multi-wavelength campaign coordinated by Haswell (*HST* PI), Chen (NASA Goddard, *XTE* PI), Harlaftis (St. Andrews, *AAT* PI) with Horne (St. Andrews); *CTIO* photometry was obtained by Kemp, Patterson, and Hynes (Sussex); spectroscopy was obtained by Hellier (Keele) and Wang (McDonald). The *HST* observations show the UV and optical spectral evolution through the outburst and decline, showing the canonical e-folding decay light curve, with significant superimposed short-term variability.

Hailey and Craig are analyzing data collected with the automated multi-object spectrograph *(AMOS)*, a multifiber robotic positioning system developed in collaboration with UC Santa Cruz and Lawrence Livermore National Laboratory. High throughput spectra have been collected on a number of targets including old open clusters, *ROSAT* selected clusters of galaxies, galactic supernovae and supernovae in M31. A survey of Hα emission is being undertaken in the Pleiades in order to study systematically rotational velocities in stars of widely varying stellar class. *AMOS* is also being upgraded through the addition of a Fabry-Perot interferometer which will permit ultra-high resolution spectroscopy taking advantage of the one-degree field of view at the 3m Shane reflector at Lick Observatory, where *AMOS* is sited.

Patterson and Kemp more officially formed the ''Center for Backyard Astrophysics,'' an organization for coordinated study of variable-star light curves. With major observing stations in Denmark, Belgium, Maryland, and Arizona (and occasional help from New Zealand, Japan, Israel, South Africa, and Chile), we try to accumulate light curves of cataclysmic variables over the 24-hour cycle, in order to free periodic signals from the effects of Earth rotation. This has been extremely beneficial in revealing signals closely spaced in frequency, such as the ''superhumps'' of dwarf novae.

New superhump periods were found for eight dwarf novae. Most were of the garden variety, a few percent greater than the corresponding $P_{\rm orb}$. RZ LMi was the most interesting, because its superhumps continued strong into quiescence. Indeed its superhumps appear to maintain phase fairly well across 4 separate eruptions (80 d). This is presumably because the disk is still ringing from the last eruption when the next one first rises. It takes a while for the superhump to forget its phase, and a new eruption occurs before the forgetting is complete.

A long campaign (4 yr) was carried out on the remnant of Nova Cygni 1992, V1974 Cyg. The light curve during 1993–6 showed the 117 min orbital period throughout, and also a 122 min modulation which wandered slightly in phase on a timescale of months.

Another intensive campaign, lasting for 110 days, was waged on the novalike variable CR Boötis. For the first 15

days, very short-lived eruptions occurred on a fundamental quasi-period of about 20 hrs; this is basically the shortest-period dwarf nova in the sky, and the only one dominated by the helium in its spectrum. For the next 90 days, the star stayed in an extended bright state, and rang with 24.8 minute superhumps all the while. Spectroscopic coverage showed helium absorption lines gyrating back and forth with a period of $\sim$30 hr — probably the apsidal precession period of the accretion disk.

Rich and Mighell in collaboration with M. Shara and M. Fall (STScI) obtained deep photometry of the old LMC globular cluster Hodge 11. The extreme blue horizontal branch of this cluster had been known for years from ground-based observations. The *HST* imaging gave a locus for the cluster that is identical to that of the oldest, most metal poor Galactic halo globular cluster M92. This result proves that the oldest, most metal poor stars in the LMC have the same age (to within observational errors) as those in the Galactic halo. If we can establish that the oldest stars in a number of Local Group galaxies are as old as this, it would suggest that there was a common era when the first stars in the Universe formed. The finding also supports the notion that the LMC itself is as old as the Galaxy; not all massive companions of spirals have merged or are destined for mergers.

Rich, in collaboration with D. Terndrup (OSU) and E. Sadler (AAT) completed analysis of a sample of bulge K giants in Baade's window ($l=0°, b=-4°$) with radial velocities, proper motions, and metallicities. It is possible to calculate the vertex deviation of the velocity ellipsoid as a statistic C_{lr}. Vertex deviation in the plot of σ_r (radial velocities) against σ_l (proper motion dispersion parallel to the Galactic plane) gives a kinematic signature of triaxiality. In the full sample of 350 stars, the subsample with $[\mathrm{Fe/H}]>-0.2$ has clear vertex deviation. When photometric parallaxes are used to further constrain the sample, one may plot C_{lr} as a function of [Fe/H] and R_{GC}. This plot shows that the strongest vertex deviation is for metal rich stars at the Galactic center. A preliminary analysis suggests that there is no correlation between abundances and kinematics, but this issue is still under study. Rich is also collaborating with R. Méndez (ESO) in the next generation of bulge proper motion studies. A collection of over 30 plates of the bulge/halo transition Plaut field ($l=0°, b=-8°$) with epochs from 1972 to 1994 has been measured. Because a rich cluster of galaxies is identified in the field, we expect ultimately to tie the proper motions to the extragalactic reference frame. In the proper motion dispersion ''vector point'' diagram, the distribution of the most accurate measurements shows some hints of clumping, as if there may be kinematically distinct moving groups involved. Radial velocities (from spectra obtained at *CTIO*) have been measured for the first 1000 stars in the sample by Scanlin.

Sandra Castro, visiting at Columbia from the University of Sao Paulo, completed two studies of metal rich stars in collaboration with Rich. In the first, analysis of a spectrum of a metal rich giant in the Galactic bulge (BW IV-167) obtained with the Keck telescope gave $[\mathrm{Fe/H}]=+0.47\pm 0.03$. Three methods were used to analyze this star and the metal rich local giant μ Leonis. The first was to measure the equivalent widths of all the lines and to obtain the physical parameters using the program MOOG, developed by C. Sneden. Spectrum synthesis of Fe lines, and the curve of growth method were also used. The bulge giant and μ Leo were found to be identical to within 0.05 dex, and the different methods were in agreement at a similar level. The results confirmed earlier work by McWilliam and Rich. Castro also analyzed a sample of local disk dwarfs selected by M. Grenon (Geneva Obs.) for their high metallicities and eccentric orbits. Formal orbit integrations suggest that some of these stars may have originated relatively close to the Galactic center. The first results indicate that their metallicites are high, with $[\mathrm{Fe/H}]=+0.5$ typical. It is hoped to compare their element abundance ratios (e.g. alpha-capture elements) with those of bulge giants to test their connection with the bulge population.

Rich, in collaboration with H. Zhao (Leiden U.) and D. Spergel (Princeton U.) analyzed the MACHO microlensing events toward the bulge. A microlensing map was constructed from Zhao's self-consistent model of the bulge, and it gives good agreement with the microlensing event distribution. The results (now based on analysis of over 50 events) continue to rule out large numbers of brown dwarfs in the bulge, as there are too few short period events.

Rich, in collaboration with S. Ortolani (Padua) and A. Renzini (ESO) has used *HST* imaging to determine the age of the Galactic bulge relative to old metal rich globular clusters. The magnitude difference between the turnoff and horizontal branch is a sensitive age indicator, and is the same (3.6 mag) for the bulge as for the clusters (NGC 6528 and 6553). The metal rich clusters, in turn, have the same 3.6 mag spread as the metal poor halo clusters. Depending on the run of horizontal branch luminosity with metallicity, this suggests that (1) the bulge is at most 3 Gyr younger than the halo, but the bulge and these clusters are the same age or (2) there is no age-metallicity relationship in these objects, and all of the objects are as old as the oldest halo globular clusters.

Rich and Mighell, in collaboration with W. Freedman (Carnegie Observatories) is continuing to analyze *HST* imagery of the nuclei of M31, M32, and M33. Division of the F555W (V) by the F814W(I) images has revealed dust structure in M31 and M33, but none in M32. In M31, there are small knots of extinction near the nucleus as well as the suggestion of a face-on spiral pattern originating at the nucleus. In M33, the dust is smoother and sheetlike and is completely unrelated to the nucleus. The 1 micron luminosity function of the giants in the bulges of these galaxies is extended 1–2 mag brighter than the first giant branch tip of the old globular cluster G1 in the halo of M31 (which itself resembles 47 Tuc). While photometric crowding may be responsible for this effect, preliminary artificial star tests indicate that it cannot explain it completely; further analysis is underway.

Crotts and Jun Xu mapped the interstellar medium in front of SN 1987A using light echoes from the SN and longslit echelle spectroscopy, tying the three-dimensional spatial structure to the gas kinematics. They have mapped a large part of the superbubble N157C surrounding the OB

association LH 90, and used its kinematics to estimate its age, as well as its energy content compared to its stellar activity. They have also placed in context the formation of stars, in particular the SN 1987A progenitor, with respect to LH 90 and a larger superbubble. This research also shows that the SN rests about 400 pc behind LH 90 and most of the mass in this part of the 30 Doradus complex in the Large Magellanic Cloud.

Applegate and Thomas have developed a stellar structure code incorporating tidal heating and irradiation or angular momentum loss driven mass loss in order to study the transition from Low-Mass X-Ray binary to Black Widow pulsar to isolated millisecond pulsar or millisecond pulsar with planets. The code development is complete and calculations are underway. When completed, these calculations will be Thomas' Ph.D. thesis.

Applegate and Thomas have used their code to follow the evolution of cataclysmic variables from orbital periods of several hours, through the 2-3 hour period gap, and past the orbital period minimum. They find, in agreement with previous work, that if gravitational radiation is the only torque acting on the system, the minimum period is 65 minutes instead of the observed 80 minutes.

Applegate and Majumudar have proposed a model in which lithium, beryllium, and boron are produced in unmixed supernova ejecta by spallation reactions in which particles accelerated in the explosion itself irradiate the metals synthesized in the star. This model gives a constant spallation to iron ratio, in agreement with observation. They find that they obtain the correct spallation-to-iron ratio if roughly one part in a thousand of the supernova energy goes to particle acceleration.

Applegate and Cress studied the statistical fluctuations in element ratios produced by the fact that only a small number of supernovae are needed to enrich a globluar cluster sized gas mass up to $[\mathrm{Fe/H}] = -2$. They find that the distribution of element ratios might discriminate between models in which globulars are self-enriched and models in which the cluster formed out of pre-entriched gas.

2. RADIO SOURCES

Helfand, in collaboration with V. Kistiakowsky (MIT) completed their identification program for Galactic plane radio sources using narrowband, near-IR filter imaging. They found a total of 36 highly extincted planetary nebulae in ~ 100 deg^2 and demonstrated the effectiveness of using the [S III]/Pa α ratio to distinguish obscured H II regions from PNe.

Helfand, along with his collaborators R.H. Becker (UC Davis) and R.L. White (STScI) continued collecting Faint Images of the Radio Sky at Twenty-cm for their *FIRST* northern hemisphere VLA radio sky survey. Over 20,000 2k $\times$ 2k maps covering 3000 deg^2 of the North Galactic Cap have been reduced and analyzed (see http://sundog.stsci.edu for the current survey status). A catalog of over 250,000 sources has been generated from these data, and a wide variety of followup programs and survey analyses are in progress. Briefly, these include:

Cress and the *FIRST* team have calculated the two-point angular correlation function for the radio sky from the first 1500 deg^2 of the survey. This represents the first significant detection of large-scale structure in the radio band. They show that faint sources are more highly clustered than bright sources, and calculate a clustering scale length of 10 Mpc.

Cress and Kamionkowski have been working out predictions for angular clustering of radio sources in various cosmological models to compare with the correlation function measured for the *FIRST* survey. Radio sources are typically at redshifts of order unity. By comparing with clustering of sources at lower redshifts, one can investigate the evolution of the matter distribution in the Universe and test various models for the origin of structure. Cress and the *FIRST* team are continuing to construct the correlation function from new data from the survey as it becomes available.

Das and the *FIRST* team announced the discovery of radio sources that vary on a timescale of days by factors of $\gtrsim 2$. VLA followup observations have shown that 2/3 of the candidate variables have flat or inverted radio spectra. A few of the sources have optical counterparts that prove to be a variety of AGN and quasars. The search for an explanation of this extraordinary behavior, which could be either intrinsic to the source or imposed by some external mechanism, will continue with daily monitoring of several sources in the coming year.

Blanton and the *FIRST* team have now accumulated deep optical images for over sixty fields containing bent double radio sources as part of a search for distant galaxy clusters. The disturbed morphology of this rare class of radio emitters is thought to arise from an interaction of the radio jets with a dense surrounding medium. To date, over 60% of the sources imaged show obvious clusters with estimated redshifts ranging from 0.25 to 1. Further photometric data and the first spectroscopy to confirm the clusters and determine their redshifts will be undertaken in the coming year.

Buchalter and the *FIRST* team have been searching for clusters by directly examining the *FIRST* images for concentrations of radio sources; several hundred candidate regions have been identified. In addition, they have been collecting a large sample of double and triple radio sources to evaluate their utility for measuring the angular diameter-redshift relation which has been proposed as a technique for determining q_0.

Refregier, Cress, Brown, Helfand, and Kamionkowski have been looking for correlations between ellipticities of sources in the *FIRST* survey which would have been induced by weak gravitational lensing due to inhomogeneities in the mass distribution in the Universe. Predictions for the amplitude of this correlation in various models of structure formation have also been performed. With hundreds of thousands of resolved sources (mostly at large redshift) over a good fraction of the sky, *FIRST* provides a unique probe of this effect over angular separations of a few degrees. It should also be noted that this probes the *mass*, as opposed to luminous-matter, distribution in the Universe.

Willman has been working with the *FIRST* team to define a sample of BL Lac candidates from cross-correlations of the *FIRST* radio catalog with the *ROSAT* All-Sky survey and the

ROSAT catalog derived from pointed observations. They find that ~50% of the bright RASS sources have *FIRST* counterparts, and that only a relatively small fraction of these are previously identified objects. The *FIRST* data reduces the positional uncertainty of the X-ray emitters by a factor of ~100, greatly simplifying optical identification. Several dozen objects lie in the region of the α_{ox}, α_{ro} plane in which BL Lacs are typically found, suggesting that *FIRST*-RASS may provide the largest homogeous sample of these rare AGN yet found.

Kinkhabwala and the *FIRST* team in collaboration with Crotts have identified a number of candidate quasar pairs for use in studies of the Lyman alpha clouds. Several new pairs have been spectroscopically confirmed and *HST* snapshot observations are planned to determine their suitability for study of the intergalactic medium at redshifts from 0.1–2.

Helfand and other *FIRST* team members are pursuing a *FIRST* Bright Quasar Survey by obtaining spectroscopic identifications for all *FIRST* radio sources with optical counterparts classified as stellar on the POSS I plates and brighter than *E* magnitude 17.5. Over two hundred spectra have been obtained to date, and over 150 new bright quasars have been found. Approximately 50% of these objects are radio quiet (although obviously not radio silent); their redshift range is from 0.1–3.7. These data will allow us to assess the incompleteness of previous bright quasar surveys based on optical colors, UV excess, etc., and to explore the extent to which radio-loud and radio-quiet quasars differ in their evolution over cosmic time. This survey has also turned up some highly unusual objects including the first radio-loud Broad Absorption Line quasar and several white dwarfs, a class of objects not previously known to be radio emitters.

3. X-RAY & γ-RAY SOURCES

Helfand and Moran have obtained an *ASCA* spectrum of the IR-luminous galaxy NGC 3256. This object was the only one in the sample of over 250 IR/X-ray selected sources for which the reported X-ray luminosity was far in excess of the brightest known starbursts, and yet for which the optical spectrum showed no evidence for a contributing AGN. In fact, their reanalysis of the *ROSAT* X-ray data in conjunction with the *ASCA* spectrum shows that the source is partially extended, and that its true luminosity is consistent with a starburst interpretation; in addition, the spectrum is consistent with soft thermal emission and requires no AGN-like power law component. Thus, yet again, the evidence for X-ray luminous starbursts, long invoked as potentially important contributors to the X-ray Background, collapses on close examination.

Helfand and Moran, along with R. Becker and R. White have also published the *Einstein* Two-Sigma Catalog, a compendium of over 40,000 X-ray source candidates derived from a complete reanalysis of the *Einstein* IPC database. The real X-ray sources in this catalog represent a factor of three increase over the number of sources detected in the original IPC catalog produced at SAO. Cross-correlation with catalogs from other wavelength regimes can be used to select objects of interest for followup study. As but one example, they find several high redshift quasars with $3<z<4.3$ from a comparison with radio catalogs; the EMSS, in contrast, found no quasars with $z>3$. Helfand and Moran have obtained an *ASCA* spectrum of the $z=4.3$ quasar, providing a high signal-to-noise spectrum from 3–53 keV in the object's rest frame. They find that a single $\alpha\sim0.4$ power law describes the spectrum well throughout this band.

Helfand, along with E. Gotthelf (GSFC) and T. Hamilton (Rand Corp.), have published their analysis of short X-ray flashes discovered in the *Einstein* IPC database. While the several dozen events resist all attempts to link them unequivocally to an instrumental or environmental effect, preliminary results from an identical analysis of the *ROSAT* PSPC database does not confirm them as having an astrophysical origin. More importantly, however, the authors show in an accompanying article that the absence of any such flashes from the directions of nearby galaxies sets important constraints on halo models for γ-ray bursts if the typical X-ray to γ-ray luminosity of such bursts is ~1% as seen in several previous missions.

Harrus and Helfand, in collaboration with J. Hughes (Rutgers), have discovered a diffuse, nonthermal X-ray nebula in the vicinity of the pulsar associated with the middle-aged supernova remnant W44. The source is spatially coincident with a recently discovered flat-spectrum radio nebula, confirming it as a new addition to the small class of pulsar-powered nebulae within SNRs. Harrus and Hughes have also recently completed an exhaustive analysis of the dominant thermal emission from this SNR. Using data from the *Einstein*, *ROSAT*, and *ASCA* X-ray satellites, they show, contrary to previous claims, that the morphology, intensity, and spectrum of the emission is inconsistent with the evaporating cloud model for such objects, but can be well-fitted by models of a remnant entering its radiative phase.

Blanton and Helfand completed their analysis of the *ASCA* data on the luminous composite supernova remnant $G29.7-0.3$. X-rays from both the nonthermal, pulsar-powered nebula in the remnant core, and a surrounding shell of thermally emiting hot plasma are detected. The Crab-like core has a luminosity higher than any such object in the Galaxy excepting the Crab itself. The elemental abundances in the shell demonstrate that the progenitor was, as expected in the case of neutron star formation, a massive star. An estimate of the current energy loss rate from the unseen pulsar based on the nonthermal emission, plus an age estimate based on the expanding shell, combine to yield a consistent picture of the object and place its age at ~1000 years.

The identity of the majority of Galactic high-energy γ-ray sources remains a mystery. Halpern and Helfand are attempting to identify several EGRET sources at intermediate Galactic latitude by covering their error circles with *ROSAT* HRI and VLA pointings. If these sources are pulsars, then they might have faint X-ray counterparts and/or steep-spectrum radio counterparts in blank optical fields. However, they may also represent a new class of Galactic object, or perhaps blazars that are relatively radio quiet, in which case they could also be indentified using this multiwavelength approach. The X-ray observations are continuing over more than one *ROSAT* AO. Analysis of the X-ray and radio data is in progress, as are followup optical observations.

Refregier, in collaboration with A. Loeb (Harvard), have presented the first calculation of the effect of the gravitational lensing of a foreground galaxy cluster on the fluctuation statistics of the X-ray background. They show that the effects on the number counts and the residual background intensity as a function of radius around a massive cluster are detectable with a deep AXAF pointing, and that analysis of the effect can reveal the shape of the X-ray $\log N - \log S$ relation at fluxes far below that at which individual objects can be resolved.

Refregier and Helfand have completed an analysis of the cross-correlation of X-ray background fluctuations with POSS I galaxy counts derived from the APM scans. They have detected a signal for galaxies in the range $13.5 < E < 19.0$ which consists both of a contribution from individual galaxies and a diffuse component which correlates with the galaxies out to a scale of $\sim 10'$. The mean X-ray intensity of galaxies in the sample at $\langle E \rangle \sim 17.5$ is 8×10^{-16}erg cm^{-2}s^{-1}, a value which agrees with the extrapolation of fluxes expected based on bright nearby galaxies, and leads to an estimated contribution to the cosmic X-ray background from normal galaxies of $\sim 2\%$.

Hailey, Craig, Keck and Hong are working on the analysis of data taken on the flight of the γ-ray arcminute telescope imaging system *(GRATIS)* from Alice Springs, Australia last fall. The *GRATIS* collaboration involves Columbia, Lawrence Livermore National Lab and UC Santa Barbara. *GRATIS* is a narrow field of view telescope operating in the 20–200 keV energy band. It has taken the first arcminute angular resolution images of the γ-ray sky. About a dozen targets were observed during the Australia flight and most were detected. Highest priority is being given to GRS1915, the double-lobed radio source which is highly variable at radio, X-ray and γ-ray energies. This source displayed unusual temporal behavior during the flight. We are also attempting to narrow down the SIGMA error box for the γ-ray emission to establish definitively the association of the γ-ray and radio emission. We anticipate localizing the γ-ray source to ~ 10 arcsec. Analysis has also begun on 1E1740.7, another mini-quasar source in the Galactic center, and 47Tuc, a globular cluster with a large number of millisecond pulsars. We expect to fly the payload again in the next year.

Hailey and Craig are also examining the *ROSAT* database to search for young, isolated neutron stars. This search involves cross-correlations of a large number of catalogs to find potential candidate fields and a combination of astrometry, temporal analysis and color photometry to identify candidates for follow-up observations with future X-ray spectroscopic missions such as *AXAF* and *XMM*. X-ray studies of SNR using *ROSAT* are also continuing, with a study of X-ray emission in CTB1 just completed and a study of the Vela SNR nearly completed.

As the multiwavelength campaign of observations of PSR B1259-63 in coincidence with the January 1994 periastron passage was completed, Tavani and Arons (Berkeley) showed that X-ray/soft γ-ray emission from the system is most likely determined by a relativistic shock of pulsar wind particles interacting with gaseous surroundings from the Be star companion. In particular, accretion onto the surface of the neutron star and 'propeller'-like emission could be excluded with high confidence. A detailed theoretical analysis of the PSR B1259-63 system shows that the remarkable intensity and spectral variability of the X-ray emission near periastron can be successfully modelled by a pulsar/outflow interaction mechanisms characterized by the plane of the pulsar being substantially misaligned with respect with the equatorial plane of the Be star outflow. Furthermore, the particle acceleration mechanism was shown to be very efficient within a cooling synchrotron and inverse Compton timescale of $\sim 10^2 - 10^3$ s. For the first time in a plerion-like system, particle acceleration could be constrained within such a short timescale by a strongly time variable environment influenced by radiative cooling. Pulsar wind physical quantities such as Lorentz factor and magnetization could be determined and shown to agree, to within an order of magnitude, with parameters inferred in the case of the Crab pulsar wind. These results have general validity and may be relevant to the interpretation of Galactic unidentified γ-ray sources which may contain pulsars in binaries producing high-energy emission by non-thermal acceleration.

Tavani, with collaborators at NASA-GSFC, Boston U. and Columbia, continued his investigation of unidentified γ-ray sources detected by *EGRET*. A summary paper including all *GRO* observations of the γ-ray source 2CG 135+1 until the end of 1995 was recently completed and submitted in collaboration with the *EGRET* team. Interesting γ-ray variability was detected from this source, even though an unambiguous correlation with the radio flaring activity of its possible counterpart LSI 61-303 could not be established. The source 2CG 135+1 might be a powerful radio pulsar surrounded by a gaseous outflow from a massive companion star as in the case of the PSR B1259-63 system. Correlated γ-ray and radio flaring behavior of the source might confirm this model. A crucial final (for *EGRET*) observation of 2CG 135+1 was carried out in September 1996 together with simultaneous radio monitoring at the VLA. Analysis of these recent data is under way. Tavani is developing a detailed theoretical model of 2CG 135+1 based on the wealth of X-ray and γ-ray data recently obtained.

Tavani and collaborators at the NASA-GSFC continued their study of time variable γ-ray sources near the Galactic plane. A new remarkable γ-ray transient near the Galactic plane (GRO 1838-04) was discovered during an *EGRET* observation in June 1995. The γ-ray flux of this new source was shown to rise within a timescale of a few days/weeks reaching a flux level comparable with that of the Geminga pulsar. No radio-loud spectrally-flat blazar is within the 99% confidence error box of GRO 1838-04. Canonical interpretations in terms of extragalactic or Galactic sources are all problematic, and GRO 1838-04 may turn out to be a manifestation of a new class of variable γ-ray sources. Further work on the identification of the counterpart of GRO 1838-04 is under way. The existence of a γ-ray transient such as GRO 1838-04 indicates that blazars and isolated pulsars (Crab, Vela, Geminga among others) are not the only sources producing γ-ray emission.

In a separate project on X-ray bursters, Tavani with col-

laborators at Columbia, NASA-MSFC and Harvard continued his analysis of high-energy emission from accreting neutron stars. The discovery by our group of anticorrelated soft and hard X-ray emission from the X-ray burster 4U 0614 +091 agrees with a non-thermal model of hard X-ray emission based on explosive magnetic field reconnection near the inner accretion disks of neutron stars. Tavani in collaboration with E. Liang (Rice) is completing a theoretical model of non-thermal high-energy emission from accreting compact stars. Of particular relevance is the discovery by our group at Columbia of quasi-periodic oscillations (QPOs) in the X-ray emission of 4U 0614+091. The complex QPO phenomenology of 4U 0614+091 and other sources requires a re-evaluation of the fundamental magnetospheric and accretion processes near accreting neutron stars. Tavani is involved in the theoretical analysis of these phenomena.

Tavani is engaged in theoretical and interpretative analysis of Galactic X-ray transients showing superluminal radio plasmoid ejections (GRS 1915+105 and GRO J1655-40). Observations of the most prolific of the transients (GRS 1915 +105) were recently carried out by *ASCA*, *GRO* and *SAX*, and Tavani is deeply involved in the interpretation of the data. A dedicated radio monitoring program of high-energy transients at the Green Bank Interferometer was also recently revived, with the aim of making the radio data available for multiwavelength analyses. Particularly important is the established correlation in the case of GRS 1915+105 and GRO J1655-40 of radio flaring activity and hard X-ray outburst emission. Tavani is developing a model of magnetic field instability in accretion disks which can be used for the interpretation of these data.

Tavani is further developing a model of γ-ray burst (GRB) emission based on synchrotron emission of relativistic MHD particle winds interacting with optically thin nebular enviroments. This emission model (applicable to both cosmological and Galactic interpretations of GRBs) successfully explains all the broad-band spectra of GRBs including X-ray and γ-ray data. Spectral features such as the peak energy of the νF_ν spectrum and the distinctive low-energy and high-energy emission are interpreted in the framework of a model of synchrotron emission of relativistic particles of Lorentz factor $10^4 \leqslant \gamma \leqslant 10^6$ in a shocked region of comoving magnetic field B in the range $1 \leqslant B \leqslant 10^3$ G. These values are strongly suggestive of nebular environments surrounding compact objects producing relativistic winds. Whereas the low-energy spectrum of GRB emission is substantially 'fixed' in this model (and affected only by self-absorption), the high-energy emission of GRBs clearly shows the existence of a supra-thermal accelerated component of radiating particles.

Tavani is currently engaged in developing a comprehensive model of GRB emission with applications to cosmological and Galactic scenarios. Different scenarios are being considered for emission from an impulsive acceleration event in an optically thin environment. In particular, constraints on GRB emission mechanism derived from the lack of inverse Compton and absorption processes in broad-band spectra are being derived. Acceleration models affected by baryon loading and strong cooling are being studied. The ultimate aim of this investigation is to provide a workable theoretical model and determine the physical nature of the GRB phenomenon. Different tests on the cosmological or local nature of GRBs are being developed.

Kaaret, Ford, and Tavani with B. A. Harmon (MSFC), S.N. Zhang (USRA), and J. Grindlay, P. Bloser, and D. Barret (CfA) have detected quasiperiodic oscillations (QPOs) at frequencies near 1 kHz from the nearby X-ray burster 4U 0614+091. The QPOs give evidence that the neutron star has a spin period of 3.1 ms. This establishes that at least some millisecond pulsars are produced in low-mass X-ray binaries. In addition, interpretation of the highest frequency QPO as a Keplerian orbital frequency leads, via considerations of the stability of orbits in general relativity, to limits on the mass and radius of the neutron star of $1.9 M_\odot$ and 17 km, respectively. The same group has an on-going program to search for hard X-ray emission from X-ray bursters. Observation of a hard X-ray outburst in April 1996 from the nearby X-ray burster 4U 0614+091 with BATSE and the XTE/ASM showed an anticorrelation of the hard (20-100 keV) and soft (2-10 keV) X-ray emission from this object.

Kaaret and Cottam have shown that the unidentified 100 MeV γ-ray point sources near the Galactic plane lie in or near OB associations and are therefore Population I objects. Recently, Kaaret has shown that the number of visible γ-ray pulsars is 5–7 times larger than the number of visible γ-ray supernovae remnants. This strengths the conclusion that young pulsars constitute the majority of the unidentified γ-ray point sources at low Galactic latitudes.

Kaaret and A. Chen are studying the diffuse high-energy γ-ray background. Their analysis has led to the first direct measurement of the inverse-Compton production of γ-rays in the Galactic halo. Recently, they have shown that the properties of the isotropic background are consistent with an origin as emission from unresolved γ-ray AGN and have placed constraints on the number versus flux relation for γ-ray AGN.

Paerels, together with Min Young Hur (Berkeley), Mauche (LLNL), and Heise (SRON Utrecht) completed a preliminary interpretation of the 70-130 Å extreme ultraviolet spectrum of the magnetic white dwarf star in the cataclysmic binary AM Herculis. The spectrum, obtained with the Short Wavelength Spectrometer on *EUVE*, shows absorption edges and absorption lines due to highly ionized Neon. While these features are expected in this band for effective temperatures of order 30 eV (which is about how hot this stellar photosphere is), the relatively low contrast at the edges, and the simultaneous presence of features due to rather different ionization stages of Ne seem to indicate that the atmosphere is not in radiative equilibrium but is heated from above. One possibility is that the atmosphere is being heated and photoionized by hard radiation produced behind an accretion shock. The quantitative interpretation of the spectrum in terms of models for such irradiated photospheres is in progress.

Paerels, together with Liedahl (LLNL), completed the interpretation of the 2–10 keV emission spectrum of the luminous X-ray binary Cygnus X-3, obtained with the Solid State Imaging Spectrometers on *ASCA*. The spectrum is dominated

by discrete emission features. Most of these correspond to the $n=2-1$ transitions in the He- and H-like ions of Mg, Si, S, Ar, Ca, and Fe. But most spectacularly, a few isolated features that do not correspond to known discrete transitions turn out to coincide exactly with the recombination edges in H-like S, Si, and Mg. The narrowness of the features immediately indicates that the gas must be photoionized and hence is cold, rather than in collisional equilibrium at high temperature. The recombination edges are even marginally resolved, which allows for a direct temperature measurement. Moreover, the measured temperatures (a few tens of eV) are roughly consistent with values predicted with X-ray photoionization codes. A full interpretation of this spectrum is expected to yield important information on the structure of and conditions in the emitting medium, which may or may not be identical with the massive Wolf-Rayet wind blowing off the companion star seen in IR spectroscopy.

The Seyfert 2 galaxy NGC 1068 was observed with *ASCA* early on in its mission. Its emission spectrum below 2 keV is completely dominated by line emission, which has been interpreted as arising in a multi-component hot gas in collisional ionization equilibrium. The hot medium has been associated with gas in the energetic starbursts occuring in the very inner regions of the galaxy. Paerels, Liedahl, Sako (LLNL) and Kahn are pursuing an alternative interpretation in which the soft X-ray line emission originates in an X-ray photoionized medium close to the nucleus. Early attempts to fit the data with model spectra appropriate to such a source (based on atomic structure calculations specifically performed for this purpose) are very encouraging, both in terms of the closeness of the models and the measured spectrum, as well as the physical interpretation of the implied parameter values.

X-ray emitting cooling young neutron stars, or reheated neutron stars detected initially as millisecond radio pulsars are expected to show photospheric absorption features in their soft X-ray spectra. In a short *Ap.J. Letter* (in press), Paerels points out that if one could measure the surface gravity of a neutron star by measuring the pressure broadening of photospheric absorption lines, as well as the gravitational redshift of the lines, one could immediately determine the mass and the radius of the star. A test of the M-R relation for neutron stars has not yet been performed, and this spectroscopic measurement may be the only feasible one. Quantum calculations of the pressure broadening show that Oxygen VIII Ly β has a large width at typical neutron star atmospheric densities and temperatures ($\sim$65 eV), easily detectable with the next generation of X-ray spectrometers. In addition, the continuum fluxes expected from typical thermally emitting neutron stars within $\sim$500 pc are such that the prospects for photospheric spectroscopy are excellent.

4. PULSARS & NEUTRON STARS

Halpern and Wang completed a comprehensive X-ray study of the Geminga pulsar using data from *ROSAT* and *ASCA*. They resolved the nature of the strongly modulated hard X-ray emission from Geminga in favor of nonthermal emission, rather than thermal emission from a small, hot polar cap. The soft X-ray spectrum continues to be well fitted by a blackbody of $T=(4-6)\times10^5$ K. Several manifestations of time variability in Geminga's X-ray pulse profile and spectrum were also found. These can be interpreted as fluctuations in the process that supplies Geminga's inner magnetosphere with the high density of pairs needed to explain the narrow dips in its soft X-ray light curve as cyclotron resonant scattering within a few stellar radii of the surface. Wang and Halpern are expanding their efforts to other rotation-powered pulsars observed by *ASCA* and *ROSAT*, and are proposing for longer *ASCA* observations of several of these to study phenomena such as the spectrum of a neutron star atmosphere, and the spectrum and pulse profile of a millisecond pulsar. These new observations are necessary to disentangle thermal and nonthermal processes that may be present in the same object, and to correctly derive quantities such as the effective temperature of the neutron star surface, and the luminosity of a heated polar cap. With the same goals in mind, Halpern is also participating in proposals to study optical and UV pulsations and spectra of intermediate-age pulsars from space and from the ground. Both thermal and nonthermal radiation apparently contribute in this wavelength range as well.

Halpern, C. Martin (Caltech), and H. Marshall (MIT) published several papers on long *EUVE* observations of rotation powered pulsars. They detected pulsed emission from Geminga ($P=0.237$ s) and the nearby 5.75 ms pulsar J0437–4715. Both light curves are similar to those in the soft *ROSAT* band. The *EUVE* flux of Geminga is consistent with an extrapolation of the blackbody spectrum fitted to the *ROSAT* data, while in PSR J0437–4715 it is still not possible to rule out either nonthermal models or thermal emission from heated polar caps. In parallel with the latter target, a 20 day light curve of the Seyfert galaxy RX J0437.4–4711 was obtained that shows rapid variability, as well as a transient period of 0.9 days in the ultrasoft X-ray flux detected by the *EUVE* Deep Survey intrument. This period could correspond to orbital motion in the inner accretion disk around a black hole of mass $\sim10^8 M_\odot$.

Harrus and Helfand are pursuing an analysis of the X-ray emission from the old radio pulsar PSR1929+10 using data from the *ROSAT* PSPC and HRI, and from *ASCA*. They find a hard component in the *ASCA* spectrum which is inconsistent with the thermal emission inferred from the earlier *ROSAT* results. They are continuing to explore the energy-dependent pulse fraction and the possibility that nearby diffuse emission is complicating the measurement of the neutron star's emission.

5. GALAXIES

Buchalter, Kamionkowski, and Rich investigated how one might learn more about the nature of the objects responsible for gravitational-microlensing events observed toward the Galactic bulge. If the deflectors are faint but otherwise ordinary dwarfs in the bulge or disk, then unresolved light from the deflector will contribute to the observed light from the source star and therefore distort the shape of the standard microlensing light curve. The shape of the light curve will also be distorted by the Earth's orbital motion. Detailed and accurate followup observations of lensing events in progress

may be able to distinguish such distortions and therefore provide information on the masses, distances, and speeds of the deflectors.

Crotts and Yihu Fang, in collaboration in part with Bechtold (Arizona) and Duncan (Texas, Austin), have continued their study of the size and nature of Lyman alpha forest clouds. They have shown that the measurement of cloud sizes with pairs of QSO sightlines of various angular separations are not consistent with a single size of unclustered, spherical clouds. Furthermore, they correct a previous error in the literature to show that the cloud size is actually 50% *larger* than our previous estimate, or about 300 kpc in diameter (for $H_o = 100$ km s^{-1} Mpc^{-1} and $q_o = 1/2$) for clouds stronger the 0.4Å rest equivalent width and for small QSO separations. They also detail the interesting similarities in the properties of Lyman α clouds and faint blue galaxies. Crotts and Fang are now using triplets of QSO sightlines to understand whether the behavior of inferred cloud size with QSO sightline separation is due to non-spherical cloud shape, small-scale clustering, non-uniform cloud size, or a combination of these.

Crotts and Tomaney have completed their second season of observations of microlensing of stars in M31 due to masses in M31 and the Galaxy. They put interesting limits on the presence of massive objects (MACHOs) of masses between $10^{-7} M_\odot$ and $0.08 M_\odot$ as major constituents of M31 and the Galaxy. Furthermore, they have found six candidate events that might be due to microlensing caused by masses of about $1 M_\odot$, although they also show that a few of these are likely caused by confusion of microlensing lightcurves with mira-like variables. They are continuing their survey in 1996 and will be able to use the new data to decide if these six events are truly due to microlensing, and to discover new candidates.

Rich and student Xinzhong Chen, in collaboration with M. Carollo (Leiden) and J. Danziger (STScI) have imaged 3 elliptical galaxies with kinematically distinct cores using *HST*. Preliminary analysis indicates that there is no indication of strong or unusual color gradients in the regions, nor is there a sign that the surface brightness profile deviates from normal in any way. NGC 2434 has a strong dust lane in the inner 2 arcsec, while IC 4880 has a round face-on torus of dust in its nuclear region.

Van Gorkom probes the formation and evolution of galaxies and the large scale structure of the universe by studying the properties of the gas of systems in different environments and by doing optically blind H I surveys. A number of projects have been completed this year. A study of the H I properties and environments of optically known galaxies in the Boötes void shows that it is the near environment that mostly affects the evolution of galaxies. Boötes void galaxies appear to have formed on local density enhancements; their properties are indistinguishable from galaxies living in large scale environments that are more dense by a factor of five. Currently, Szomoru (UCSC), van Gorkom and Gregg (IGPP) are investigating the shape of the density enhancements found in Boötes to test theories of structure formation, which predict that galaxies form along filamentary structures.

Another project to study the large scale distribution of gas is the search for H I emission from the environment of nearby Lyman alpha absorbers. The Lyman alpha absorbers have been found by probing sightlines toward UV bright AGN's which are located behind well defined local superclusters and voids. Currently, van Gorkom, Carilli (NRAO), Stocke and Shull (Univ of Colorado) are making a uniform data set in which a fixed volume is searched around each absorber to a fixed mass limit. A puzzling result that seems to be emerging is that the galaxies found in H I close to the absorber always seem to be within 20 km/s of the velocity of the Ly alpha system, though they are sometimes at large projected distances (60–300 kpc).

The very advanced stages of mergers of galaxies are being studied by Schiminovich, van Gorkom and van der Hulst (Kapteyn Institute, Groningen). H I data have been obtained for a sample of 20 elliptical galaxies with optical fine structure, *i.e.*, arcs, ripples and shells, as revealed in deep optical images. More than half the sample has been detected in H I. From the kinematics and the distribution of the gas, some insight may be obtained into the type of event that created the shells and the possible future evolution of the galaxies.

Various studies of the effect of cluster environment on galaxy evolution and on the formation history of clusters are under way. Deep H I observations of Abell 2670 at a redshift of 0.08 have been obtained by van Gorkom, Guhathakurta (UCSC) and Dwarakanath (RRI, Bangalore) and the data are currently being analyzed. Szomoru (UCSC), Poggianti (IoA, Cambridge) and van Gorkom have been allocated time to observe Abell 2390, a well known Butcher-Oemler cluster at a redshift of 0.2 with the WSRT. Related to this is a search for H I from a spectroscopically selected sample of so called E+A galaxies by Zabludoff (UCSC), van Gorkom, Zaritsky (UCSC) and Shectman (DTM) at low redshift ($z = 0.1$). Two galaxies have been observed so far, one in a cluster which was not detected in H I, one in the field, which showed long tidal tails in H I.

Valluri & G. C. Anupama (IIA) completed a study of the properties of the Hα emission-line regions in the inner 3 kpc of three of the four elliptical galaxies in the Hickson Compact Group 62. The study showed that there is no evidence that the emission-line nebulae are associated with the large scale cooling flow in the X-ray halo associated with the group and the emission probably arises from photoionization by hot stars.

D. Merritt (Rutgers) and Valluri investigated the development of chaos in triaxial elliptical galaxies with a central cusp or black hole. In large ensembles of stochastic orbits chosen to have identical energies, we found mixing on timescales of less than ~ 100 orbital times; a near-invariant density distribution was reached. These results suggest that the stochastic regions of phase space in most ellipticals are likely to be fully mixed, which strongly constrains the existence of self-consistent triaxial equilibria. J. Sellwood (Rutgers) and Valluri investigated the stability of oblate spheroidal Kuzmin-Kutuzov models. Non-rotating models flatter than E7 were unstable to a lopsided ($m = 1$) mode which was stabilized by increasing streaming motion. Interestingly, all rotating models rounder than an E7 galaxy model were found to be completely stable to bar and spiral instabilities.

Van Gorkom and Valluri are studying the substructure in the Hydra cluster based on a volume limited 21-cm survey of this cluster. From the H I properties of the galaxies they find evidence for a foreground spiral rich group superposed on the center of the cluster.

Prendergast is continuing his collaboration with L. Athanassoula (Marseille) on the structure and evolution of dE galaxies. The extensive numerical work on this problem has yielded theoretical correlations of various measurable quantities (such as central surface brightness and effective radius) with absolute magnitude, in excellent agreement with the observations. A crude analytic treatment has been developed which shows that the numerical results are physically plausible.

6. ACTIVE GALACTIC NUCLEI

Forster is studying *ROSAT* and *ASCA* observations of a variety of intermediate-type Seyfert galaxies for their variability, spectra, and spatial distribution of soft X-rays. These data will be used to address unifying schemes for Seyfert galaxy classification, the relationship between AGNs, normal and starburst galaxies, and the sources of the X-ray background. Included in these studies are Seyfert 1.8 and 1.9 galaxies, narrow-line Seyfert 1 galaxies, and LINERs. Forster and Halpern discovered that one of the most luminous narrow-line QSOs with permitted Fe II emission, PHL 1092, has a very steep X-ray spectrum and rapid X-ray variability that stretches the limits of efficiency of accretion onto a nonrotating black hole. In this respect, PHL 1092 is the most luminous known member of the class of narrow-line Seyfert 1 galaxies, also known as I Zw 1 objects, which are characterized by these same spectral and variability properties. Forster has also found a correlation between X-ray spectral index and X-ray luminosity among a sample of optically discovered I Zw 1 objects that is not biassed by X-ray selection.

Halpern and E. Moran (IGPP/LLNL) are studying the *ASCA* X-ray spectrum of another interesting I Zw 1 object, *IRAS* 2018.1−2244. This was one of 20 similar objects found by Moran, Halpern, & Helfand in their spectroscopic classification of *IRAS* galaxies detected in the *ROSAT* All-Sky Survey. Their optical spectroscopy also identifed a number of composite Seyfert 2/H II region galaxies among this survey, making composites a possibly significant factor in understanding the nature of low-luminosity AGNs and the X-ray background.

Halpern and Eracleous (UC Berkeley) are continuing their long-term spectroscopic monitoring program of very broad, double-peaked Balmer lines, which are found preferentially in radio-loud AGNs. The main source of data for this program is the KPNO 2.1m, but telescopes at *CTIO* and Lick Observatory are also being used. The profiles of these double-peaked lines are often highly variable on time scales of months to years, a behavior which can be exploited to evaluate models for their origin. For example, the lack of systematic variations in the velocites of the line peaks obtained from spectra spanning 10−20 years in several objects (Arp 102B, 3C 332, 3C 390.3) strongly disfavors a model in which the two displaced peaks are associated with distinct broad-line regions belonging to binary black holes.

However, accretion-disk emission is still a viable model for double-peaked emission lines in AGNs. Halpern *et al.* published UV *HST* spectra of the prototypical double-peaked emitter Arp 102B, showing striking behavior in the line intensity ratios among the disk-like emission-line components. In particular, the disk-like component is completely absent in Lyman α, as well as in the higher ionization UV resonance lines, while all of the lines possess normal intensity ratios in the ''ordinary,'' low-velocity broad line region. In addition to proving the existence of two different sources of the broad lines in the same object, the upper limit on double-peaked Lyman α is in agreement with the models of photoionized accretion disks by Collin-Souffrin and collaborators. A serendipitous discovery in the UV *HST* spectrum of Arp 102B was a plethora of associated absorption lines, many of which arise from excited levels of Fe II. These metastable absorbers are extremely rare in BAL QSOs, and virtually unknown in Seyfert and radio galaxies, so their presence in Arp 102B is a mystery.

Eracleous and Halpern are continuing their UV spectroscopy of double-peaked emitters with the *HST*. One object turns out to be a dead ringer for Arp 102B, while two others show different behavior in their ultraviolet lines. Analysis of these additional data is in progress. A new *HST* proposal for UV spectroscopy includes newly discovered double-peaked emitters whose Balmer lines are even brighter than those of Arp 102B, as well as radio-quiet objects in which previously unknown double-peaked components appeared suddenly (NGC 1097, M 81). Halpern and Eracleous are also continuing their study of the X-ray spectra of double-peaked emitters with *ASCA*, looking for similar behavior in the Fe Kα lines of broad-line radio galaxies.

Spectropolarimetry is another tool that is beginning to be applied intensively to the double-peaked Balmer lines in AGNs. K. Chen, Halpern, & Titarchuk (NASA/GSFC) calculated the polarization properties expected for line emission from an accretion disk under various assumptions about the source function of the line and the electron scattering optical depth. They showed that the surprisingly high polarization observed for the Hα emission line in Arp 102B by Antonucci *et al.* can be understood in terms of a photoionized atmosphere on a disk with electron scattering optical depth of order unity.

Helfand and Halpern, in collaboration with E. Moran (IGPP), completed their series of papers on X-ray-selected IRAS samples of AGN, concluding that there is no evidence for a population of X-ray luminous starburst galaxies in either the *Einstein* EMSS or *ROSAT* RASS samples. They did discover a new class of composite Seyfert/starburst galaxies in which the spectrum is dominated by starburst-like lines, but weak, broad O III and a high X-ray luminosity imply that an AGN is also present. If such objects are common, they could make a significant contribution to the X-ray Background. They also find that these far-IR/X-ray samples contain a large fraction of rare I ZwI-type, narrow-line Seyferts with strong Fe II emission.

7. COSMOLOGY

Kamionkowski and his collaborators, Jungman (IAS), Kosowsky (Harvard), and Spergel (Princeton), investigated what can be learned about the values of various cosmological parameters from NASA's MAP and ESA's COBRAS/SAMBA satellite missions to map the cosmic microwave background (CMB) with good angular resolution. In particular, it was found that with minimal assumptions, Ω can potentially be determined to better than 10%, and with additional reasonable assumptions, perhaps as good as $O(1\%)$. The CMB will also be able to constrain other parameters such as the Hubble parameter, the baryon density, the cosmological constant, and others, and test with precision structure-formation theories such as inflation.

Kamionkowski and his collaborators, Kosowsky (Harvard) and Stebbins (Fermilab), developed a formalism for describing a polarization map of the CMB. With this formalism, the contributions to CMB anisotropy and polarization from density perturbations and long-wavelength gravity waves can be geometrically decomposed. This therefore would yield a model-independent probe of a stochastic gravity-wave background, which could be important for testing inflationary models.

In related work, Kamionkowski also pointed out that if the Universe is open, there should be a cross correlation between the cosmic microwave background temperature and tracers of the mass distribution at large redshift, like the X-ray background or radio sources.

Kamionkowski and Toumbas investigated classical cosmological tests of an alternative cosmological model in which the Universe is closed but still has a nonrelativistic-matter density less than the critical density. This is made possible by the presence of a topologically-nontrivial field configuration throughout the Universe known as a ''texture.'' The model was found to be viable and some future tests were proposed. Kamionkowski and X. Chen, with Liddle and Hindmarsh (Sussex) have been investigating the stability of this scalar-field configuration and its dynamics.

Kamionkowski and Freese (Michigan) investigated the possibility of indirectly detecting a specific supersymmetric dark matter candidate, a light Higgsino hinted at by accelerator experiments. If present in the halo, these particles should accumulate in the Sun, annihilate therein and produce energetic neutrinos which could be observed in neutrino telescopes such as Kamiokande, MACRO, AMANDA, and NESTOR. Kamionkowski and collaborators Bergstrom (Stockhom) and Edsjö (Uppsala) have been investigating the improvement in the sensitivity of such neutrino telescopes to point sources that can be achieved with better angular and energy resolution.

Murante (Turin), Provenzale (Turin), Spiegel and Theiberger (Beer Sheba) have discussed possible interpretations of the galaxy distributions (Provenzale, Spiegel, & Thieberger, R., 1996; Murante, Provenzale, Spiegel, & Thieberger, R., 1996). For the smallest scales (below about 5 Mpc) they suggest that the statistics are dominated by density singularities but for larger scales they find (using the CfA data) that the correlation dimension is 1.8 and that there is evidence for a lacunarity function. This suggests a conventional fractal picture at these larger scales. The estimated period of the lacunarity function is the same in both the northern and southern data and this provides a good measure of global homogeneity of the galaxy distribution. At scales upward of 100 Mpc the dimension appears to be climbing to the limiting value of 3.

8. OTHER THEORETICAL INVESTIGATIONS

Having considered various aspects of instabilities of disks (e.g., Balmforth & Spiegel 1995), Balmforth and Spiegel have pushed their studies into the nonlinear regime. As they have not included dissipation in their models, the center manifold is infinite dimensional, even though there may be only one or two unstable modes in the system. This is in contrast to the usual situation in nonlinear instability of dissipative systems. They have filtered out the infinitude of neutral modes by using slow time techniques. Some simple models which could be studied in detail numerically bear out their results but there are deep issues in the study of nonlinear instability of nondissipative systems that need to be resolved at the theoretical level. Their paper (Balmforth & Spiegel 1996) is really meant to illustrate this rather general difficulty.

Umurhan and Spiegel have contued their study of acoustic instabilities in simple model atmospheres. If the heat flux is fixed on the top and bottom surfaces, there are archimedean instabilities for waves of large horizontal wavelengths. For these, a nonlinear pattern evolution equation can be derived and coupled to convective modes in the case of mild instabilities. Other instabilities have been studied numerically with the help of E.T. Scharlemann (LLNL) but their physical origin has not been fully clarified.

Kamionkowski, X. Chen and Bahcall (IAS) have recalculated the electron-screening correction to nuclear-fusion rates in stellar interiors. A small correction to previous results was obtained and verified by numerical calculations.

Pilla has been continuing research begun with Shaham on non-equilibrium processes in $e^{\pm}$ pair plasmas. A new numerical code which evolves the complete Boltzmann equations for $e^{\pm}$-photon pair plasmas of arbitrary energies and initial distributions has been developed. The calculation is being used to study possible origins of non-thermal γ-ray spectra from AGN and γ-ray bursters.

A. Slyz is completing an axisymmetric version of the kinetic-theory (BGK) based hydrocode developed by Xu and Prendergast. This code will replace the one currently in use for the dE problem, and should make it possible to examine the role of instabilities during galaxy formation.

Zhu and Ruderman finished their study of electron-positron pair production and annihilation within the Crab pulsar's closed magnetosphere. Outer-magneto- sphere accelerator models seem capable of giving the $10^{40}\mathrm{s}^{-1}e^{\pm}$ pair annihilation rate and the narrow gravitationally red-shifted $e^{\pm}$ annihilation line shape in the pulsar spectrum which have been reported by the Figaro collaboration. The line intensity and the red-shift magnitude would be expected to decrease together whenever the net current through outer-magnetosphere accelerators is diminished. An essential feature is the expected formation of an electron-positron layer

well above the pulsar surface in which gravitational pull toward the star is balanced by a push from cyclotron scattering of polar cap X-rays. Applications to other γ-ray pulsars with smaller spin-down powers than that of the Crab pulsar were also considered.

Zhu and Ruderman also continued to explore consequences of the interaction between moving neutron superfluid vortex lines in spinning-down radiopulsars and the stellar magnetic field. The consequent evolution of surface magnetic field was used to describe the observed spin-down indices (n) in the Crab pulsar family and to show how the Vela pulsar's index should differ from $n=3$ by a much larger value than that for the Crab. An attempt is in progress to try to understand glitches as crust breaking events caused by core magnetic field motions overstressing the conducting crust. An early result raises serious questions about the conventional assumption that any sudden spin-up of the stellar crust is shared with the core's superfluid neutrons within much less than 10^2 seconds.

Kahn and Paerels, in collaboration with C.J. Hess, now at Illinois Wesleyan University, have completed a study of the properties and spectroscopic implications of thermal instability in X-ray binary and AGN accretion flows. This project was undertaken to address apparent discrepancies between the discrete soft X-ray spectra of some low-mass X-ray binaries and Seyfert galaxies, and the predictions of photoionization codes, via an examination of the thermal stability properties of model accretion flows. The possibility of suppressing the thermal instability, which coincides with the abundance peaks of the lowest-few iron-L ions, was investigated by varying conditions in the model plasmas. They identified in detail the mechanism which controls the onset of instability and found that the existence of thermal instability at temperatures where the line-emitting iron-L ions peak in abundance, is robust to changes in the ionizing spectrum and elemental abundances. These results have implications for the interpretation of spectra from dynamic accretion flows in low-mass X-ray binaries, Seyfert galaxies, and ''warm absorber'' systems.

9. LABORATORY ASTROPHYSICS & INSTRUMENT DESIGN

The Gamma-Ray Detector group at CAL (Aprile, Egorov, Zhou Ishida, Silver, Tabibian, and Xu) in collaboration with Waseda University, the University of New Hampshire, and NASA/MSFC is continuing the development of an imaging γ-ray telescope based on a Liquid Xenon Time Projection Chamber (LXe-TPC) for observations of astrophysical sources emitting at MeV energies. An engineering prototype LXe-TPC, with a sensitive volume of 20 cm $\times$ 20 cm $\times$ 8 cm has been built and its performance as a γ-ray spectrometer and three-dimensional imager has been tested in laboratory experiments. By combining the LXe-TPC as position sensitive γ-ray detector for the 0.3–10 MeV band, with a coded aperure mask, one can achieve arcminute point source localization accuracy in a highly efficient, low background telescope. The application of such a telescope to a study of ^{26}Al Galactic emission has been reported.

Currently the experimental effort by the collaboration is on the preparation of the LXe-TPC detector as balloon-borne instrument for a turnaround flight in Spring 1997 from Ft. Sumner (NM) (E. Aprile et al., 1996a). In this first flight, the TPC, with its 1 millimeter spatial resolution and 6% (FWHM) energy resolution at 1 MeV, will be tested as Compton telescope, sensitive to γ-rays from 300 keV to 10 MeV within a 1 sr FOV. Its detection efficiency for Compton events is expected to be 4% in the 1–3 MeV energy band, one of great astrophysical interest for both continuum and line emission. The calculated 3 sigma continuum sensitivity of $1.8\times10^{-7}\mathrm{cm}^{-2}\ \mathrm{sec}^{-1}\ \mathrm{keV}^{-1}$ in the 1–3 MeV range for a nominal 10 hours observation time, is sufficient to detect a variety of sources at MeV energies with an imaging accuracy as good as 1 degree.

Following the calibration flight with observations of the Crab Nebula, the collaboration will pursue a vigorous program of balloon flights with this new type of imaging telescope to achieve the maximum science return. Cygnus X-1, which is readily detectable with the LXe-TPC in a 3-hour observation, and the Orion region are among the science targets of interest. As a result of the recent competion for funding under the NASA Gamma-Ray Astronomy Supporting Research and Technology program, the Columbia team has been approved to continue the balloon flight program with the present prototype and to engage in further development of liquid rare gas imaging technology for a next generation Liquid Xenon Gamma-Ray Imaging Telescope (LXe-GRIT) that will permit a drastic improvement in sensitivity and angular resolution for medium energy γ-ray astrophysics. In collaboration with R. Mukherjee and J. Esposito of NASA/GSFC and T. Dame, S. Digel and P. Thaddeus of CfA, the Columbia group is also involved in an analysis of the Orion cloud region using *EGRET* data.

The Orion complex, owing to its proximity, large mass and solid angle is ideally suited for the analysis of its high energy γ-ray emission to determine the uniformity of the cosmic ray intensity on the scale of a molecular cloud, identify regions of possible enhanced cosmic ray density, and determine the molecular mass. The goal of our investigation is to use the increased statistics from the new exposure data obtained with *EGRET* to better distinguish cosmic ray excesses from background compact sources and variations in molecular column density. Fang Xu and Silver have made significant progress on this analysis so far. A detailed analysis of the final data set will involve a more precise calibration of the X-ratio, relating H II emission to CO densities, and will also look for any energy dependence of X, and for significant variations of X or the emissivity across Orion. This work on Orion will contribute to our understanding of gamma-ray and cosmic ray production mechanisms, the local cosmic ray density, and the properties of the ISM.

Kaaret, Novick, and Tomsick continue work on the Stellar X-Ray Polarimeter *(SXRP)* for the Spectrum-X-Gamma mission. The flight model of the *SXRP* has been completed and has undergone calibration and environmental testing. When launched, in 1998, the *SXRP* will provide an order of magnitude increase in polarization sensitivity relative to any previously flown X-ray polarimeter.

Paerels and Kahn completed work on a recalibration of the diffraction efficiency of the X-ray transmission gratings on *EXOSAT*. In the course of the analysis of a set of Transmission Grating Spectrometer data on Scorpius X-1 they noticed that radiation diffracted into large angles had apparently been detected from this source. The most likely explanation for this detection was short-wavelength radiation diffracted into high ($m>5$) spectral orders. The quantitative interpretation of the spectrum therefore required a calibration of these high order efficiencies, which had never been done. The new calibration was based on an explicit electromagnetic model for the grating efficiencies, and allowed for variation of the grating properties across the gratings. The new calibration successfully accounts for the large-angle dispersed flux in the Sco X-1 spectra. This effort is also relevant as a model for the still-to-be-performed calibration of the transmission grating spectrometers on *AXAF*.

Hailey and Hong are involved with the *INTEGRAL* experiment, studying the anticipated background levels in the imaging instrument on *INTEGRAL* and possible means for optimizing background rejection. This is being done in collaboration with researchers at Marshall Space Flight Center and the *INTEGRAL* imaging team.

Hailey is involved in the *EXIST* mission concept study. Columbia is working on sensitivity and background calculations as well as issues related to the design and fabrication of the mechanical elements of the telescope. *EXIST* (Energetic X-ray Imaging Telescope) is a collaboration additionally involving Harvard, CalTech, GSFC, MSFC, JPL and several European institutions. *EXIST* is a wide field of view instrument to perform an all-sky survey in the 20–600 keV energy band.

Hailey, Craig, Kahn and Jimenez-Garate are working on the development of ultrathin, lightweight mirrors for arcminute angular resolution imaging of soft γ-rays on a balloon payload called *HEFT* (high energy focussing telescope). This is a collaboration between Columbia, CalTech, Lawrence Livermore National Lab and the Danish Space Research Institutue. They are investigating mirrors made from thermally slumped glass or SiC, as well as more traditional epoxy-aluminum substrate replica optics. In each case the optics are coated with graded-density multilayers to enhance high energy reflectivity. In addition to work on the γ-ray optics, Columbia will be responsible for the gondola and precision aspect reconstruction system.

Hailey and Hong are studying neutron-induced background in γ-ray detectors. They are developing novel neutron shields called supershields which can be used to obtain very large reductions in the effect of neutron background compared to conventional shielding techniques. Supershields are passive shields consisting of multiple layers. This project involves the use of coupled particle-production — neutron-radiation transport codes (3-dimensional) to model the evolution of neutrons in a payload. It also involves more refined analytic calculations of the neutron source function and optimization of the supershield design. Laboratory and balloon-borne demonstration of the supershield designs will be undertaken in the next year.

Recent *ASCA* spectra exhibit discrepancies with the relative line intensities of various Fe XXIII and XXIV L-shell emission lines predicted by standard plasma emission codes. To address this issue, Kahn and Savin with their collaborators P. Beiersdorfer (LLNL), J. Crespo López-Urrutia (LLNL), V. Decaux (LLNL), E. M. Gullikson (LBNL), D. A. Liedahl (LLNL), K. J. Reed (LLNL), and K. Widmann (LLNL) have carried out a series of high resolution, broadband measurements of Fe XXIV line emission using an electron beam ion trap facility. X-ray lines produced in the trap were detected and resolved using Bragg crystal spectrometers. They carried out measurements of various $3\rightarrow2$ and $4\rightarrow2$ transitions, which result primarily from electron impact excitation. Overall, good agreement is found with distorted wave calculations.

Kahn and his collaborators V. Decaux (LLNL), P. Beiersdorfer (LLNL), and V. L. Jacobs (NRL) have carried out laboratory measurements of high-resolution spectra of iron K α emission under transient ionization conditions similar to those that are believed to exist in stellar flares and young supernova remnants. Using high spectral resolution ($\lambda/\Delta\lambda\geqslant2000$), they identified a number of transitions which can serve as diagnostics of ionizing plasma. The effects of the electron distribution on these diagnostic lines were constrained by varying the excitation energy in the experiment. Using the measured line ratios, they deduced values for the ionization time, $\eta=N_e t$, in the plasma, which agree with the actual values to $\sim$20 % accuracy. This adds confidence to the ability to derive similar constraints on astrophysical plasmas from remote X-ray spectroscopic observations.

Kahn and Savin and their collaborators J. Linkemann (MPI for Nuclear Physics), A. Wolf (Univ. Heidelberg), and A. Müller (Univ. Giessen) have initiated a collaboration to measure the $\Delta n=0$ dielectronic recombination (DR) cross sections for Fe^{17+}-Fe23+ (the iron L-shell ions). These measurements are important for understanding the ionization structure and line emission from X-ray photoionized nebulae (XPNs). Measurements have been carried out for Fe^{17+} which is predicted to exist in XPNs with electron temperatures of $\sim$ 15 eV. The measured DR resonance energies in the 10-25 eV energy range lie more than 2 eV below the resonance energies predicted by the best existing calculations in the literature. These calculations therefore significantly underpredict the Fe^{17+} $\Delta n=0$ DR rate coefficient for exactly those electron temperatures where $\Delta n=0$ DR is most important.

Kahn, Gu, and Savin and their collaborators P. Beiersdorfer (LLNL), G. V. Brown (Auburn), J. Crespo López-Urrutia (LLNL), D. A. Liedahl (LLNL), and K. Widmann (LLNL) continued their investigations to carry out a series of definitive measurements of line emissivities for the iron L-shell ions in optically thin, thermal plasmas in collisional equilibrium. Using the Lawrence-Livermore National Laboratory electron beam ion trap (EBIT) they are carrying out measurements using a monoenergetic electron beam and also by ramping the electron beam energy in time to simulate the electron energy distribution of Maxwellian plasmas. The aim of the quasi-Maxwellian measurements is to achieve the ionization balance appropriate for a Maxwellian plasma and observe the resulting line emissivities. Achieving the ionization

balance appropriate for a Maxwellian plasma is important because line emission from a given charge state is coupled with the one lower charge state by inner shell ionization and by the one higher charge state by dielectronic and radiative recombination.

Kahn is the Senior Co-Investigator and Principal Investigator for US Participation in the development of the Reflection Grating Spectrometer *(RGS)* for the European Space Agency's X-Ray Multi-Mirror Mission *(XMM)*, which will launch in August 1999. *XMM* is a facility class mission designed for high throughput spectroscopy of cosmic sources in the energy range 0.1–15 keV. It incorporates three densely nested, grazing incidence telescopes, all co-aligned with their own focal plane instrumentation. The RGS incorporates arrays of grazing incidence X-ray reflection gratings mounted in the X-ray optical path directly behind two of the three telescopes. The dispersed light is imaged by strips of CCD detectors located near, but slightly offset, from the telescope focal plane. The spectrometer achieves a spectral resolving power $\sim$200–700 over the energy band, 0.3–2 keV, coupled with very high effective area, greater than $\sim$200 cm^2. The Columbia role in this experiment involves the design, development, fabrication, and calibration of the reflection grating arrays, which is being undertaken at the Laboratory's Nevis facility by Kahn in collaboration with Paerels, Rasmussen, Hailey, and graduate students, Cottam and Spodek. During the last year, this group completed the development of the Engineering Qualification Model for the grating array which is fully flight-representative except that it only includes $\sim$20% of the gratings that will be integrated into the flight models. This unit is currently undergoing testing at the Panter X-ray Calibration Facility near Munich, Germany.

Kahn is a member of the Science Working Group and Paerels and Hailey are members of the Study Team for the High Throughput X-Ray Spectroscopy *(HTXS)* mission which is under consideration by NASA as a major new start in the 2000–2005 timeframe. In its current ''strawman'' configuration, *HTXS* consists of six separate spacecraft, each equipped with a large, grazing incidence soft X-ray telescope that ''feeds'' both a reflection grating spectrometer and a cryogenic microcalorimeter spectrometer, as well as a companion hard X-ray telescope that may consist of one or more grazing incidence modules with non-dispersive imaging detectors at the foci. This design yields very high effective area (2000–10,000 cm^2) across a large bandpass, 0.2–40 keV, coupled with high spectral resolving power, $>$300 at all energies. Columbia has played a significant role in the design and development of both the reflection grating instrument and the hard X-ray telescopes and detectors.

Craig, Hailey, Kahn, and Ruderman, as well as S. Ritz and F. Scuilli of Columbia's Nevis Laboratory for High Energy Physics, have joined the collaboration developing the *GLAST* (Gamma-Ray Large Area Space Telescope) mission concept for consideration as a new start by NASA within the next few years. *GLAST* is a follow-on to the *EGRET* experiment of *GRO* which explores the very high energy gamma-ray range, 30 MeV–100 GeV, with significant improvements in effective area, angular resolution, and field of view. As currently envisioned, *GLAST* will comprise an array of silicon microstrip ''trackers'' backed by crystal calorimeters. Together with Hong, the group is working on a redesign of the calorimeter which incorporates scintillating fiber readout to provide an imaging capability, useful for retaining sensitivity to events which do not convert in the tracker. The group has also played a role in refining the scientific goals and spacecraft requirements for this mission.

Kay spent part of the year on sabbatical as an NSF International Research Fellow at the Institute of Astronomy and Geophysics, University of São Paulo, Brazil. She is collaborating with Dr. A.M. Magalhães on implementing polarimetry optics into the RC spectrograph at the *CTIO* 4m telescope to allow for spectropolarimetry observations. Kay received a 1995 NSF Faculty Early Career Development (CAREER) grant, ''Spectropolarimetry of Accretion Powered Compact Sources,'' to continue her research on AGN.

PUBLICATIONS

Aprile, E. *et al.* 1996, ''Liquid Xenon Gamma-Ray Imaging Telescope (LXeGRIT) for Medium Energy Astrophysics,'' *SPIE Conference Proceedings on Gamma-Ray and Cosmic-Ray Detectors, Techniques, and Missions*, Volume 2806, in press.

Aprile, E., Bolotnikov, A., Chen, D., Tawara, H., Xu, F., Chupp, E., Dunphy, P., Doke, T., Kikuchi, J., Masuda, K., Fishman, G. & Pendleton, G. 1995, ''The Imaging Liquid Xenon-Coded Aperture Telescope (LXe-CAT),'' in *Experimental Astronomy*, Proc. of the Workshop on Imaging in High Energy Astronomy, eds. L. Bassani and G. diCocco, p. 333.

Aprile, E., Chupp, E., Bolotnikov, A. & Dunphy, P. 1995, ''Determination of the ^{26}Al Celestial Source Distribution,'' *Ap.J.*, **453**, 685.

Baldwin, J.A., Crotts, A., DuFour, R.J., Ferland, G.J., Heathcote, S., Hester, J.J., Korista, K.T., Martin, P.G., O'Dell, C.R., Rubin, R.H. Tielens, A.G.G.M., Verner, D.A., Verner, E.M., Walter, D.M. & Wen, Z. 1996, ''Physical Conditions in Low Ionization Regions of the Orion Nebula,'' *Ap.J. (Letters)*, in press.

Balmforth, N.J. & Spiegel, E.A. 1995, ''Sinuous Modes and Steady Warps of Polytropic Discs,'' in *Waves in Astrophysics*, G. Contopoulos, J.H. Hunter, Jr. and R.E. Wilson, eds., Ann. N.Y. Acad. Sci., **773**, 55.

Balmforth, N.J. & Spiegel, E.A. 1996, ''Nonlinear ringing of polytropic disks,'' *Physica D*, in press.

Becker, R.H., White, R.L., & Helfand, D.J. 1995, ''The *FIRST* Survey: Faint Images of the Radio Sky at Twenty-cm,'' *Ap.J.*, **450**, 559.

Becker, R.H., White, R.L., Helfand, D.J., Gregg, M.D. & McMahon, R.G. 1996, ''Stellar Results from the FIRST Survey,'' in *Radio Emission from the Stars and the Sun*, eds. J.M. Paredes and R. Taylor, ASP Conf. Ser. 93, p.422.

Becker, R.H., Helfand, D.J., White, R.L., McMahon, R.G. & Gregg, M.D. 1996, ''First Results from the VLA *FIRST* Survey,'' in *Proc. IAU Symposium*, **175**, in press.

Beiersdorfer, P., Vogel, D.A., Reed, K.J., Decaux, V., Scofield, J.H., Widmann, K., Hölzer, G., Förster, E., Wehrhan, O., Savin, D.W. & Schweikhard, L. 1996, ''Mea-

surement and Interpretation of the Polarization of the X-Ray Line Emission of Heliumlike Fe XXV excited by an Electron Beam,'' *Phys. Rev. A*, **53**, 3974.

Blanton, E.L. & Helfand, D.J. 1996, ''ASCA Observations of the Composite Supernova Remnant G29.7-0.3,'' *Ap.J.*, in press.

Borra, E.F., Levesque, S., Beauchemin, M., Morton, D., Stoughton, C., Vanden Berk, D., York, D.G., Green, R.F. & Crotts, A.P.S. 1996, ''Spectroscopy of Quasar Candidates Found with Slitless Spectroscopy, II: 6 Northern Fields,'' *A.J.*, **111**, 1456.

Brandt, W.N., Halpern, J.P. & Iwasawa, K. 1996, ''*ROSAT* PSPC and HRI Observations of the Composite Starburst/ Seyfert 2 Galaxy NGC 1672,'' *MNRAS*, **281**, 687.

Brinkman, A.C., Aarts, H.J.M., den Boggende, A.J.F., Dubbeldam, L., den Herder, J.W., Kaastra, J.S., de Korte, P.A.J., van Leewen, B.J., Mewe, R., Decker, T.A., Hailey, C.J., Kahn, S.M., Paerels, F., Pratuch, S.M., Rasmussen, A., Branduardi-Raymont, G., Guttridge, P., Bixler, J., Thomsen, K., Zehnder, A. & Erd, C. 1996, ''The Reflection Grating Spectrometer On-Board XMM,'' *Proc. SPIE*, **2808**, in press.

Buchalter, A., Kamionkowski, M. & Rich, R. M. 1996 ''Rates for Color-Shifted Microlensing Events,'' *Ap.J.*, **469**, 676.

Buchalter, A. & Kamionkowski, M., 1996, ''Rates for Parallax-Shifted Microlensing Events from Ground-Based Observations of the Galactic Bulge,'' *Ap.J.*, submitted.

Castro, S., Rich, R.M., McWilliam, A., Ho, L.C., Spinrad, H., Filippenko, A.V. & Bell, R.A. 1996, ''Echelle Spectroscopy of a Metal-Rich K Giant in Baade's Window Using the Keck High-Resolution Spectrograph,'' *A.J.*, **111**, 2439.

Chen, A., Dwyer, J. & Kaaret, P. 1996, ''The Inverse-Compton and Extragalactic Components of the Diffuse Gamma-Ray Emission,'' *Ap.J.*, **463**, 169.

Chen, K., Halpern, J.P. & Titarchuk, L.G. 1996, ''Polarization of Line Emission from an Accretion Disk and Application to Arp 102B,'' *Ap.J.*, submitted.

Craig, W., Hailey, C. & Pisarski, R. 1996, An X-ray Study of the Supernova Remnant CTB1,'' *Ap.J.*, submitted.

Cress, C.M., Helfand, D.J., Becker, R.H., Gregg, M.D. & White, R.L. 1996, ''The Angular Two-Point Correlation Function for the *FIRST* Radio Survey,'' *Ap.J.*, in press.

Cress, C.M., Helfand, D.J., Becker, R.H., Gregg, M.D. & White, R.L. 1996, ''The Angular Two Point Correlation Function for the *FIRST* Radio Survey,'' in *Clusters, Lensing, and the Future of the Universe*, eds. V. Trimble and A. Reisenegger, ASP Conf. Series Vol. 88, p.193.

Crotts, A.P.S. & Tomaney, A.B. 1996, ''Results from a Survey of Gravitational Microlensing in M31 and the Galaxy,'' *Ap.J. (Letters)*, in press.

Decaux, V., Beiersdorfer, P., Kahn, S.M. & Jacobs, V L. 1996, ''High Resolution Measurement of the Kα Spectrum of Fe XXV to Fe XVIII: New Spectral Diagnostics of Non-Equilibrium Astrophysical Plasmas,'' *Ap.J.*, accepted.

Eracleous, M., Halpern, J.P. & Livio, M. 1996, ''The Resolved Fe Kα Line of the Broad-Line Radio Galaxy 3C 390.3 and its Implications,'' *Ap. J.*, **459**, 89.

Fang, Y, Duncan, R., Crotts, A.P.S. & Bechtold, J. 1996, ''The Size and Nature of the Lyman α Forest Clouds Probed by QSO Pairs and Groups,'' *Ap.J.*, **462**, 77.

Fang, Y., Fan, X., Tytler, D. & Crotts, A.P.S. 1996, ''Remeasurement of the H I Gunn-Peterson Effect toward QSO PKS 1937-101 with Keck Observations,'' *Ap.J.*, submitted.

Ford, E., Kaaret, P., Harmon, B.A., Tavani, M., Zhang, S.N., Barret, D., Grindlay, J., Bloser, P. & Rmillard, R.A. 1996, ''Anticorrelated Hard/Soft X-Ray Emission from the X-Ray Burster 4U 0614+091,'' *Ap.J. (Letters)*, **469**, L37.

Ford, E., Kaaret, P., Tavani, M., Barret, D., Bloser, P., Grindlay, J., Harmon, B.A., Pacisesas, W.S. & Zhang, S.N. 1996, ''Evidence from Quasi-Periodic Oscillations for a Millisecond Pulsar in the Low-Mass X-Ray Binary 4U 0614+091,'' *Ap.J. (Letters)*, submitted.

Ford, E., Kaaret, P., Harmon, B.A., Tavani, M. & Zhang, S.N. 1996, ''A Search for Hard X-Ray Emission from Globular Clusters: Constraints from *BATSE*,'' *Ap.J.*, **467**, 272.

Forster, K., Rich, R.M. & McCarthy, J.K. 1995, ''Echelle Spectroscopy of the Na I D Absorption-Line Systems of Markarian 231,'' *Ap.J.*, **450**, 74.

Forster, K. & Halpern, J.P. 1996, ''Extreme X-ray Variability in the Narrow-Line QSO PHL 1092,'' *Ap.J.*, **468**, 565.

Foster, R.S., Waltman, E.G., Tavani, M., Harmon, B.A. & Zhang, S.N. 1996, ''X-Ray and Radio Variability Observations of the Superluminal Galactic Source GRS 1915 +105,'' *Ap.J. (Letters)*, **467**, L81.

Freese, K. & Kamionkowski, M. 1996, ''Indirect Detection of a Light Higgsino Motivated by Collider Data,'' *Phys. Rev. D*, submitted

Gates, E., Kamionkowski, M. & Turner, M. S. 1996, ''Comment on 'The Dispersion Velocity of Galactic Dark Matter Particles,'' *Phys. Rev. Lett.*, in press.

Gotthelf, E.V., Hamilton, T.T., & Helfand, D.J. 1996, ''The *Einstein* Observatory Detection of Faint X-ray Flashes,'' *Ap.J.*, **466**, 795.

Gregg, M.D., Becker, R.H., White, R.L., Helfand, D.J., McMahon, R.G., & Hook, I.M. 1996, ''The *FIRST* Bright Quasar Survey,'' *A.J.*, **112**, 407.

Grindlay, J., Gehrels, N., Hailey, C., Harrison, F., Mahoney, W., Prince, T., Ramsey, B., Skinner, G., Ubertini, P. & Weisskopf, M. 1996, ''Energetic X-ray Imaging Survey Telescope,'' *Proc. SPIE*, 2518.

Hailey, C. & Craig, W. 1995, ''Discovery of a Candidate Isolated Neutron Star in a New Supernova Remnant Near CTB1,'' *Ap.J. (Letters)*, **455**, L151.

Hailey, C. & Harrison, F. 1995, ''A New Concept for Background Rejection in Gamma-ray Astronomy - the Supershield,'' *Nucl. Instr. Meth.*, **A365**, 518.

Halpern, J.P., Martin, C. & Marshall, H.L. 1996, ''The Geminga Pulsar: Soft X-ray Variability and an *EUVE* Observation,'' J. P. Halpern, C. Martin, & H. L. Marshall, *Ap.J. (Letters)*, in press.

Halpern, J.P. & Wang, F.Y.-H 1996, ''A Broad-Band X-ray Study of the Geminga Pulsar,'' *Ap.J.*, in press.

Halpern, J.P., Eracleous, M. & Filippenko, A.V. 1996,

''*Hubble Space Telescope* Ultraviolet Spectrum of Arp 102B, the Prototypical Double-Peaked Emission-Line AGN,'' *Ap.J.*, **464**, 704.

Halpern, J.P. & Marshall, H.L. 1996, ''A Long *EUVE* Observation of the Seyfert Galaxy RX J0437.4-4711,'' *Ap.J.*, **464**, 760.

Halpern, J.P., Martin, C. & Marshall, H.L. 1996, ''Soft X-ray Properties of the Binary Millisecond Pulsar J0437−4715,'' *Ap.J.*, **462**, 908.

Halpern, J.P. 1996 ''A Possible X-ray Detection of the Binary Millisecond Pulsar J1012+5307,'' *Ap. J. (Letters)*, **459**, L9.

Halpern, J.P., Helfand, D.J., & Moran, E.C. 1995, ''No X-ray−Luminous Starbursts in the *Einstein* Medium Sensitivity Survey, Either,'' *Ap.J.*, **453**, 611.

Hamilton, T.T., Gotthelf, E.V. & Helfand, D.J. 1996, ''The Absence of X-ray Flashes from Nearby Galaxies and the Gamma-Ray Burst Distance Scale,'' *Ap.J.*, **466**, 779.

Hardenberg, J. von, Paparella, F., Platt, N., Provenzale, A., Spiegel, E.A. & Tresser, C. 1996, ''The Missing Motor of On-Off Intermittency,'' *Phys. Rev. E*, in press.

Hardenberg, J. von, Paparella, F., Provenzale, A. & Spiegel, E.A. 1996, ''Through a glass darkly: distinguishing stochastic from chaotic resonance'' *Ann. N.Y. Acad. Sci.*, in press.

Harrison, F., Gehrels, N., Grindlay, J., Hailey, C., Mahoney, W., Prince, T., Ramsey, B., Skinner, G., Ubertini, P. & Weisskipf, M. 1996, ''Gamma-ray Burst Studies with the Energetic X-ray Imaging Survey Telescope (EXIST),'' in *AIP Conference Proceeding of the Compton Symposium.*

Harrus, I.M., Hughes, J.P. & Helfand, D.J. 1996, ''Discovery of an X-ray Synchrotron Nebula Associated with the Radio Pulsar PSR B1953+01 in the Supernova Remnant W44,'' *Ap.J.*, **464**, L161.

Harvey, D. & Patterson, J. 1995, PASP, 107, 1055. ''Superhumps in Cataclysmic Binaries. VII. CY Ursae Majoris,'' *PASP*, **107**, 1055.

Haswell, C.A. 1996, ''Optical Photometry of Black Hole Binaries,'' Invited Review in: *IAU Symposium 165: Compact Stars in Binaries*, eds: E. P. J. van den Heuvel and J. van Paradijs, p. 351.

Haswell, C.A. & Patterson, J. 1996, ''*HST* FOS Observations of YY Draconis'' in: *IAU Coll. 158: Cataclysmic Variables*, eds: A. Evans and J.H. Wood, 169.

Haswell, C.A., Patterson, J., Thorstensen, J.R., Hellier, C., & Skillman, D.R. 1997, ''Pulsations and Accretion Geometry in YY Draconis: A Study Based on *Hubble Space Telescope* Observations,'' *Ap.J.* in press.

Helfand, D.J., Becker, R.H., & White, R.L., ''The X-ray Emission of 3C58 Revisited,'' *Ap.J.*, **453**, 741.

Helfand, D.J., Das, S.R., Becker, R.H., White, R.L. & McMahon, R.G. 1996, ''Rapid Variability in Faint Extragalactic Radio Sources,'' in *Proceedings of the Workshop on Blazar Variability*, eds. H.R. Miller and J.R. Webb, in press.

Helfand, D.J. 1996, ''Far From the Madding Clouds,'' *Mercury*, **25**, 16.

Helfand, D.J. 1996, ''X-rays From the Rest of the Universe,'' *Physics Today*, **48**, 58.

Hess, C.J., Kahn, S.M. & Paerels, F. 1996, ''Properties and Spectroscopic Implications of Thermal Instability in X-Ray Binary and AGN Accretion Flows,'' *Ap.J.*, in press.

Hibbard, J.E. & van Gorkom, J.H. 1996, '' H I, H II and R-band Observations of a Galactic Merger Sequence,'' *A.J.*, **111**, 655.

Hiroyama, M., Nagase, F., Tavani, M., Kaspi, V. & Arons, J. 1996, in ''Post-Periastron *ASCA* Observation of the PSR 1259-63 System,'' *Proceedings Astronomical Society, Japan*, **48**, No. 6, Dec. 25, 1996.

Hiroyama, M., Nagase, F., Tavani, M., Kaspi, V., Cominsky, L., Hoshino, M. & Kawai, N. 1996, ''*ASCA* Observations of PSR 1259-63,'' in in *Proceedings of the 3rd ASCA* Symposium, in press.

Hong, J. & Hailey, C. 1996, ''Modeling and Suppression of Neutron Background in Gamma-ray Detectors,'' to appear in *SPIE Proceedings*.

Jungman, G., Kamionkowski, M., & Griest, K. 1995, ''Supersymmetric Dark Matter,'' *Phys. Rep.* **267**, 195.

Jungman, G., Kamionkowski, M., Kosowsky, A., & Spergel, D. N. 1996, ''Weighing the Universe with the Cosmic Microwave Background,'' *Phys. Rev. Lett.* **76**, 1007.

Jungman, G., Kamionkowski, M., Kosowsky, A., & Spergel, D.N. 1996, ''Cosmological-Parameter Determination with Microwave Background Maps,'' *Phys. Rev. Lett.* **76**, 1007.

Kaaret, P. 1996 ''The Unidentified Galactic EGRET Sources,'' to appear in *Adv. Space Res*.

Kaaret, P. & Cottam, J. ''Do the Unidentified Galactic *EGRET* Sources Lie in Star-Forming Regions?'' *Ap.J. (Letters)*, **462**, L35. (1996).

Kahn, S.M., Cottam, J., Decker, T.A., Paerels, F.B.S., Partuch, S.M., Rasmussen, A., Spodek, J., Bixler, J.V., Brinkman, A.C., den Herder, J.W. & Erd, C. 1996, ''The Reflection Grating Arrays for the Reflection Grating Spectrometer On-Board XMM,'' *Proc. SPIE*, **2808**, in press.

Kamionkowski, M., Jungman, G., Kosowsky, A., & Spergel, D.N. 1996, ''Future Cosmic Microwave Background Constraints to the Baryon Density,'' in *Cosmic Abundances*, proceedings of the Conference, College Park, MD, October 9−11, 1995, edited by S.S. Holt and G. Sonneborn (ASP, San Francisco, 1996).

Kamionkowski, M. & Toumbas, N. 1996, ''A Low-Density Closed Universe,'' *Phys. Rev. Lett.* **77**, 587.

Kamionkowski, M. 1996, ''Matter/Microwave Correlations in an Open Universe,'' *Phys. Rev. D* **54**, 4169.

Kamionkowski, M. & Toumbas, N. 1996, ''Do We Know the Geometry of the Universe?'' CU-TP-750, CAL-606, astro-ph/9605100. To appear in *Microwave Background Anisotropies*, proceedings of the the XVIth Moriond Astrophysics Meeting, Les Arcs, France, March 16−23, 1996.

Kamionkowski, M., Kosowsky, A., & Stebbins, A. 1996, ''A Probe of Primordial Gravity Waves and Vorticity,'' *Phys. Rev. Lett.*, submitted.

Kamionkowski, M. 1996, ''Particle Dark Matter,'' CU-TP-786, CAL-616, hep-ph/9609531. To appear in *Neutrinos*,

Dark Matter, and the Universe, proceedings of the VIIIth Rencontres de Blois, June 8–12, 1996, Blois, France.

Kistiakowsky, V. & Helfand, D.J. 1995, ''The Identification of Galactic Plane Radio Sources: Distant Planetary Nebulae at $|b|<2$ Degrees,'' *A.J.*, **110**, 2225.

Kniffen, D.A., Alberts, W.C.K., Bertsch, D.L., Dingus, B.L., Esposito, J.A., Fichtel, C.E., Foster, R.S., Hartman, R.C., Hunter, S.D., Kanbach, G., Lin, Y.C., Mattox, J.R., Mayer-Hasselwander, H.A., Michelson, P.F., von Montigny, C., Nolan, P.L., Paredes, J.M., Ray, P.S., Schneid, E.J., Sreekumar, P., Tavani, M. & Thompson, D.J. 1996, ''*EGRET* Observations of the Gamma-Ray Source 2CG 135+01,'' *Ap.J.*, submitted.

Kosowsky, A., Kamionkowski, M. Jungman, G. & Spergel, D.N. 1996, ''Determining Cosmological Parameters from the Microwave Background,'' CU-TP-749, CAL-605, astro-ph/9605147. To appear in proceedings of the International Conference on Sources and Detection of Dark Matter in the Universe Santa Monica, CA, February 14–16, 1996, edited by D. Cline (Elsevier Science, Amsterdam) [*Nuclear Physics B Supplement*].

Liedahl, D.A. & Paerels, F.B.S. 1996, ''Photoionization-Driven X-ray Line Emission in Cygnus X-3,'' *Ap.J. (Letters)*, **468**, L33.

Mattox, J.R. Halpern, J.P. & Caraveo, P.A. 1996, ''Timing the Geminga Pulsar with EGRET Data,'' *Astr. Ap.*, in press.

Merritt, D. & Valluri, M. 1996 ApJ, ''Chaos and Mixing in Triaxial Stellar Systems,'' *Ap.J.*, **417**, in press.

Mighell, K.J. & Rich, R.M. 1996, ''The Leo II Dwarf Spheroidal – An Old Galaxy with a Large Intermediate-Age Population,'' in *Formation of the Galactic Halo*, ASP Conf. Ser. Vol. 92, H. Morrison & A. Sarajedini eds. p. 528.

Mighell, K.J., Rich, R.M., Shara, M. & Fall, S.M. 1996, ''WFPC2 Observations of Star Clusters in the Magellanic Clouds. I. The Large Magellanic Cloud Globular Cluster Hodge 11,'' *A.J.*, **111**, 2314.

Mighell, K.J. & Rich, R.M. 1996, ''The Leo Dwarf Spheroidal – An Old Galaxy with a Large Intermediate-Age Population,'' *A.J.*, **111**, 777.

Mighell, K.J. & Rich, R.M. 1995, ''Hubble Space Telescope Planetary Camera Observations of the Stellar Populations Near the Nucleus of M33,'' *A.J.*, **110**, 1649.

Moran, E.C., Halpern, J.P. & Helfand, D.J. 1996, ''Classification of *IRAS*-Selected X-ray Galaxies in the *ROSAT* All-Sky Survey,'' *Ap.J. Suppl.*, **106**, 341.

Moran, E.C., Helfand, D.J., Becker, R.H., & White, R.L. 1996, ''The *Einstein* Two-Sigma Catalog: Silver Needles in the X-ray Haystack,'' *Ap.J.*, 461, 127.

Murante, G., Provenzale, A., Spiegel, E.A. & Thieberger, R., 1996, ''Density Singularities and Cosmic Structures,'' *MNRAS*, submitted.

Norris, J.E., Freeman, K.C., & Mighell, K.J. 1996, ''The Giant Branch of Omega Centauri. V. The Calcium Abundance Distribution,'' *Ap.J.*, **462**, 241.

Norris, J.E., Da Costa, G.S., Freeman, K.C. & Mighell, K.J. 1996, ''The Enrichment of Omega Centauri,'' in *Formation of the Galactic Halo*, ASP Conf. Ser. Vol. 92, H. Morrison & A. Sarajedini eds. p. 375.

Olling, R.P. 1996, ''NGC 4244, A Low Mass Galaxy with a Falling Rotation Curve and a Flaring H I Layer,'' *A.J.*, **112**, 457.

Olling, R.P. 1996, ''The Highly Flattened Dark Matter Halo of NGC 4244,'' *A.J.*, **112**, 481.

Ortolani, S., Renzini, A., Gilmozzi, R., Marconni, G., Barbuy, B., Bica, E. & Rich, R.M. 1996, ''The Age of the Galactic Bulge from Globular Cluster *HST* Observations,'' in *Formation of the Galactic Halo*, ASP Conf. Ser. Vol. 92, H. Morrison & A. Sarajedini eds. p. 960.

Ortolani, S., Renzini, A., Gilmozzi, R., Marconi, G., Barbuy, B., Bica, E., & Rich, R.M. 1995, ''Near-Coeval Formation of the Galactic Bulge and Halo Infrared from Globular Cluster Ages,'' *Nature*, **377**, 701.

Paerels, F.B.S., Hur, M.Y., Mauche, C.W. & Heise, J. 1996, ''Extreme Ultraviolet Spectroscopy of the White Dwarf Photosphere in AM Herculis,'' *Ap.J.*, **464**, 884.

Paerels, F.B.S., Kahn, S.M. & Wolkovitch, D. 1996, ''A recalibration of the Transmission Grating Spectrometers on *EXOSAT*,'' *Ap.J.*, submitted.

Paerels, F.B.S. 1996, ''Pressure Broadening of Absorption Lines in Neutron Star Atmospheres and Prospects for Measuring Neutron Star Masses and Radii,'' *Ap.J. (Letters)*, in press.

Patterson, J., Patino, R., Harvey, D. Skillman, D.R., Ringwald, F., & Thorstensen, J.R. 1996, ''Periods and Quasi-periods in the Novalike Variable BZ Camelopardalis'' *A.J.*, **111**, 2422.

Patterson, J. *et al.* 1996, ''Superhumps in Cataclysmic Binaries XI. V603 Aquilae Revisited'' *PASP*, in press.

Patterson, J. *et al.* 1995, ''Superhumps in Cataclysmic Binaries VIII. V1159 Orionis,'' *PASP*, **107**, 1183.

Patterson, J. *et al.* 1996, ''Superhumps in Cataclysmic Binaries IX. AL Comae Berenices,'' *PASP*, in press

Provenzale, A., Spiegel, E.A. & Thieberger, R., 1996, ''Cosmic Lacunarity,'' *Chaos*, in press.

Refregier, A., Helfand, D.J. & McMahon, R.G. 1996, ''Isolating the Foreground of the X-ray Background,'' in *Rontgenstrahlung from the Universe*, eds. H.U. Zimmermann, J.E. Trumper, and H. Yorke, p.337.

Refregier, A., Helfand, D.J. & McMahon, R.G. 1997, ''Detailed Analysis of the Cross-Correlation Function Between the X-ray Background and Foreground Galaxies,'' *Ap.J.*, in press.

Refregier, A. & Loeb, A. 1997, ''Gravitational Lensing of the X-ray Background by Clusters of Galaxies,'' *Ap.J.*, submitted.

Rich, R.M. 1996, ''The Relationship of the Galactic Bulge to the Stellar Halo,'' in *Formation of the Galactic Halo*, ASP Conf. Ser. Vol. 92, H. Morrison & A. Sarajedini eds. p. 24.

Rich, R.M., Mighell, K.J., & Neill, J.D. 1996, ''The Metal Rich Halo of M31,'' in *Formation of the Galactic Halo*, ASP Conf. Ser. Vol. 92, H. Morrison & A. Sarajedini eds. p. 544.

Rich, R.M., Mighell, K.J., Freedman, W.L. & Neill, J.D. 1996, ''Local Group Populations with the Hubble Space

Telescope. I. The M31 Globular Cluster G1=Mayall II,'' *A.J.*, **111**, 768.
Sadler, E.M., Rich, R.M. & Terndrup, D.M. 1996, ''K Giants in Baade's Window. II. The Abundance Distribution,'' *A.J.*, **112**, 171.
Savin, D.W., Beiersdorfer, P., Crespo López-Urrutia, J., Decaux, V., Gullikson, E.M., Kahn, S.M., Liedahl, D.A., Reed, K.J., & Widmann, K. 1996, ''Laboratory Measurements of Fe XXIV *L*-Shell Line Emission,'' *Ap.J. (Letters)* **470**, L73.
Sellwood, J. & Valluri, M. 1996, ''Instabilities of a Family of Oblate Stellar Spheroids,'' *MNRAS*, submitted.
Skillman, D.R. *et al.* 1995, ''Superhumps in Cataclysmic Binaries V. MV Lyrae,'' *PASP*, **107**, 545.
Skillman, D.R., Patterson, J., Harvey, D. & Vanmunster, T. 1997, ''Superhumps in Cataclysmic Binaries. X. V1974 Cygni'' *PASP*, in press.
Smith, E.O., Neill, J.D., Mighell, K.J., & Rich, R.M. 1996, ''Fornax Globular Clusters 1 and 5: A Confirmed Extragalactic Second Parameter Pair,'' *A.J.*, **111**, 1596.
Spiegel, E.A. 1995, ''A Prelude to Stellar Convection Theory,'' in Physical Processes in Astrophysics, I.W. Roxburgh and J.-L. Masnou, eds., Lecture Notes in Physics (Springer-Verlag) 129.
Szomoru, A., van Gorkom, J.H. & Gregg, M.D. 1996, ''An H I Survey of the Bootes Void (part I),'' *A.J.*, **111**, 2141.
Szomoru, A., van Gorkom, J.H., Gregg, M.D. & Strauss, M.A. 1996, ''An H I Survey of the Bootes Void (part II),'' *A.J.*, **111**, 2150.
Tavani, M. 1996, ''A Shock Emission Model for Gamma-Ray Bursts,'' in *Proceedings of the 3rd Huntsville Symposium on Gamma-Ray Bursts*, eds. C. Kouveliotou, M. S. Briggs & G. J. Fishman, AIP, in press
Tavani, M. 1996, ''A Cosmological Test for Shock-Powered Gamma-Ray Bursts,'' in *Proceedings of the 3rd Huntsville Symposium on Gamma-Ray Bursts*, eds. C. Kouveliotou, M. S. Briggs & G. J. Fishman, AIP, in press.
Tavani, M. 1996, ''A Shock Emission Model for Gamma-Ray Bursts,'' *Phys. Rev. Letters*, **76**, 3478.
Tavani, M. 1996, ''A Shock Emission Model for Gamma-Ray Bursts II: Spectral Properties,'' *Ap.J.*, **466**, 768.
Tavani, M. & Arons, J. 1996, ''Theory of High Energy Emission from the Pulsar/Be-Star System PSR 1259-63 System I: Radiation Mechanisms and Interaction Geometry,'' *Ap.J.*, in press.
Tavani, M., Mukherjee, R., Mattox, J., Halpern, J., Thompson, D.J., Hermsen, W., Zhang, S.N. & Foster, R. 1996, ''Discovery of a Non-Blazar Gamma-Ray Transient Near the Galactic Plane: GRO J1838-04,'' *Ap.J.*, submitted.
Tavani, M. 1996, ''X-Ray Emission of Gamma-Ray Bursts,'' *Ap.J.*, submitted.
Tavani, M., Fruchter, A., Harmon, B.A., Zhang, S.N., Hjellming, R.N. Bailyn, C. & Livio, M. 1996, ''The 'Dual' Nature of Outbursts from the Superluminal X-Ray Transient Source GRO J1655-40,'' *Ap.J. (Letters)*, in press.
Terndrup, D.M., Sadler, E.M. & Rich, R.M. 1995, ''K Giants in Baade's Window. I. Velocity and Line-Strength Measurements,'' *A.J.*, **110**, 1774.
Thompson, D.J., Bailes, M., Bertsch, D.L., Esposito, J.A., Fichtel, C.E., Harding, A.K., Hartman, R.C., Hunter, S.D., Manchester, R.N., Mattox, J.R., von Montigny, C., Mukherjee, R., Ramanamurthy, P.V., Sreekumar, P., Fierro, J.M., Lin, Y.C., Michelson, P.F., Nolan, P.L., Kanbach, G., Mayer-Hasselwander, A., Merck, M., Kniffen, D.A., Schneid, E.J., Kaspi, V.M., Johnston, S., Daugherty, J. & Ruderman, M. 1996, ''*EGRET* Observations of High-Energy Gamma Radiation from PSR B1706−44,'' *Ap.J.*, *465*, 385.
Tomaney, A.B. & Crotts, A.P.S. 1996, ''Expanding the Realm of Microlensing Surveys with Difference Image Photometry,'' *A. J.*, in press.
Valluri, M. & Anupama, G.C. 1996, ''Hα Imaging of the Hickson Compact Group 62,'' *A.J.*, **112**, 1390.
Van Grokom, J.H., Carilli, C.L., Stocke, J.T., Perlman, E.S. & Shull, J.M. 1996, ''The H I Environment of Nearby Lyman-alpha Absorbers,'' *A.J.*, **112**, 1397.
Van Gorkom, J.H. 1996, ''The Evolution of Galaxies in Different Environments,'' in *Minnesota Lectures on Extragalactic Neutral Hydrogen*, ed. E.D. Skillman, *ASP Conf Ser.*, **106**, 293.
White, N.E., Tananbaum, H. & Kahn, S.M. 1996, ''The High Throughput X-Ray Spectroscopy (HTXS) Mission,'' in *Proceedings of the Next Generation X-Ray Observatory Workshop*, Leceister, England, July 1996, ed. M. Turner, in press.
White, R.L., Becker, R.H., Helfand, D.J. & Gregg, M.D. 1997, ''A Catalog of 1.4 GHz Radio Sources from the FIRST Survey,'' *Ap.J.* (in press).
Xu, J. & Crotts, A.P.S. 1996, ''Structure and Kinematics of the Interstellar Medium in front of SN 1987A,'' *Ap.J.*, submitted.
Zhao, H.S., Rich, R.M. & Spergel, D.N. 1996, ''A Consistent Microlensing Model for the Galactic Bar,'' *MNRAS*, **282**, 175.
Zhao, H.S., Rich, R.M. & Biello, J. 1996, ''Proper-Motion Anisotropy, Rotation, and the Shape of the Galactic Bulge,'' *Ap.J.*, **470**, 506.
Ziock, K., Hailey, C., Sandler, P. & Sprehn, G. 1995, ''A Large Area, Broad Bandwidth Gamma-ray Imaging Spectrometer for Astrophysics,'' *Proc. IEEE Nucl. Sci. Symposium*.