NASA Goddard Space Flight Center
Laboratory for High Energy Astrophysics

Greenbelt, Maryland 20771

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This report covers the period from July 1, 2001 to June 30, 2002.

This Laboratory's scientific research is directed toward experimental and theoretical investigations in the areas of X-ray, gamma-ray, gravitational wave and cosmic-ray astrophysics. The range of interests of the scientists includes the Sun and the solar system, stellar objects, binary systems, neutron stars, black holes, the interstellar medium, normal and active galaxies, galaxy clusters, cosmic ray particles, gravitational wave astrophysics, extragalactic background radiation, and cosmology. Scientists and engineers in the Laboratory also serve the scientific community, including project support such as acting as project scientists and providing technical assistance for various space missions. Also at any one time, there are typically between ten and fifteen graduate students involved in Ph.D. research work in this Laboratory. Currently there are graduate students from Drexel U., George Washington U., and the U. of Maryland.

1. PERSONNEL

Dr. Nicholas White is Chief of the Laboratory for High Energy Astrophysics. Dr. Neil Gehrels is Head of the Gamma Ray, Cosmic Ray, & Gravitational Wave Astrophysics Branch and Dr. Robert Petre is Head of the X-Ray Astrophysics Branch.

The civil service scientific staff includes: Drs. Louis Barbier, Scott Barthelmy, David Bertsch, Elihu Boldt, Kevin Boyce, Jordan Camp, Joan Centrella, Thomas Cline, Tali Figueroa-Feliciano, Keith Gendreau, Alice Harding, Robert Hartman, Stanley Hunter, Keith Jahoda, Frank Jones, Timothy Kallman, Demosthenes Kazanas, Richard Kelley, Frank Marshall, Stephen Merkowitz, John Mitchell, Richard Mushotzky, Jay Norris, Ann Parsons, William Pence, F. Scott Porter, Donald Reames, Steven Ritz, Peter Serlemitsos, Caroline Stahle, Robin Stebbins, Floyd Stecker, Robert Streitmatter, Tod Strohmayer, Jean Swank, Bonnard Teegarden, David Thompson, Jack Tueller, Tycho von Rosenvinge, Kim Weaver, and William Zhang. The death of Dr. Reuven Ramaty is a great loss, particularly for this laboratory. The recently launched Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) spacecraft has been so named to memorialize his seminal contributions to high energy astrophysics.

The following scientists are National Research Council Associates: Drs. John Baker, Gregory Brown, J. David Brown, Analia Cillis, Jean Cottam, Georgia de Nolfo, Markos Georganopoulos, Timothy Hamilton, Thomas Hams, Kouichi Hirotani, Mark Lindeman, Claudio Mendoza, Makoto Sasaki, and Alfred Stephens.

The following researchers are University Space Research Association Scientists: Drs. Lorella Angelini, Zaven Arzoumanian, David Bertsch, Kevin Black (Forbin), Jerry Bonnell, Kai-Wing Chan, Dae-ll Choi, Eric Christian, Robin Corbet, Michael Corcoran, Fred Finkbeiner (SSAI), Philip Deines-Jones, Joseph Dodoo, Stephen Drake, Michael Harris, Ilana Harrus, Hans Krimm, John Krizmanic, James Lochner, Thomas McGlynn, Alex Moiseev, Koji Mukai, Kirpal Nandra, Chris Shrader, Alan Smale, Steven Snowden, Yang Soong, Martin Still, Steve Sturner, and Georg Weidenspointner.

The following investigators are University of Maryland Scientists: Drs. Keith Arnaud, David Band (UMBC), Simon Bandler, Patricia Boyd (UMBC), John Cannizzo (UMBC), James Chiang (UMBC), David Davis (UMBC), Ian George (UMBC), Una Hwang, Taro Kotani (UMBC), Kip Kuntz (UMBC), Michael Loewenstein, Craig Markwardt, Igor Moskalenko (UMBC), Chee Ng, Patrick Palmeri, Christopher Reynolds, Ian Richardson, Jane Turner (UMBC), and Tahir Yaqoob (now JHU).

Visiting scientists from other institutions: Drs. Hilary Cane (U. Tasmania), Ralph Fiorito (Catholic U.), Tae Furusho (JSPS), Massimiliano Galeazzi (U. Wisconsin), Lev Titarchuk (George Mason U.), and Alan Tylka (NRL).

Graduate Students doing their thesis research in this Laboratory are: from the U. of Maryland, Wayne Baumgartner, Frederick Berendse, Derek Hullinger, Breno Imbiriba, Giridhar Nandikotkur, Andy Tillotson, and David Wren; from George Washington U., Alaa Ibrahim; and from Drexel U., Orhan Donmez

2. RESEARCH PROGRAMS

2.1 Sun and Solar System

Drs. Reames and Ng discovered a strong phase asymmetry in the 27-day modulation of anomalous and galactic cosmic rays, primarily using observations from the EPACT experiment on NASA's Wind spacecraft. These observations suggest a persistent asymmetry in the global structure of the Sun's magnetic field. Using the LASCO coronagraph on SOHO, Dr. Reames, in collaboration with Drs. S. W. Kahler (AFRL) and N. R. Sheeley, Jr. (NRL) discovered narrow coronal mass ejections (CMEs) in association with the small impulsive solar flares that produce ^{3}He-rich energetic-particle events observed on Wind. Dr. Reames suggested that these narrow CMEs might come from the magnetic topology proposed for solar X-ray jets and type III radio bursts, where magnetic reconnection occurs on open field lines so that both plasma and energetic particles are constrained to follow the nearby flux tubes out from the Sun.

2.2 Stars

Dr. Corcoran with Dr. J. Pittard (Leeds) successfully modeled the high-energy grating spectrum of η Car with a synthetic spectrum generated from a hydrodynamic simulation of a wind-wind collision, showing that even at high spectral resolutions the observed spectrum is consistent with colliding wind binary models.

Dr. Corcoran, in collaboration with Dr. R. Viotti (IAS), Dr. L. A. Antonelli (INAF-Osservatorio Astronomico di Roma), Dr. A. Damineli (Universidade de Sao Paulo), P. Grandi (IAS), Dr. J. Muller (University Hospital Nijmegen), Dr. S. Rebecchi (ASI Science Data Center), Dr. C. Rossi (Universita La Sapienza), and Dr. M. Villada (Observatorio Astronomico U.N.C.), published X-ray observations of η Car obtained by BeppoSAX, in which they showed a flux deficit in March 1998 consistent with X-ray absorption by a thick medium.

Drs. Drake and White together with Dr. T. Simon (U. Hawaii) and Dr. K. Singh (TIFR, India) have been studying XMM-Newton X-ray spectra of the inactive evolved stars β Gem and β Hyi. The XMM observation of β Gem found its corona in a very low luminosity state, a factor of 3 below previously observed levels and the first evidence for X-ray variability of this star. The X-ray spectrum was very soft ($T \leqslant 2$ MK), and implying a relative N/O abundance ratio in its corona that is enhanced by 0.42 dex relative to the solar value, but which is consistent with β Gem's measured photospheric N/O value of 0.56 solar.

Dr. Corcoran with Drs. J. Pittard (Leeds), I. Stevens (Birmingham), P. Williams (U. Edinburgh), A. Pollock (C & S Ltd), S. Skinner (U. Colorado), and A. Moffat (Montreal) presented the first attempt to spatially resolve the X-ray emission from the colliding wind binary WR 147 with the Chandra X-ray Observatory High Resolution Camera. They showed that the X-ray emission was indeed extended.

Dr. Corcoran with Drs. J. Rho (IPAC), Dr. Y.-H. Chu (U. Illinois), and Dr. W. Reach (Space Infrared Telescope Facility Center) published a comparison of X-ray and 2-micron sources in the young star-forming Trifid Nebula.

Dr. Drake and Dr. B. Slee (CSIRO, Australia) continued a long-term study of the radio emission properties of active stars for which there are at least one Parkes Telescope detection. Because of the low spatial resolution of these single-dish observations, the reality of some of these detections has been questioned, and so follow-up observations with the Australia Telescope radio interferometer were carried out in May 2002 which confirmed 3 out of 10 of the observed stars to be intrinsic radio sources.

Dr. Corcoran with Drs. J. Arias, N. Morrell, R. Barba, and G. Bosch (Universidad Nacional de La Plata), along with Dr. M. Grosso (Complejo Astronmico El Leoncito), presented a new optical spectroscopic study of the O-type binary HD 165052 which found evidence of apsidal motion in the system.

2.3 Galactic Binaries

Drs. Corbet, Markwardt, and Swank, with Dr. J. in't Zand (SRON), observed the Be X-ray binary SAX J2239.3+6116 with RXTE and BeppoSAX during a predicted 262 day recurrence and both saw pulsations, at 1247 s, the longest pulse period as well as the longest binary period of Be star/X-ray binaries.

Dr. Cottam, with Drs. F. Paerels (Columbia) and M. Méndez (SRON), analyzed the burst spectra of the Low Mass X-ray Binary EXO 0748−676 acquired with the RGS on board the XMM-Newton Observatory. They discovered features in the high-resolution spectra that are consistent with gravitationally red-shifted absorption lines of iron and oxygen at $z = 0.35$. This provides a constraint on the equation of state for nuclear matter.

Dr. Cottam with Dr. M. Méndez (SRON) has begun analysis of the RGS data of the ultracompact X-ray binary 4U 1626−37. The spectra show strange broadening in the line emission indicating an unusual accretion geometry.

Mr. Ibrahim and Dr. Swank with Dr. W. Parke (GWU) studied a large number of bursts from the Soft Gamma Repeater SGR 1806−20 and detected an absorption feature near 5 keV. The feature is inconsistent with an electron cyclotron resonance in a typical neutron star magnetic field but is well explained as a proton cyclotron resonance in an ultrastrong magnetic field. The feature allows for a direct measurement of SGR 1806−20's magnetic field ($\sim 10^{15}$ G), supporting the supposition that it is a magnetar. Together with the spin-down estimate of the magnetic field, it provides an estimate of the gravitational redshift and the mass-radius ratio of the star.

Drs. Markwardt and Swank continued a monitoring program of the Galactic center using the RXTE PCA instrument. Using frequent but brief observations which cover a large solid angle around the Galactic bulge, X-ray outbursts and state changes of new and previously known sources can be detected quickly, which facilitates follow-up observations.

A highlight of the Galactic center monitoring program was the discovery of a new millisecond accreting pulsar. Drs. Markwardt, Swank, Strohmayer, and Marshall, with Dr. J. in't Zand (SRON) reported the discovery of a 435 Hz pulsar designated XTE J1751−305. The pulsar is in a binary orbit with a 42 minute period. The companion is likely to be a degenerate helium dwarf with a mass of 0.013–0.028 $M_{\odot}$. Since millisecond radio pulsars are thought to be descended from accreting X-ray binaries, the discovery of additional accreting millisecond pulsars provides constraints on binary evolution theories. Dr. Markwardt with Dr. A. Dobrzycki (CfA) found the best position of XTE J1751−305 to date via a Chandra target of opportunity observation.

Drs. Markwardt and Swank with Mr. E. Smith (Emergent) actively followed up newly discovered X-ray sources in the Galactic plane with the RXTE PCA. PCA observations of the new transient XTE J1650−500 determined its best X-ray position, and found behavior reminiscent of a black hole candidate. A resurgence of the confirmed black hole systems XTE J1550−564 and V4641 Sgr were detected in January and May, 2002, respectively. SAX J1805.5−2031, a likely neutron star system, was observed in March 2002.

Drs. Markwardt and Swank with Drs. J. in't Zand (SRON), A. Bazzano (CNR), M. Cocchi (CNR), R. Cornelisse (SRON), J. Heise (SRON), E. Kuulkers (SRON), L. Natalucci (CNR), M. Santos-LLeo (XMM SOC), and P. Ubertini (CNR) combined BeppoSAX and RXTE observations of a new galactic black hole candidate near the galactic center, SAX J1711.6−3808, to find a broad iron emission line. Such a line may be due to relativistic broadening near the event horizon of a black hole, or the effects of Comptonization by a hot plasma.

Dr. Markwardt with Drs. R. Wijnands (MIT), M. Méndez

(SRON), M. van der Klis (Astronomical Institute ‘‘Anton Pannekoek’’), D. Chakrabarty (MIT) and E. Morgan (MIT), used Galactic monitoring data to show that the first millisecond accreting pulsar, SAX J1808.4−3658, had an extremely erratic outburst in the year 2000, during which the source intensity varied by a factor of a thousand. This suggests that accretion onto the neutron star was not steady, and may have been affected by magnetic ‘‘propeller’’ effect.

Dr. Markwardt with Drs. R. Wijnands (MIT), M. van der Klis (Astronomical Institute ‘‘Anton Pannekoek’’), W. Lewin (MIT) and Mr. J. Miller (MIT) combined RXTE PCA monitoring and Chandra observations of the neutron star binary KS 1731−260. Using the PCA they found that the source had entered quiescence, which triggered a follow-up Chandra observation. The source was detected, but at a lower than expected luminosity and temperature. Such a cool temperature suggests that KS 1731−260 does not spend a large fraction of its time accreting.

Drs. Mukai and Still with Dr. F. Ringwald (Fresno) have observed DQ Herculis with Chandra. DQ Her, the cataclysmic variable system which erupted as a nova in 1934, shows a deep eclipse in the optical, and its white dwarf primary appears to be hidden from direct view by the accretion disk at all orbital phases. In the Chandra observation, DQ Her shows a partial eclipse; it is therefore likely that they have observed X-ray photons scattered in an accretion disk wind. In addition, they found faint, extended X-ray emission near the binary, presumably from the materials ejected in the 1934 outburst.

Dr. Mukai with Dr. M. Orio (U. Wisconsin and Osservatorio Astronomico di Torino) has been analyzing the Chandra grating spectrum of Nova Aquilae 1918. Strong aperiodic variabilities are seen during the Chandra observation, without obvious spectral changes. The average spectrum is rich in emission lines that indicate a range of temperatures, from 10 keV (H-like Fe Kα) to below 1 keV (O K lines). In addition, the strength of the fluorescent Fe Kα line at 6.4 keV indicates that the hard X-ray continuum is emitted close to the white dwarf surface, while the presence of a forbidden component of He-like triplets of Ne and Mg indicates that the density cannot be very high.

Dr. Smale with Drs. M. Church and M. Balucinska-Church (Birmingham) has analyzed data from the low mass dipping X-ray binary XB1254−690. Deep dipping was seen on the 3.9-hr orbital period, along with ‘‘shoulders’’ 15 percent deep during extended intervals on each side of the main dips. Intensity-selected dip spectra were well-fit by a model in which a point-like blackbody is rapidly covered, while the extended Comptonized emission is progressively overlapped by the absorber, with the covering fraction rising to 95 percent in the deepest part of the dip. The intensity decrease in the dip shoulders is energy-independent, consistent with electron scattering in the outer ionized regions of the absorber. No dipping at all was detected during a second observation carried out seven months later, but (remarkably) bursting and flaring were observed contemporaneously.

Dr. Still with Drs. L. Morales-Rueda (Southampton), P. Roche (Leicester), J. Wood, and J. Lockley (Keele) used the assumption that companion stars in cataclysmic variables are tidally locked to their orbits in order to determine the masses of the binary components in GK Per using the width and motion of photospheric companion lines. They inferred $M_{\mathrm{WD}}=0.87\pm0.24\ \mathrm{M}_\odot$ and $M_{\mathrm{comp}}=0.48\pm0.32\ \mathrm{M}_\odot$.

Drs. Still and Mukai discovered a burst from the direction of the intermediate polar UZ For using XMM-Newton. Caught simultaneously with the X-ray and UV cameras, the burst was determined to be an accretion event rather than coronal activity on the companion star.

Drs. Still, B. Boroson (CfA) and Boyd with Drs. K. O’Brien (Amsterdam), K. Horne (St. Andrews), R. Gomer (Rice), B. Oke (DAO) and S. Vrtilek (CfA) discovered mHz QPOs from Her X-1 within optical data from the Keck II observatory. QPO lifetimes were short, consistent with the thermal timescale of the inner accretion disk.

Dr. Strohmayer with Drs. A. Giles, K. Hill (Tasmania), and Mr. N. Cummings (UMD) have studied the properties of oscillations in a sample of 26 thermonuclear bursts (so-called burst oscillations) from the low mass X-ray binary (LMXB) 4U 1636-53. They found that bursts occurring over a timespan of four years had oscillation periods which were stable to one part in a thousand, providing further evidence that the burst oscillation frequency is set by the rotation frequency of the neutron star. Using new optical data they refined the orbital ephemeris for this system and searched for a binary orbital modulation in a sub-sample of the bursts with a stability in frequency of 1 part in 10,000. No such modulation was detected, however, a constraint on the projected neutron star velocity of 50 km/s is implied by this subset of the data.

Drs. Strohmayer and Markwardt studied the timing properties of a three hour long ‘‘superburst’’ from 4U 1636-53. They found a coherent pulsation, at the 582 Hz burst oscillation frequency known in this source, during the flux maximum of the superburst. The pulsation was detected for about 900 seconds and revealed a frequency modulation consistent with the predicted orbital motion of the neutron star. This confirms the presence of a rapidly rotating neutron star in this object and further strengthens the association of burst oscillation frequencies with the spin frequencies of neutron stars. This discovery also supports the idea that fast spinning radio pulsars were spun-up by accretion in LMXBs.

Dr. Swank with Drs. A. Baykal (Ankara) and M. Stark (Systems Integration & Engineering Branch) studied the spin rate of the 358 s pulsar SAX J2103.5+4545 during a year-long transient outburst seen with RXTE. The spin-up was correlated with the X-ray flux and could be fit to theoretical spin-up in accretion from a thin disk for a particular distance and magnetic field – a rather high 1.2×10^{13} G. A short phase of spin-down occurred as the flux decayed, the first that has been seen in such an event. Flux modulations during the transient’s decay imply change in the wind from the still unidentified companion.

Dr. Swank with Drs. D. Smith (UC Berkeley) and W. Heindl (UC San Diego) used RXTE to study the long term light curves of persistent black hole sources, 1E 1740.7−2942, GRS 1758−258, Cyg X-1, and GX 339−4. Changes of state can be identified through monitoring the hardness ratio. Spectra indicate that for the low mass binaries accreting via Roche lobe overflow, the coronal contribution can suddenly disappear, while the soft disk component decays over a week. For high mass binaries like Cyg X-1, which accrete via the donor's wind, the hardness and flux correlations are different.

Drs. Cannizzo and Gehrels with Dr. Janet Mattei (AAVSO) studied the long term AAVSO light curve of U Geminorum, an eclipsing dwarf nova with a 4.4 hr orbital period. Of all outbursts ever recorded in dwarf novae above the $2-3$ hr ''period gap,'' only the October 1985 outburst of U Gem was long enough to be able to measure reliably the decay time constant, thereby providing our only measure of the viscous decay rate in such systems. The resulting measure of the Shakura-Sunyaev alpha parameter is ~ 0.1.

Drs. Cannizzo and Gehrels with Dr. E. Vishniac (JHU) are developing a formalism to calculate spectra for accretion flows with low radiative efficiency. A first application of this methodology is the investigation of a ''hysteresis'' relation between flux and hardness ratio in accreting binaries (in all 3 types of systems − WD, NS, and BH) which show outbursts: i.e., the transition from the hard to soft state during outburst rise occurs at a higher flux level than the soft to hard state transition during outburst decay. It appears this can be explained by the filling of the inner disk due to mass redistribution during outburst onset, and evaporation of the inner disk during outburst decay.

Drs. Shrader and Titarchuk are exploring the possibility that the X-ray nova light curves may be, in at least certain instances, a result of sporadic mass-transfer rates, followed by diffusive propagation in the accretion disk. A large body of observational data has been collected, and an analytic (approximation) form of the disk-diffusion model calculation has been applied. Early results indicate that the so called fast-rise exponential decay light curves, and the often seen, superposed secondary outburst profiles superposed are well represented by the model calculations.

Drs. Shrader and Kazanas obtained high temporal and spectral resolution data for LMC X-1 with the XMM EPIC instrument. A complex-cross-correlation analysis will be applied to the data for the purpose of modeling hard/soft temporal lags, as well as their dependence on the broad-band X-ray spectral energy distribution.

Dr. Shrader with Dr. W. Cui (Purdue U.), and Drs. C. Haswell and R. Hynes (The Open University, UK) are studying the X-ray to UV time-series complex cross correlation spectrum for the X-ray nova XTE J1118+480. Time lags of order 1 second between the two bands had already been established. The lags are surprisingly large, consistent with a reprocessing site situated at about 10^4 Schwarzschild radii from the central X-ray source. However, preliminary analysis reveals the evidence for ''negative'' lags (i.e. UV leads X-rays for some frequency bands, which is inconsistent with reprocessing). These occur at frequencies of ~ 0.5 Hz, which coincides with the presence of a ''precognition dip'' feature in the optical-X-ray correlation analysis of an independent group. Additionally, quasi-periodic oscillations at a common frequency (~ 0.08 Hz) at optical, UV and X-ray energies. The same collaboration is involved with the broad-band spectral modeling of X-ray nova as they evolve from outburst peak to quiescence.

2.4 Pulsars and Magnetars

Dr. Arzoumanian with Drs. J. Cordes and D. Chernoff (Cornell) numerically modeled 0.4 GHz radio pulsar surveys to infer the velocity and luminosity distributions of the underlying neutron star population without selection biases. They found that a two-component velocity distribution with characteristic velocities of 90 km/s and 500 km/s is greatly preferred to any one-component distribution, and that nearly 50 percent of pulsars born in the Galactic plane will escape the Galaxy's gravitational pull. Also, the inferred radio beam luminosity is proportional to the voltage drop available for acceleration of particles in rotating-magnetosphere models, similar to the scaling of non-thermal X-ray luminosity from rotation-powered pulsars.

Dr. Arzoumanian, with Drs. F. Camilo (Columbia), I. Stairs (NRAO), D. Lorimer, M. McLaughlin, M. Kramer (Manchester), D. Backer (UC Berkeley), and B. Klein, R. Wielebinski, and P. Muller (Max Planck Institut fur Radioastronomie), reported the discovery, using the newly-constructed 100 m Green Bank Telescope, of radio pulsations from the youngest neutron star known, PSR J0205+6449 at the heart of the supernova remnant 3C 58. The measured pulse period and spin-down rate are consistent with those previously reported at X-ray wavelengths, but the radio luminosity is the lowest among known young radio pulsars.

Dr. Arzoumanian with Drs. M. McLaughlin and J. Cordes (Cornell), D. Backer, A. Lommen (UC Berkeley), D. Lorimer (Arecibo Observatory), and A. Zepka (Numerical Technologies) reported on the unusual properties of the young radio pulsar J1740+1000, which lies well out of the Galactic Plane, requiring a very high birth velocity. Alternative birth scenarios include possible birth sites away from the midplane (e.g., globular clusters or birth through merger of a pair of old white dwarfs), contributions from the unmeasured radial velocity, and age or velocity biases.

Drs. Harding and A. Muslimov (DoD) are working on Polar Cap (PC) model for high-energy emission from isolated pulsars. They investigated the regimes of acceleration of primary electrons, conditions for electron-positron pair creation above pulsar PCs, efficiencies and luminosities of thermal X-Ray and non-thermal high-energy emission from the PC regions of pulsars. They also revised the standard method of calculation of the pulsar death-lines used in the literature.

Drs. Harding and P. Gonthier (Hope College) have been modeling the galactic population of rotation-powered pulsars in order to compare and test high-energy emission models and to make predictions for the number of detectable radio-quiet and radio-loud pulsars. They use a Monte-Carlo code to simulate the birth and evolution of a large number of neutron stars, as well as their predicted radio and gamma-ray emission characteristics. For polar cap high-energy emission models, they find that GLAST should detect about 100 radio-loud pulsars and about a similar number of radio-quiet gamma-ray pulsars.

2.5 Supernovae and Supernova Remnants

Drs. Harrus and Petre with Drs. S. Safi-Harb (U. Manitoba), G. Pavlov, A. Koptsevich, and D. Sanwal (Penn. State) published the results of their combined X-ray analysis (ROSAT, ASCA and Chandra) of the supernova remnant G21.5 −0.9. They found no evidence of line emission from any part of the remnant which is dominated by non-thermal emission. No pulse is detected from the HRC data and they put a 16 percent upper limit on the pulsed fraction.

Drs. Hwang and Petre with Drs. A. Decourchelle (Saclay) and S. Holt (Olin College) carried out an X-ray spectral study of the forward shocked gas in the Galactic remnant of Tycho's supernova using data from the Chandra Observatory. They used Chandra's high spatial resolution to study the evolution of the spectrum behind the shock wave, and to measure electron temperatures that are substantially below the mean temperatures behind the shock. They also infer the presence of non-thermal emission to account for the hard emission detected above 10 keV by SAX and Ginga. Chandra images of Tycho's SNR show that Si ejecta have been turbulently mixed out to the forward shock.

Dr. Hwang with Mr. E. Michael, Drs. S. Zhekhov, R. McCray (Colorado), D. Burrows, and G. Garmire (Pennsylvania) studied the high resolution X-ray spectrum of SNR 1987A. The X-ray spectrum shows a low level of electron heating compared to ion temperatures inferred from the X-ray line profiles and the X-ray expansion of the remnant.

Drs. Gehrels with C. Laird (U. Kansas), C. Jackman (Lab. for Atmospheres, GSFC), and Cannizzo, B. Mattson (GSFC) and W. Chen (Sprint) have completed a study of the effect of nearby supernovae on the ozone layer of the Earth. As first shown by Prof. M. Ruderman (Columbia U.), a large impulsive addition of energy into the atmosphere causes catalytic reactions, producing odd-numbered nitrogen compounds that react with and destroy ozone. Using the Goddard two-dimensional photochemical transport model for a variety of input energies, we find, however, that the effect is less than found by previous investigators, and probably not a major cause of extinction events on Earth. In addition, there are several self-limiting physical that lessen the extrapolated ozone depletion for increasingly large energy input (i.e., very energetic and/or nearby events).

2.6 Cosmic Rays

Drs. Jones and Streitmatter joined with Drs. Kazanas and A. Nicolaidis (U. Thessaloniki) to further the study of "new physics" as an explanation of the cosmic ray knee. Employing a "toy model" of air shower propagation, they demonstrated that if there exists a new secondary not detected in any interaction with a projectile particle of greater than 10^{15} eV, the knee could be produced by the penetration of these interactions deeper into the atmosphere as the primary energy increases. Further, they demonstrated that if the secondary multiplicity of observable particles also increases, the apparent increase in mean mass of the primary could be understood even if the primaries are, in fact, pure protons. Jones presented this work at the 27th International Cosmic Ray Conference in Hamburg in August of 2001.

Dr. Moskalenko with Dr. A. Strong (MPI Extraterrestrische Physik, Germany) and Dr. S. Mashnik (LANL) continued to develop of a model of cosmic ray propagation in the Milky Way galaxy, GALPROP. This model, the most realistic so far, combines modern theoretical developments with extensive nuclear cross section database and Galactic distributions of gas and radiation fields. It includes all cosmic ray species from hydrogen to Nickel, secondary antiprotons and positrons, electrons, gamma rays and synchrotron emission. It can run in the proper 3D or cylindrically symmetrical modes, and is able to handle stochastic and known supernova events in 3D mode. Realistic astrophysical input together with inclusion of all the species in one model provides a powerful tool to test hypotheses of cosmic ray origin and propagation.

Combining a realistic cosmic ray propagation model with a steady-state drift model for heliospheric modulation, Dr. Moskalenko with Drs. A. Strong (MPI, Germany), J. Ormes (Code 600), and M. Potgieter (Potchefstroom U., South Africa) have made a calculation of the interstellar antiproton spectrum. It was found that there is no simple model capable of accurately describing the whole variety of cosmic ray data: boron/carbon and sub-iron/iron ratios, spectra of protons, helium, antiprotons, positrons, electrons, and diffuse gamma rays. For the best-fit model they made predictions of proton and antiproton fluxes at 1 AU for different heliospheric modulation levels and magnetic polarity.

Using the LANL cross section database and theoretical models of nuclear reactions, Dr. Moskalenko with Dr. A. Strong and Dr. S. Mashnik made a new calculation of the abundances of long-lived radioactive isotopes in cosmic rays, ^{10}Be, ^{26}Al, ^{36}Cl, ^{54}Mn. This allows for better constrains of the effective Galactic volume filled with cosmic rays.

2.7 Black Hole Astrophysics

Drs. Boldt, Hamilton and Loewenstein with Dr. D. Torres (Princeton) have utilized a redshift limited ($z<0.01$) sample of giant elliptical galaxies (at high galactic latitude) for the purpose of extracting possible evidence indicative of apparently dormant nearby quasar remnant nuclei that could involve spinning supermassive black hole driven dynamos capable of generating ultra-high energy cosmic rays [e.g., as previously speculated by Drs. Boldt, P. Ghosh (Tata Institute), A. Levinson (Tel Aviv) and Loewenstein]. For this sample, the eleven brightest (absolute blue magnitude <-21) non-cluster member galaxies with sky coordinates accessible to AGASA (Akeno Giant Air Shower Array) are all found to harbor core black-holes estimated at $\sim$0.1 billion solar masses or greater. Well within measurement uncertainty, four of these eleven bulge dominated ($T<-4$)] galaxies are found to be closely aligned with the observed arrival directions of ultra-high energy cosmic rays (44–105 EeV). These preliminary findings provide the first direct indication of a strong correlation between specific candidate sources and actual cosmic ray induced air shower events.

2.8 Our Galaxy

Dr. Corcoran with Drs. A. Muecke (Montreal), B. Koribalski (ATNF), A. Moffat (Montreal), and I. Stevens (Birmingham) published radio observations of the supergiant HII region NGC 3603 and measured the first radio spectrum of the so-called "Proplyds" in this region.

In a companion paper, Dr. Corcoran, Ms. Brenneman (UMD) and Dr. Mushotzky with Drs. A. Moffat (Montreal), I. Stevens (Birmingham), Mr. G. Skalkowski (Montreal), Drs. S. Marchenko (Montreal), A. Muecke (Montreal), A. Ptak (Carnegie Mellon), B. Koribalski (ATNF), J. Pittard (Leeds), A. Pollock (C & S Ltd), and W. Brandner (U. Hawaii) published their analysis of X-ray images of NGC 3603 obtained by the Chandra X-ray observatory.

2.9 Normal Galaxies

Drs. Angelini, Loewenstein, and Mushotzky investigated the population of luminous low mass X-ray binaries associated with globular clusters in the giant elliptical galaxy NGC 1399 using Chandra observations. Seventy percent of the sources in a region overlapping with a Hubble Space Telescope observation were identified with globular clusters – all brighter than any Milky Way globular cluster source. Many of the sources have luminosities exceeding the neutron star Eddington luminosity, indicating the unexpected presence of black hole binaries or multiple sources.

Drs. Kuntz and Snowden have continued their analysis of the diffuse emission from M101. The bulk of the emission is associated with spiral arms, and there are no strong spectral variations with either radius or surface brightness. The spectrum can be reasonably fit by a two component equilibrium model, but non-equilibrium models are likely to be more appropriate. Particularly interesting is the lack of emission in the inter-arm regions, which places a strong upper limit to any extended axisymmetric halo.

Drs. Loewenstein and Mushotzky determined the 0.7–35 kpc mass profile in the elliptical galaxy NGC 4636 based on the hot interstellar medium temperature profile measured using the Chandra X-ray Observatory, and other X-ray and optical data. At least half, and as much as 80 percent, of the mass within the optical half-light radius is non-luminous, implying that NGC 4636 has an exceptionally low baryon fraction. Results are consistent with the upper end of the range expected for standard cold dark matter halos, and conflict with most self-interacting dark matter and other alternative models.

Drs. Mukai, Pence, Snowden and Kuntz have studied the bright point-like sources detected in their Chandra observation of the nearby spiral galaxy, M101. There are 5 sources that are similar to black hole candidates in other nearby galaxies, whereas one is found to be extremely soft and highly variable. Although a disk blackbody model fits the data well, this leads to inferred inner disk radius which is large and highly variable at the same time. They suggest an alternative interpretation of the soft component is necessary for this object.

2.10 Starburst Galaxies

Dr. Weaver with Drs. D. Strickland, E. Colbert, T. Heckman (Johns Hopkins U.), M. Dahlem (ESO) and I. Stevens (Birmingham), presented a Chandra observation of a luminous (10^{40} erg s^{-1}) point source located $\sim$ 970 pc from the nucleus of the nearby starburst galaxy NGC 3628. The source has no radio, optical, or near-IR counterpart, but is undoubtedly the reappearance of a strongly variable X-ray source that had faded by a factor of $\sim$27 between 1991 and 1994. This source is a member of an enigmatic class of X-ray sources that are considerably more luminous than conventional X-ray binaries but less luminous than active galactic nuclei. Its spectrum is similar to Galactic black hole binary candidates in their hard state.

Dr. Weaver with Drs. D. Strickland, T. Heckman, C. Hoopes (JHU) and M. Dahlem (ESO) presented a detailed case study of the diffuse X-ray and Hα emission in the halo of NGC 253. There is statistically significant structure within the diffuse emission on angular scales down to $\sim 10''$ ($\sim$130 pc) but no significant evidence for spatial variation in the spectral properties of the diffuse emission over scales from $\sim$400 pc to $\sim$3 kpc. The X-shaped soft X-ray morphology of the superwind is matched by similar, X-shaped H α emission, extending at least 8 kpc above the plane of the galaxy. Also, the 0.3–2.0 keV X-ray luminosity of the northern halo is similar to the halo Hα luminosity, both of which are a small fraction of the estimated wind energy injection rate of $\sim 10^{42}$ erg s^{-1} from supernovae in the starburst. These findings indicate that the physical origin of the X-ray-emitting million-degree plasma in superwinds is closely linked to the presence of much cooler and denser $T \sim 10^4$ K gas.

Dr. Weaver with Drs. N. Levenson, R. Fernandes and T. Heckman (JHU) and T. Storchi-Bergmann (Instituto de Fisica) published a detailed study of the X-ray-loud composite galaxy NGC 6221. Its optical spectrum characterizes NGC 6221 as a starburst galaxy, but in X-rays it is similar to Seyfert 1 galaxies, exhibiting a power-law spectrum, a broad Fe Kα line, and continuum variability on timescales of days and years. The active nucleus is weak in both optical and near-IR wavelengths, but an obscuring starburst accounts for these peculiar features. Optical surveys would not identify the active nucleus that makes this galaxy a significant X-ray source but such objects may be important contributors to the X-ray background.

2.11 Active Galaxies

Drs. George, Turner, and Nandra with Dr. H. Netzer and Mr D. Chelouche (Tel Aviv), Drs. D. Crenshaw (Georgia State) and S. Kraemer (Catholic U.) presented the results from a Chandra observation of the Seyfert 1 galaxy NGC 3516. These, when compared to archival ASCA observations, indicate the line-of-sight to NGC 3516 most likely contains the same column density of ionized gas as 7 years earlier. The change in the observed spectrum between the ASCA and Chandra observations is the result of the ionized material reacting to changes in the ionizing continuum.

Drs. George, Turner, Nandra, Mushotzky, and Yaqoob with Dr. H. Netzer and Mr D. Chelouche (Tel Aviv), Dr. S. Kraemer and Mr J. Ruiz (Catholic U.), and Dr. D. Crenshaw (Georgia State), used three Chandra observations to present the first high-resolution X-ray image of the circumnuclear regions of the Seyfert 1 galaxy NGC 3516. A previously-unknown X-ray source was detected approximately 6 arcsec (1.1 h_{75}^{-1} kpc) NNE of the nucleus. Assuming a location within NGC 3516, isotropic emission implies a luminosity $L \sim 2-8 \times 10^{39} h_{75}^{-2} ergs^{-1}$ in the 0.4–2 keV band. Large-scale, extended X-ray emission was also detected out to $\sim$10 arcsec ($\sim 1.7 h_{75}^{-1}$ kpc) from the nucleus to the NE and SW. This emission is approximately aligned with the morphology of the radio emission and extended narrow emission line region.

Drs. George, Turner, Nandra, and Mushotzky with Drs. S. Kaspi, W. Brandt (Penn State), H. Netzer (Tel Aviv), D. Crenshaw (Georgia State), S. Kraemer and Mr J. Gabel (Catholic U.), Drs. F. Hamann (Florida), M. Kaiser, G. Kriss, W. Zheng (JHU), A. Koratkar (STScI), S. Mathur, B. Peterson (Ohio State U.), and J. Shields (Ohio) presented the results from Chandra observations of the Seyfert 1 galaxy NGC 3783. The combined exposure ($\sim$ 900 ksec), making use of the HETGS, provided a high-resolution spectrum with the highest signal-to-noise ratio yet obtained for an active galaxy, enabling a detailed study of the photoionized gas along the line-of-sight. Absorption lines from H-like and He-like ions of N, O, Ne, Mg, Al, Si, and S were detected, along with inner-shell lines from lower-ionization ions such as Si VII– XII, S XII–XIV, and Fe XVII–XXIV (and probably also Fe XXV). The absorption lines are blueshifted relative to the systemic velocity by a mean velocity of -590 ± 150 km/s. Many of the absorption lines were resolved, and their mean FWHM is 820 ± 280 km/s. Most the absorption lines show asymmetry, having more extended blue wings than red wings. In O VII this asymmetry arises from an additional absorption system at ~ -1300 km/s. The two X-ray absorption systems are consistent in velocity shift and FWHM with the ones identified in the UV lines of C IV, N V and H I.

Dr. Hamilton with Drs. S. Casertano (STScI) and D. Turnshek (Pittsburgh) have created a QSO host luminosity function for redshifts of $0.06 \leqslant z \leqslant 0.46$. This shows that QSO host galaxies tend to be more luminous than the brightest known normal galaxies. Furthermore, the ratio of the number of QSO hosts to the number of normal galaxies increases monotonically with luminosity and can be described in a simple functional form.

Dr. Hamilton has analyzed archival Hubble and ROSAT data to discover a fundamental plane for QSOs. This fundamental plane expresses the close relationship between a QSO's nuclear luminosity (optical or X-ray) and its host's surface magnitude and size. This may be related to the known fundamental plane for elliptical galaxies and to the fueling mechanisms in different types of active galaxies.

Drs. Turner, George, Mushotzky, Nandra, Snowden, and Yaqoob with Drs. Kraemer (Catholic U.), H. Netzer (Tel Aviv) and Mr. D. Chelouche (Tel Aviv), obtained overlapping Chandra/HETG and XMM observations of the Seyfert 1 galaxy NGC 3516. The spectral data show several narrow components of Fe Kα, sitting atop a broad line base. The lines show variable flux across the observation and may arise from illumination of narrow regions, approximately 35 and 175 gravitational radii from the central black hole. The illumination may be due to magnetic reconnection. The presence of narrow features indicates there to be no Comptonization region along the line-of-sight to the nucleus. This is compelling support for the hypothesis that broad Fe Kα components are, in general, produced by strong gravity.

Drs. Turner, George, Nandra, Yaqoob, with Dr. S. Kraemer (Catholic U.), Ms P. Romano (OSU), Drs. M. Crenshaw (GSU), J. Storm (Potsdam), D. Alloin (ESO), D. Lazarro and L. Da Silva (National Astronomical Observatory of Spain), J. Pritchard (ESO), J. Kriss (JHU, STSCI), W. Zheng (JHU), S. Mathur (OSU), J. Wang (JHU), P. Dobbie (Leicester), and N. Collins (Catholic U.), presented spectral results from a multi-satellite, broad-band campaign on the narrow-line Seyfert 1 galaxy Ton S180, performed at the end of 1999. They constructed the spectral-energy distribution of the source, combining simultaneous Chandra, ASCA and EUVE data with contemporaneous FUSE, HST, and ground-based optical and infra-red data. The resulting SED showed that most of the energy is emitted in the 10–100 eV regime, which must be dominated by the primary energy source. No spectral turnover is evident in the UV regime. This, the strong soft X-ray emission, and the overall shape of the SED indicate that emission from the accretion disk peaks between 15 and 100 eV. High resolution FUSE spectra showing UV absorption due to O VI and the lack of detectable X-ray absorption in the Chandra spectrum demonstrated the presence of a low column density of highly ionized gas along our line-of-sight. The highly-ionized state of the circumnuclear gas is most likely linked to the high luminosity and steep spectrum of the active nucleus. Given the strong ionizing flux in Ton S180, it is possible that the clouds within a few tens of light days of the central source are too highly ionized to produce much line emission. Thus the narrow width of the emission lines in Ton S180 is due to the emission arising from large radii.

Drs. Yaqoob and Nandra with Dr. T. Dotani (ISAS) and Ms. U. Padmanbhan (JHU) investigated the effects of the changes in the calibration of the instruments aboard the X-ray astronomy satellite ASCA with respect to measurements of the broad iron K emission line in active galactic nuclei. The emission line is believed to originate from an accretion disk in the vicinity of a supermassive black hole and is therefore an important probe of strong gravity effects near black holes. The study found that the effects of improvements in the calibration of the instruments has a neglible effect on the spectroscopic results from the emission line, thus laying to rest doubts in the literature that earlier results may have been erroneous.

Dr. Stecker has continued work on the absorption of very high energy gamma-rays by pair production interactions with intergalactic IR, optical and UV photons. This work has lead to a derivation of the source spectrum of multi-TeV gamma-rays from Mkn 501 during the 1997 flare by Dr. O.C. De Jager (Potchefstroom U., South Africa) and Stecker. The fact that the expected absorption is seen in this spectrum up to 20 TeV has allowed Stecker and Prof. S. Glashow (Boston U.) to place stringent limits on the violation of Lorentz invariance.

Dr. Georganopoulos continued his investigations of high energy emission from sources where bulk relativistic flows are thought to exist. Such sources are radio loud active galaxies, microquasars and gamma ray bursts. In collaboration with D. Kazanas and A. Mastichiadis (U. of Athens), a model for gamma ray bursts was developed based on a criticality condition similar to that of a nuclear pile. The model is attractive in that it presents a way for transferring energy from baryons to leptons within a light crossing time, and it predicts a characteristic spectral peak at energies $\sim m_e c^2$, consistent with observations.

Drs. Shrader and Titarchuk are interpreting the application of the bulk-motion Comptonization model and physical parameter estimation to a subclass of AGN, the narrow-line Seyfert-1 galaxies (NLS1s). The NLS1s are known to exhibit unusually steep X-ray spectra and rapid, energy-dependent variability. It has been speculated that they may represent the extra-galactic analog of the high-soft spectral state seen in Galactic black-hole X-ray binaries where the soft X-rays. Similar work on the apparent new class of accreting ‘‘intermediate mass’’ black holes, using data with improved spatial resolution is also being undertaken.

Drs. Davis and Mushotzky have completed a study of a luminous IXO (Intermediate X-ray Object) in the disturbed spiral galaxy NGC 2276. A 53 ksec XMM observation of the NGC 2300 group revealed a bright source along the western edge of this galaxy. The IXO spectrum is well fit by a multicolor disk blackbody model used to fit optically thick standard accretion disks around black holes. The derived luminosity of this IXO in the 0.5 - 10 keV band makes this one of the most luminous discovered to date. As such it allows various models for IXO emission to be tested. The large source luminosity implies a large mass black hole if the source is radiating at the Eddington rate. On the other hand, the inner disk temperature determined here is too high for such a massive object, given the standard accretion disk model. Along with the high luminosity, this implies that either the singularity must be rotating or that a non-standard disk model must be employed. In addition, the high star formation rate seen in this disturbed galaxy lends weight to the proposals that intermediate mass black holes can form in regions of intense star formation.

Drs. O. Blaes (UCSB) and Chiang modeled the spectral energy distributions of type 1 Seyfert galaxies using a geometry for the accretion flow near the central black hole that is similar to the Advection Dominated Accretion Flow (ADAF) model proposed by Narayan and collaborators. Extending the work of Poutanen, Krolik & Ryde (1997) and Zdziarski, Lubiński, & Smith (1999), Drs. Blaes and Chiang found that the interaction between the X-rays produced in the hot central part of the disk via thermal Comptonization and the thermally reprocessed optical and UV photons produced in the cooler surrounding thin disk yielded equilibrium states for the accretion flow that can account for the seemingly uncorrelated optical/UV and X-ray light curves previously seen for these objects from multiwavelength monitoring observations. This work comprised both Monte Carlo and semi-analytic modeling. Using some fairly generic constraints on the efficiency of the ADAF-like flow, these methods provide a means of estimating the mass of the central black hole (and the accretion rate through the disk) that is independent of other methods such as reverberation mapping and the $M_{\rm BH}$-σ relation.

Drs. M. Böttcher (Rice U.) and Chiang used analytic and numerical methods to model the broad band non-thermal emission from blazars. They found an extremely robust spectral signature in the time-integrated synchrotron part of the spectral energy distribution that results from synchrotron self-Compton (SSC) emission being the dominant energy loss mechanism for the electrons producing the synchrotron and SSC radiation. The spectral signature is an $\alpha \simeq 1.5$ energy index that appears in the infrared to UV spectra of low-energy peaked BL Lac objects (LBLs) and flat spectrum radio quasars (FSRQs) and in the X-rays for high-energy peaked BL Lac objects (HBLs). From the presence (or absence) of this spectral signature, constraints on several physical and observational parameters can be inferred, including the observer's viewing angle with respect to the jet axis, the Thomson depth and magnetic field of the non-thermal plasma, and the energy density of photons from the accretion disk or Broad Line region that enter the plasma.

2.12 Gamma Ray Bursts

Dr. Band has been studying the burst luminosity function using bursts with known redshifts; thus far the burst database is insufficient to determine the distribution's correct functional form, or to rule out a low luminosity tail. With R. Jimenez (Rutgers) and T. Piran (Hebrew U.) he extended the burst database by estimating redshifts from the magnitudes of their host galaxies.

Dr. Band has also been analyzing the burst rate triggers of different detectors to compare their sensitivities, and determine the burst populations to which they are sensitive.

2.13 Sky Background Radiation

Analysis of the soft X-ray spectra taken by Chandra of the Galactic halo and the diffuse extragalactic emission has been stymied by inadequate understanding of the non-cosmic background in the Chandra instruments. Dr. Kuntz, working with various calibration data from the Chandra Science Center, has implemented a scheme for measuring and removing the particle background spectrum from observations of extended soft emission. Not only does this scheme allow for better background subtraction for diffuse objects, such as galaxies, but allows direct measurements of the diffuse emission due to the Galactic halo and putative diffuse extragalactic background. Preliminary investigation has shown that some Chandra spectra of the diffuse background are well fit by the ROSAT based Kuntz and Snowden spectral model of the background. The O VII and O VIII emission by the diffuse background appears to be quite variable.

2.14 Gravitational Wave Astrophysics

Dr. Camp, with the LIGO Scientific Collaboration (LSC), is taking part in a study of interferometer data generated in the commissioning of the Laser Interferometric Gravitational-wave Observatory (LIGO). For the purpose of detector characterization, and development of specialized data analysis techniques for placing an upper limit on incident gravitational radiation from inspiraling binary neutron star systems, the LSC has begun a preliminary study of LIGO data.

Dr. Baker and collaborators Drs. C. Lousto (U. Texas, Brownsville), M. Campanelli (U. Texas, Brownsville), and R. Takahashi (TAC, Denmark) have produced a theoretical model for the final gravitational radiation burst from the coalescence of two black holes. The model applies to both supermassive and stellar scale black hole systems. For a binary system of equal-mass nonspinning black holes, they calculate a few cycles of the gravitational radiation waveform near its peak, and find that during this time nearly 3% of the system's mass-energy is lost, coresponding to a peak gravitational wave luminosity of roughly 5×10^{56} ergs s^{-1}. Predominant circular polarization along the system's rotational axis results in efficient radiative angular momentum loss, leaving the final single Kerr black hole with an angular momentum parameter of approximately $a\sim0.7m$.

Drs. Brown, Centrella, and Choi, with students Donmez and Imbiriba, are applying the techniques of numerical relativity to carry out more refined gravitational wave source modeling. This group has developed computational techniques for finite difference solutions of Einstein's gravitational field equations using Adaptive Mesh Refinement (AMR) as implemented in the PARAMESH package. They have found that the fully nonlinear gravitational field equations can be successfully evolved if higher order interpolation methods are applied at the refinement boundaries. They will apply this code in more detailed studies of binary black hole interactions, with the particular goal of supporting the LISA mission. The group is also involved in the Lazarus project, an effort producing approximate models for gravitational waves from binary black hole systems using a combined approach involving numerical simulation together with perturbation theory techniques in the regimes where they are applicable.

Drs. Strohmayer and Boldt presented papers at the 4th Amaldi Conference on Gravitational Waves at Perth, Western Australia July 8-13, 2001. Strohmayer's presentation was "Gravitational waves from rotating neutron stars and evaluation of fast chirp transform techniques," and Boldt's work, in collaboration with with Drs. A. Levinson (Tel Aviv) and Loewenstein, was "Black-hole galactic nuclei: a high energy perspective."

3. OPERATING ORBITAL FLIGHT MISSIONS

3.1 Compton Gamma Ray Observatory (CGRO)

The Compton Gamma Ray Observatory (CGRO) Project is completing its last year of work following the de-orbit on June 4, 2000. The current activity at Goddard and at the instrument team sites is to finish production of data products and to finish archiving data and software at the HEASARC. Dr. Gehrels is Project Scientist, Dr. Norris and Dr. Bertsch (now retired) are Deputy Project Scientists and Dr. Shrader is the head of the Science Support Center.

3.2 Solar Anomalous and Magnetospheric Explorer (SAMPEX)

Dr. von Rosenvinge is Project Scientist for and a Co-Investigator on the SAMPEX small explorer mission launched in 1992. SAMPEX is in an extended mission phase to study both trapped and interplanetary anomalous cosmic rays, the charge states of solar energetic particles, and the acceleration of magnetospheric particles and their effects on the upper atmosphere. SAMPEX has also documented the build-up of energetic particles in the magnetosphere which frequently accompany satellite failures. A very successful model for predicting MeV electron fluxes at geosynchronous orbit based solely on solar wind measurements as input has been recently developed at the U. of Colorado in Boulder. Measurements in solar events using the geomagnetic cut-off continue to show an unexpected correlation between the mean iron charge state and the observed iron to oxygen ratio.

3.3 Advanced Satellite for Cosmology and Astrophysics (ASCA)

The last proprietary data taken with the joint Japanese-US ASCA mission were released to the public in October 2001, completing the ASCA archive at HEASARC. In addition to providing support for archival researchers, the ASCA GOF continues to assist the hardware teams in further refining the calibrations of the time-dependent instrument responses.

3.4 Rossi X-ray Timing Explorer (RXTE)

The RXTE mission observes X-ray emitting compact objects, in order to study gravity in the strong-field regime, physics of ultra-dense matter and ultra-strong magnetic fields, and mass flows in accretion-powered systems. Dr. Swank is the Project Scientist. The satellite carries three instruments, the All Sky Monitor, the Proportional Counter Array, and the High Energy X-Ray Timing Experiment. The mission and satellite are operated by the Science and Mission Operations Centers at Goddard. Dr. Marshall is the director of the SOC with Drs. Corbet and Smale, respectively, managing the Science Operations and the Guest Observer functions.

Operating since 1996, RXTE has transitioned to an extended mission phase. Cycle 7 observations are being carried out. Cycle 8 proposals will be due in the fall of 2002. The Senior Review of 2002 has authorized operations until 2006 (subject to the 2004 review), with return of guest observer support to the RXTE program. Information on the mission and the opportunity to propose can be found at (http://xte.gsfc.nasa.gov/docs/xte/xte_1st.html.

RXTE has always accepted both pre-planned and target of opportunity proposals and carries out both proposed (proprietary) target of opportunity observations and requested (public) observations that were not proposed. Currently RXTE is devoting a higher fraction of time to targets of opportunity, in accordance with advice from the RXTE User's Group. Extended monitoring programs for certain classes of sources are in progress, bright Seyfert galaxies, Anomalous X-ray Pulsars, selected rotation-powered pulsars, Soft Gamma Repeaters, selected low-mass X-ray binaries, and selected black holes, for examples. Observations coordinated with Chandra, XMM-Newton, INTEGRAL, and ground based observatories, from radio through TeV, are supported.

RXTE has found kilohertz oscillations in the flux from twenty one accreting neutron stars. In ten of them, thermonuclear flash bursts have revealed oscillations probably coherent, but of slightly varying frequency. In three low-mass X-ray binaries now, millisecond spins are persistently visible. RXTE has found frequencies up to 450 Hz in the flux from black hole candidates, sometimes discerned in pairs of quasi-periodic oscillations. Observations of these neutron star and black hole systems are unique to RXTE. If additional observations can establish definitive interpretations, they will also yield such fundamental information as the equation of state of neutron stars and the angular momenta of black holes.

Drs. Markwardt and Jahoda, in collaboration with Dr. D. Smith (UMD), Ms. Brenneman (UMD), Mr. S. Duckett (Purdue U.) and Mr. D. Parker (UMD), developed a new set of models of the particle backgrounds of the RXTE PCA instrument, appropriate for both faint and bright sources. These new models, which are now being distributed to the user community, are an improvement by a factor of 2 or more compared to the previously available models.

3.5 The Energetic Particle Acceleration, Composition, and Transport Experiment (EPACT) on the ISTP/Wind Spacecraft

Dr. von Rosenvinge is the Principal Investigator for the Energetic Particles: Acceleration, Composition, and Transport (EPACT) experiment, developed in conjunction with Drs. Reames and Barbier for the Wind spacecraft and launched in November, 1994. Dr. G. Mason (UMCP) is also a co-investigator. Sensitivity for low energy particles has been increased by two orders of magnitude, so that high sensitivity studies of the anomalous component, Corotating Interaction Regions and ^{3}He-rich events have been possible. Trans-iron nuclei were discovered in impulsive solar particle events. This discovery, subsequently confirmed by the ULEIS instrument on the ACE spacecraft, depended on both high sensitivity and the fact that the trans-iron elements are enhanced relative to normal solar abundances by a factor of approximately one thousand. This enhancement had been speculated upon for years, but has only now been confirmed.

3.6 Konus, a Gamma-Ray Burst Experiment from Russia on the ISTP/Wind Spacecraft

Konus is a gamma-ray monitor on the ISTP/Wind spacecraft that has provided isotropically sensitive and nearly continuous gamma ray burst (GRB) coverage since launch in November 1994. Dr. E. P. Mazets of the Ioffe Physico-Technical Institute in St.Petersburg, Russia and Dr. Cline are the co-Principal Investigators. Konus has always been a primary near-Earth vertex of the Interplanetary GRB Network (see IPN section), but now that both the CGRO mission and the BeppoSAX mission are no longer operating, Konus is the only full-coverage near-Earth GRB monitor in the network, with HETE-2 and R-HESSI missions providing more limited GRB monitoring from their Earth orbits. A termination of data collection from the Wind spacecraft had been temporarily contemplated in late 2001, but that mission is now being maintained indefinitely, although with a severely reduced operating budget. Nevertheless, revised software has been completed to permit the Konus GRB data to be automatically analyzed soon after each download, as had been the case in 2000-2001. It is anticipated that Konus may now continue to provide this critical support to the GRB community for some years to come.

3.7 Interplanetary Gamma-Ray Burst Timing Network (IPN)

The interplanetary GRB network (IPN) now involves three space probes at mutually great separations: Ulysses (Dr. K. Hurley, UC Berkeley, PI), the Konus experiment on the GGS-Wind spacecraft (see Konus section), and the Mars Odyssey, with both a gamma-ray-sensitive neutron detector (I. Mitrofanov, Moscow, PI) and a gamma-ray spectrometer (W. Boynton, Arizona, PI). In addition, near-Earth GRB data can also be provided by the HETE-2, R-HESSI and RXTE missions, depending on the event circumstances. Although the Mars Odyssey spectrometer is not yet fully configured, due to orbit considerations, the neutron detector has been providing continuous GRB coverage for some time. Thus, now that the Wind data downloads have been reprogrammed for more rapid availability (see Konus section), the IPN is again functioning at full capability, as it was in 2001 when the IPN incorporated the NEAR mission. Its precise (several-arc-minute) GRB source localizations, delivered to the community on receipt by the Goddard GCN (see GCN section), both made possible unilateral GRB localizations and had assisted BeppoSAX and HETE-2 by narrowing down many of their localizations, thus providing the opportunities for many follow-on GRB afterglow studies. The IPN in its present configuration should be able to provide this service again, in parallel with HETE-2 and, possibly, INTEGRAL, continuing until at least 2004, approximating the launch time of Swift, the next-generation GRB mission.

3.8 X-Ray Multi-Mirror Mission (XMM-Newton)

The ESA XMM-Newton X-ray observatory launched in 1999 December continues to operate well and is observing Guaranteed Time (GT), Guest Observer (GO), and Target of Opportunity targets. XMM-Newton covers the 0.1–15 keV energy range with large effective area, moderate angular resolution (15 arcsec), and moderate (CCD) and high (grating) spectral resolution. XMM-Newton also includes an Optical Monitor for simultaneous coverage of the UV/optical band. Information about the project can be found in the NASA/GSFC Guest Observer Facility web pages (http://xmm.gsfc.nasa.gov).

After a slow start due to lagging software development and data processing, data are now flowing to the community both through the GO program and through archived calibration, performance verification, science verification data sets, and GO and GT data sets when the proprietary periods elapse. Archived data are available both through the ESA SOC as well as a mirror site at GSFC. The average time for delivery of a data set after an observation has dropped to less than a month. The currently available project software is both robust and complete, and the instrument calibration is accurate.

The NASA/GSFC XMM-Newton Guest Observer Facility (GOF) continues to support US participation in the project. The GOF is currently supporting software development at Leicester U. (the Standard Analysis Software, SAS). GOF scientists Drs. Snowden, Still, and Harrus, under the direction of US Project Scientist Dr. Mushotzky, have worked closely with both the instrument hardware teams and software development teams, both in the US and in Europe. The NASA part of the XMM-Newton project underwent the biannual Senior Review process in June 2002 and was given a high grade.

3.9 Advanced Composition Explorer (ACE)

The Advanced Composition Explorer (ACE) was successfully launched on August 25, 1997. LHEA scientists involved include Drs. Christian and von Rosenvinge (Project Scientist). ACE includes two instruments which were developed jointly by Caltech, GSFC, and Washington U. in St. Louis. The Cosmic Ray Isotope Spectrometer has made unprecedented new measurements of heavy cosmic ray isotopes. These measurements include observations of the isotopes ^{59}Ni and ^{59}Co which suggest that there is a delay of $\sim 10^5$ years or more between the synthesis of ^{59}Ni by supernovae and its acceleration to cosmic ray energies. The Solar Isotope Spectrometer (SIS) has measured isotopes in the Anomalous Cosmic Rays (ACRs) and in solar energetic particle events. The large collection power and resolution of SIS have allowed it to observed many previously unmeasured rare elements as well as to make measurements of different isotopes. The isotopic abundances are observed to vary significantly from event to event.

4. FUTURE FLIGHT MISSIONS

4.1 Solar-TErrestrial RElations Observatory (STEREO)

Drs. von Rosenvinge and Reames are Coinvestigators for the IMPACT investigation on the STEREO mission. Dr. J. Luhmann (U. California, Berkeley) is the Principal Investigator. Duplicate instruments on each of two spacecraft, one leading the Earth and one trailing the Earth, will image Coronal Mass Ejections from the Sun heading towards the Earth. This will permit stereo images to be constructed to investigate the three-dimensional structure of Coronal Mass Ejections. The IMPACT investigation will provide corresponding in situ particle measurements. The two STEREO spacecraft are being built by the Applied Physics Laboratory of Johns Hopkins U. for launch by a single rocket in 2004.

4.2 International Gamma-Ray Astrophysics Laboratory (INTEGRAL)

The International Gamma Ray Astrophysics Laboratory (INTEGRAL) is a joint ESA-NASA gamma-ray astronomy mission that will be the successor to the Compton Observatory and GRANAT missions. It was selected by ESA in June 1993 as its next Medium Class scientific mission (M2) with payload selection in June 1995. The launch is scheduled for October 2002. It will be an observatory class mission that will perform high-resolution spectroscopy and imaging in the 20 keV to 30 MeV region. There will be two main instruments, a spectrometer and an imager. By taking advantage of new technology, the INTEGRAL will have greatly improved performance over prior comparable missions, e.g., 40 time better energy resolution and 10 times better angular resolution than the Compton Observatory. Goddard is participating in the mission planning and in the development of the scientific data analysis software for the spectrometer. The US Guest Observer Facility (GOF) will be at Goddard. The Goddard scientists involved are Drs. Teegarden (NASA Project Scientist), Gehrels (Mission Scientist), White, Shrader, and Sturner.

4.3 Gamma-ray Large Area Space Telescope (GLAST)

Drs. Gehrels, Hartman, Moiseev, Norris, J. Ormes (Code 600), Ritz, and Thompson are GSFC members of a large consortium (Prof. P. Michelson of Stanford is the PI) that was selected to build the Large Area Telescope (LAT) main instrument for the Gamma-ray Large Area Space Telescope (GLAST), the next-generation high-energy gamma-ray mission. With a large field of view (2.4 sr), large peak effective area, greatly improved point spread function (<0.15 degrees for $E>10$ GeV), and unattenuated acceptance to high energies, GLAST will measure the cosmic gamma-ray flux in the energy range 20 MeV to >300 GeV with unprecedented precision and a factor 40 better sensitivity than the previous EGRET detector. The launch is planned for 2006. GLAST will open a new and important window on a wide variety of high energy phenomena, including supermassive black holes and active galactic nuclei; gamma-ray bursts; supernova remnants; and searches for new phenomena such as supersymmetric dark matter annihilations. The instrument consists of a large effective area Si-strip precision converter-tracker, an 8.5 radiation length CsI hodoscopic calorimeter, and a segmented plastic tile anticoincidence detector (ACD).

GSFC is the lead institution responsible for the LAT ACD, including all hardware and readout electronics. Dr. Thompson, the ACD subsystem manager, and Drs. Moiseev, Hartman, and Ormes are designing the flight unit. An engineering model for the ACD was constructed and used in a flight-scale GLAST tower beam test in 1999. This same tower was used in a balloon flight in 2001, for which Dr. Thompson was the leader.

Drs. Moiseev and Ritz are performing instrument and science simulations. Under Stanford leadership, Dr. Norris is helping to coordinate the LAT team gamma-ray burst science software preparation. Drs. Gehrels, J. Ormes (Code 600), Ritz and Thompson are members of the LAT Senior Scientist Advisory Committee, which is chaired by Dr. Gehrels. Dr. Ritz is the LAT Instrument Scientist and is part of the core LAT management team. Dr. Thompson is a LAT team member of the GLAST Science Working Group, and is also the LAT team multiwavelength coordinator. Drs. Harding, Hunter, and Stecker are Associate Investigators on the LAT team, working on the preparation for science analysis. NRC Research Associate Dr. Cillis works on both ACD design and science analysis software. Mr. Wren is a U. of Maryland Ph.D. student working on GLAST performance evaluation and science preparation.

Drs. Thompson, Moiseev, and a large number of scientists from the many institutions that make up the GLAST LAT collaboration flew a GLAST LAT prototype telescope on a balloon from Palestine, Texas, in August, 2001. The engineering flight successfully demonstrated the performance of the instrument concept and provided a set of data that is being used to compare with simulations of the primary and secondary cosmic and gamma radiation seen in the upper atmosphere.

A number of important mission-level science functions are also provided by Goddard. The project scientist is Dr. J. Ormes (Code 600), with Drs. Gehrels and Ritz serving as Deputy Project Scientists. The GLAST Science Support Center (SSC) is located at Goddard, and is led by Drs. Norris and Band. LHEA GLAST Education and Public Outreach activities, under the leadership of Prof. L. Cominsky of Sonoma State U., by Drs. Gehrels, Bonnell, and Lochner include teacher workshops, museum exhibits, posters, videos and web pages.

4.4 Astro-E2

Following a series of proposal efforts in the US and Japan, the LHEA is working directly with the Institute of Space and Astronautical Science (ISAS) in Japan to rebuild the Astro-E observatory and launch it in early 2005. The original Astro-E mission was created to provide astrophysicists with broadband, high-resolution X-ray spectroscopy for high sensitivity observations of a wide variety of celestial X-ray sources. Astro-E was launched in February 2000, but did not reach orbit due to a launch vehicle failure. The unique feature of Astro-E2 is the microcalorimeter X-ray spectrometer (XRS), an instrument with high spectral resolution and quantum efficiency over a large energy bandwidth. The energy resolution of <12 eV in a 32 pixel array will enable powerful diagnostics of high energy processes from measurements of L- and K-shell atomic transitions through Ni, and velocity information, to be determined with high precision. The XRS utilizes a three stage cooling system capable of operating the microcalorimeter array at 0.06 K for about two years in orbit.

The other instruments on Astro-E2 are the responsibility of ISAS and extend the capabilities of the observatory. The X-ray Imaging Spectrometer (XIS) consists of four individual CCD cameras that provide imaging over a larger field of view with moderate spectral resolution. The instrument is being built in collaboration with MIT. The Hard X-Ray Detector (HXD) covers the energy band 10–700 keV with high sensitivity.

Astro-E2 will necessarily be built according to the original designs and drawings. However, a few changes are being considered that would enhance the capabilities of the observatory. ISAS is planning to install mechanical precollimators in front of the XIS and XRS mirrors to reduce stray X-ray light. This will significantly increase the sensitivity to faint sources and low surface brightness regions that are within a degree or so of brighter sources. For the XRS, a mechanical cooler is being considered (to be provided by ISAS) that would increase the lifetime of the solid Ne cryogen. This could increase the overall operational lifetime of the XRS to three years. For the detector array, continued research and development on microcalorimeters with ion-implanted Si thermometers has paid off and led to new devices that have almost 50 percent better spectral resolution. Devices fabricated from Si wafers with a buried oxide layer have allowed thermistors to be formed that are deeper. This has essentially eliminated the $1/f$ noise that previously limited the resolution of the original XRS array to about 12 eV. Without this noise contribution, and by optimizing various detector parameters, it is now possible to produce mechanically robust arrays with ~ 6 eV resolution at Fe K ($\sim$ 6 keV). Full arrays have been successfully fabricated and are being tested mechanically for flight qualification.

The microcalorimeter array for the XRS is the responsibility of Dr. Stahle. The detector assembly is being built by a team in the Lab under the direction of Dr. Porter. Dr. Boyce is responsible for the microcalorimeter electronics and flight software. The calibration plans and instrumentation are being developed by Drs. Brown and Cottam.

The XRS and XIS instruments sit at the focus of large collecting area, lightweight X-ray mirrors developed in the LHEA under the direction of mirror principal investigator Dr. Serlemitsos. Work is continuing on improving the imaging quality of these mirrors by Drs. Soong and Chan.

Dr. Kelley is the Principal Investigator for the US participation in the mission and the XRS instrument and Dr. White is the NASA Project Scientist.

4.5 Swift

The Swift gamma-ray burst MIDEX proposal was selected by NASA October 14, 1999. The observatory will be launched in September 2003 for a nominal two year lifetime. Swift is an international payload consisting of wide and narrow field-of-view instruments with prompt response to gamma-ray bursts. A 1.4-steradian wide-field gamma-ray camera will detect and image >100 gamma-ray bursts per year with $1-4$ arcmin positions. The Swift spacecraft then slews automatically in $20-70$ seconds to point narrow-field X-ray and UV/optical telescopes at the position of each gamma-ray burst to determine arcsecond positions and performs detailed afterglow observations. The goal of the mission is to determine the origin of gamma-ray bursts and to use bursts to probe the early universe. The mission is managed at Goddard. Dr. Gehrels is the Principal Investigator, Dr. White chairs the Executive Committee and Dr. John Nousek is the lead scientist at Penn State, the prime US university partner. Key hardware contributions are made by international collaborators in the UK and Italy. This year the 3 instruments are in final stages of fabrication. Instrument testing is planned for summer and fall 2002 with observatory testing in 2003. A mission operations review is scheduled for August 2002.

4.6 Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA)

Sensitive measurements of the antiproton and positron components of the cosmic radiation can constrain models of the Dark Matter that pervades the universe. The PAMELA instrument in a high-inclination orbit will measure these spectra from 50 MeV to over 100 GeV using a magnetic-rigidity spectrometer with precision silicon tracking combined with a time-of-flight (TOF) system, a transition-radiation detector, and a silicon-imaging calorimeter to fully identify charged particles. PAMELA is under construction for flight in 2003 by a collaboration that includes Italy, the US, Germany, Sweden, and Russia, headed by Prof. P. Picozza of INFN Roma II (Italy). Dr. Mitchell leads the US work on PAMELA, serves as a member of the International Program Committee, and is jointly responsible for the TOF and Trigger systems with Prof. G. Barbarino of INFN Naples (Italy) and Prof.-Doctor M. Simon of the U. Siegen (Germany). Dr. Streitmatter is a member of the Scientific Committee and Dr. Moiseev is involved in instrument definition and modeling. The instrument is nearing completion and accelerator tests of the detector subsystems have been carried out at CERN.

4.7 Constellation-X

The Constellation-X observatory is a revolutionary mission in X-ray spectroscopy providing a factor of 25–100 increase in sensitivity at high spectral resolution ($E/\Delta E \sim 300-3000$) in the 0.25–10 keV band, and a factor of 100 increased sensitivity at 40 keV. The mission was strongly endorsed in the McKee-Taylor National Academy of Sciences survey report ‘‘Survey on Astronomy and Astrophysics’’ which compared and prioritized new large ground and space based facilities. Constellation-X was rated as a priority for this decade, just a notch behind NGST. The science goals are to study the formation of black holes, the formation of the elements, and to trace dark matter. Technical progress continues at a good pace, and the technology funding is now ramping up. The basic elements of the mirror technology have been demonstrated in advance of building an engineering model of an optics segment scheduled for next year. The fabrication of a small array of 2 eV micro-calorimeter devices has begun. The multi-layering of foil optics is being test flown on the InFOCμS balloon flight.

There is substantial participation by LHEA in the Constellation-X project. Dr. White serves as Study Scientist. Dr. Petre is one of two Mission Scientists (along with J. Bookbinder of SAO), and leads the development of the Spectroscopy X-ray Telescope (SXT), an effort involving participants from SAO, MSFC, and MIT. Dr. Zhang is responsible for the SXT reflector development. Dr. Kelley leads the X-ray Calorimeter consortium, which includes Drs. Stahle, Finkbeiner, Porter, and collaborators from NIST, Stanford, SAO and Lawrence Livermore National Laboratory (LLNL). Drs. Petre, Zhang, Tueller, Gehrels and Parsons are members of the Hard X-ray Telescope (HXT) team, led by F. Harrison (CalTech) and includes collaborators from Columbia, LLNL, SAO, MSFC, Danish Space Research Institute, and Observatoria Astronomica de Brera.

4.8 Laser Interferometer Space Antenna (LISA)

Gravitational radiation has the potential of providing a powerful new window on the universe for observing the behavior of astronomical systems under conditions of strongly non-linear gravity and super-high velocities. Because of seismic and gravity gradient noise on Earth, searches for gravitational radiation at frequencies lower than 10 Hz must be done in space. The frequency range 10^{-4} to 1 Hz contains many of the most astrophysically interesting sources. In this band, predicted emission includes that associated with the formation or coalescence of massive black holes in galactic nuclei. Laser interferometry among an array of spacecraft in heliocentric orbit with separations on the order of a thousand Earth radii could reach the sensitivity to observe low frequency gravitational radiation from likely sources out to cosmological distances, and would be an important complement to the ground-based experiments already being constructed. A specific concept for this space observatory known as Laser Interferometer Space Antenna LISA is under study as an advanced mission for the next decade. The LISA observatory for gravitational radiation is a cluster of three spacecraft that uses laser interferometry to precisely measure distance changes between widely separated freely falling test masses housed in vehicles situated at the corners of an equilateral triangle 5×10^6 km on a side. It is a NASA/ESA mission that is part of the NASA SEU road map for the latter half of the next decade. The NASA scientists involved in LISA are: Drs. Teegarden (Gravity Group leader), Stebbins (LISA Project Scientist), Centrella (Numerical Relativity Group Leader), Camp (laser development, data analysis) and Merkowitz (LISA end-to-end modeling, micro-newton thruster characterization).

4.9 The Heavy Nuclei Explorer (HNX)

Dr. Barbier was the NASA lead Co-investigator on the Small Explorer proposal for the Heavy Nuclei Explorer (HNX). HNX (Dr. Robert Binns, Washington U., St. Louis, PI). HNX combines two previous missions to study heavy ($Z>26$) cosmic ray particles in the galactic radiation. HNX was one of 7 successful missions selected for a Phase A study by HQ for the Explorer program. That Phase A report was turned in to NASA HQ in May and was followed by a site visit from the TMCO review panel.

HNX consists of two main instruments: ENTICE and ECCO. ECCO measures from charge 70 up through the rare actinides: Th, U, Np, Cm. ENTICE measures the nuclei from iron up through charge $\sim$83, so that the two overlap. HNX will enable us to determine whether grains are an important source of heavy cosmic rays, the admixture of *r* and *s* process material, and the lifetime of the galaxy (through the abundances of heavy, radioactive nuclei).

Ultimately, HNX was unsuccessful in being selected for flight due to concerns about Shuttle manifesting. A reconfiguration that will be compatible with the ISS for the next opportunity is planned.

4.10 Energetic X-ray Imaging Survey Telescope (EXIST)

The Energetic X-ray Imaging Survey Telescope (EXIST) is a NASA mission to survey the gamma-ray sky in the 5 - 600 keV energy band. It is being studied as a cosmic probe mission in the NASA Structure and Evolution of the Universe division for launch in $\sim$2011. The theme of the mission is surveying black holes of all size scales. Objectives include the following: 1) determine the population and physical nature of obscured Seyfert II AGN; 2) detect gamma-ray bursts out to redshifts of 20 and use them to study the early Universe; and 3) study stellar-mass and intermediate-mass black holes in the Galaxy. Prof. J. Grindlay (Harvard) is the EXIST Principal Investigator. At Goddard, Dr. Gehrels is the Study Scientist and Drs. Barthelmy, Parsons and Tueller are team members.

5. INSTRUMENTATION, SUB-ORBITAL, AND NON-FLIGHT PROGRAMS

5.1 Balloon-borne Experiment with a Superconducting Spectrometer (BESS)

BESS was developed to make high-statistics measurements of cosmic ray antimatter and has recorded over ninety five percent of all measured cosmic ray antiprotons. Prof. A. Yamamoto of the High Energy Accelerator Research Organization (KEK) leads the BESS project in Japan, involving four institutions and Dr. Mitchell leads the US effort at GSFC and the University of Maryland. BESS combines the largest geometric acceptance of any balloon-borne magnetic-rigidity spectrometer ($0.3m^2sr$) with powerful particle identification, using an advanced superconducting magnet and precision time-of-flight (TOF), Cherenkov, and tracking systems. It has had eight successful balloon flights since 1993, measuring the spectra of cosmic ray antiprotons and light nuclei, and performing a sensitive search for antihelium, and is currently in Canada for a 2002 flight. A new BESS-Polar instrument is being developed for an Antarctic flight program beginning in 2003/2004 to measure antiprotons with unprecedented statistical precision from 100 MeV to 4.2 GeV, and extend measurements of cosmic ray spectra to energies of 500 GeV. Drs. Hams, Mitchell, Moiseev, Ormes, Sasaki, Stephens, and Streitmatter are working on analysis and interpretation of current BESS data and on the development of instrumentation for BESS-Polar. Dr. Sasaki is responsible for the BESS-Polar trigger and digital electronics, Dr. Hams is responsible for the Aerogel Cherenkov Counter photomultipliers, and Dr. Mitchell is responsible for the TOF system.

5.2 Trans-Iron Galactic Element Recorder (TIGER)

The Trans-Iron Galactic Element Recorder (TIGER) is a balloon-borne spectrometer designed to measure the cosmic ray abundances of elements heavier than iron. From Goddard, Drs. Barbier (GSFC Lead Co-I), Christian (USRA), de Nolfo (NRC), and Mitchell supplied the two large-area high-resolution Cherenkov detectors for TIGER. Dr. W. R. Binns from Washington U. (St. Louis) is the PI, and the team also includes Dr. M. Israel (Wash. U.), J. Link (Wash. U.), L. Scott (Wash. U.), Drs. S. Geier (Caltech), R. Mewaldt (Caltech), S. Schindler (Caltech), E. Stone (Caltech), and J. Waddington (U. of Minnesota).

TIGER had an extremely successful balloon flight from Antarctica during December 2001 and January 2002, being the first payload to circumnavigate Antarctica twice and having a record-breaking 31.5 days at the top of the atmosphere. Dr. Christian spent two months down at McMurdo Station in Antarctica preparing for and supporting this flight. The experiment worked very well for the entire flight, and despite a landing in which TIGER was dragged for 75 miles across the Ross Ice Shelf (another record), the instrument sustained only minor damage.

A preliminary look at the data shows that the resolution was better than is required to distinguish individual elements, which is the goal of TIGER. Because the ultra-heavy cosmic rays are so rare, the TIGER measurements are limited by statistics. Another Antarctic flight of TIGER is planned for December 2003 to accumulate more data.

While in Antarctica, Dr. Christian also led a very successful Education and Public Outreach campaign with a number of high school classes back in the states. This included several projects done in Antarctic for the students, a web-based journal, and email questions and answers with the students and others.

5.3 High Energy Astrophysics Science Archive Research Center (HEASARC)

The High Energy Astrophysics Science Archive Research Center (HEASARC) is one of NASA's wavelength-specific science archive research centers and is operated by LHEA, in partnership with the Harvard-Smithsonian Center for Astrophysics (CfA). The Director of the HEASARC is Dr. White, the Associate Director is Dr. S. Murray (CfA), the Chief Archive Scientist is Dr. McGlynn, and the Archive Scientists are Drs. Angelini, Corcoran, Drake, Lochner, Arnaud and Pence. The HEASARC provides the astrophysics community with access to the archival data from extreme-ultraviolet, X-ray, and gamma-ray missions. In order to maximize the scientific utilization of this archive, the HEASARC also makes available multi-mission analysis software, as well as Web utilities that are appropriate both for high-energy data analysis, e.g., tools for simulation of X-ray spectra and for calculation of the diffuse X-ray background level in any direction in the sky, and also for more general astronomical purposes, e.g., tools to convert sky coordinates, dates, and energies to and from the various alternate systems in common usage.

Highlights from the past 12 months of HEASARC operation include: (i) a total volume of archival data that has reached 2.7 Terabytes (TB). (ii) record amounts of data, software, images, and webpages downloaded by HEASARC users (2.2 TB via anonymous ftp and/or the ftp server, and 2.2 TB via the Web http server). (iii) a record 1,170,000 queries of the HEASARC's web-based multi-mission database and catalog service, Browse, representing an increase of 75 percent compared to the previous 12-month period. (iv) continued heavy usage (630,000 images served) of the HEASARC's Web-based SkyView facility (a tool to display images of selected portions of the sky in various projections and in any of a wide range of wavelengths), and the addition of the Second Generation Digitized Sky Survey (DSS2) and the CDS Vizier-hosted Guide Star Catalog 2.2, 2MASS and USNO A2 Catalogs to its extant large-area surveys. (v) the ongoing creation (which had reached 5000 entries by the end of June 2002) of bibliographic code/dataset cross-identification tables for HEASARC datasets so as to enable users of the NASA Astrophysics Data System (ADS) to link immediately from the ADS bibliographic record of a paper to the datasets analyzed therein. (vi) the opening in February 2002 of the HETE-2 Data Archive, the contents of which reached 76 Gigabytes (GB) of public data by June 2002. (vii) two new releases of HEAsoft, the unified FTOOLS and XANADU software package, version 5.1 in August 2001 and 5.2 in June 2002. (viii) the continuing ingest of BeppoSAX Narrow-Field Instrument (NFI) data from the Sax Data Center, and of guaranteed time, guest observer, and calibration data from the XMM-Newton Project, the volume from each of which exceeded 100 GB by April 2002. (ix) the completion of the public data archives for the ASCA and EUVE missions. (x) the unveiling of the ‘‘High Energy Astrophysics Picture of the Week’’ on the HEASARC website. (xi) a major enhancement of the HEASARC’s Browse software that allowed access to thousands of tables contained in the CDS Vizier database. (xii) the continuing Applied Information Systems Research Program (AISRP)-funded development of the Hera software, which has as its ultimate goal the enabling of users to browse for data in the HEASARC archive, and then to immediately reduce and analyze the data, using the same integrated Web interface. (xiii) the continuation of another AISRP-funded effort called ClassX to develop a prototype National Virtual Observatory (NVO) utility, viz. a source classifier that will use a range of distributed, multiwavelength datasets so as to allow users to classify samples of X-ray sources based on a large number of scientific criteria.

5.4 High Resolution Detector Development

The X-ray astrophysics branch continues to develop and improve X-ray microcalorimeters for high resolution X-ray spectroscopy. The specific areas of development include low noise, high sensitivity thermometers, schemes for fabricating large arrays with high filling factor, and X-ray thermalizing absorbers that can be directly incorporated into the device fabrication process. The instrument electronics that will be required for large arrays of microcalorimeters are also being developed. Members of the LHEA microcalorimeter team include Drs. Bandler, Boyce, Figueroa-Feliciano, Finkbeiner, Furusho, Kelley, Lindeman, Porter, and Stahle. Dr. Bandler, previously of SAO, joined the group in April 2002, bringing expertise in a variety of microcalorimeter implementations. During this period, Dr. M. Galeazzi (Wisconsin) participated in the full range of the detector development activities as a visiting scientist, in particular making many valuable contributions to our detector modeling and design optimization.

Work is being done on improving devices with ion-implanted Si thermometers and superconducting transition edge thermometers. The implanted Si detectors have near-term applications in the X-ray sounding rocket program, laboratory astrophysics with an electron beam ion trap, and potentially on Astro-E2. Test devices have been fabricated using a new process that produces thermometers that are significantly deeper, and thus less sensitive to non-ideal effects apparent in thermistors with very thin current-carrying channels. These have produced lower noise thermometers, and higher yields of usable wafers. In collaboration with GSFC Code 553, arrays of such devices have been designed and produced with characteristics suitable for Astro-E2. First tests are extremely encouraging, showing 6.4 eV resolution at 6 keV, nearly a factor of two better than the devices launched on Astro-E.

For the Constellation-X mission, an energy resolution of 2 eV at 6 keV and below is required in an array capable of 5–10 arcsec imaging over a field of view of at least 2.5 arcmin. This requires 0.25 mm pixels in close-packed arrays that are of the order 30x30, with high uniformity across the array. This is a major leap for high-resolution imaging spectroscopy and presents many challenges. To achieve arrays with this level of performance, microcalorimeters with superconducting transition edge thermometers, or transition edge sensors are being pursued. Following the attaining of 2.4 eV resolution at 1.5 keV using a Mo/Au bilayer on a low stress silicon nitride membrane, work on these devices continues on several fronts: characterizing the thermal conductance of thin silicon nitride membranes used for thermal isolation, noise properties of the superconducting bilayer films that form the thermometer, absorber fabrication, and array schemes. Over the last year, Dr. Lindeman has made precise measurements of the heat capacity and current noise in our TES devices at different bias points within the superconducting transition. These measurements are consistent with the TES being in a mixed state, with both normal and superconducting regions present and the fraction in the normal state increasing as the fully normal resistance is approached.

5.5 Micro-Well Pixel Proportional Counter Development

Imaging micro-well proportional counters and related gas micro-pattern devices are being developed in the LHEA (Drs. Black, Deines-Jones, Hunter, and Jahoda) for large-format X-ray imaging and for electron tracking in X-ray polarimeters and gamma-ray telescopes. Gas micro-pattern detectors exploit narrow-gap electrodes, rather than thin anodes, to achieve gas amplification. The LHEA is currently developing higher resolution ($\sim$ 100 micron pixels) devices and pixel-by-pixel readout electronics which are highly transparent to X-rays.

X-ray imagers. Micro-well detectors are a demonstrated, mechanically-simple means of high-resolution ($\sim$ 50 micron) imaging over large areas. We have demonstrated that this detector geometry offers: 1) Sub-pixel resolution: detectors with 400 micron pixel spacing having 85 micron resolution. 2) Stable operation: gas gains of 30,000 are routine. 3) Mechanical robustness: uses flexible printed circuit technology. 4) Typical proportional counter energy resolution: 20 percent FWHM at 6 keV.

The detectors are arrays of proportional counter pixels with a well-like geometry. The well itself is formed in an insulating substrate. Metal filling the bottom of the well forms the anode while a metal annulus around the top of the well acts as the cathode. The active volume, bounded by the cathode and a drift electrode some distance above the cathode, is filled with a proportional counter gas. With appropriate voltages applied to the three electrodes, ionization electrons created in the active volume are swept into the wells, where the electric fields are strong enough to create electron avalanches. The avalanches create equal, but opposite signals on the anode and cathode. Connecting the anodes in rows and the cathodes in columns then forms a simple, two-dimensional readout scheme for X-ray imaging.

Micro-well detectors are the focal-plane detector on Lobster-ISS, an ESA mission which has recently been approved for Phase A funding. Current Lobster development is directed toward 1) manufacturing 2400 square cm micro-well arrays, and and 2) modifying a double-sided silicon detector readout system developed by Dr. G. Kanbach's gamma-astronomy group at the Max-Plank-Institut fur extraterrestriche Physic for MEGA, a medium energy gamma-ray telescope.

Track imagers. Micro-pattern electron track imagers differ essentially from X-ray imagers in their readout. The crossed-strip readout scheme is appropriate for imaging X-rays, but track imaging requires pixel-by-pixel readout to determine the track's direction and shape. Also, trackers for an efficient polarimeter must be made of optically thin materials, so that most X-rays stop in the gas, rather than in inactive metal electrodes, support structure, or embedded electronics.

Two readout systems are being developed: an amplifier-per pixel scheme for small arrays, and an active matrix scheme for larger arrays. Both are fabricated on thin polyimide, which is optically thinner, more rugged, and scatters less than glass. The amplifier-per-pixel system is being developed at Goddard. The active-matrix readout array is being developed in collaboration with Prof. T. Jackson's group at the Center for Thin Film Devices at the Pennsylvania State U., using a process demonstrated there for fabricating amorphous Si thin-film transistors on polyimide.

5.6 Laboratory Astrophysics

A microcalorimeter spectrometer has been assembled for the LLNL electron beam ion trap (EBIT). Magnetic fields confine and focus a beam of electrons that can be accelerated to any energy between 100 eV and 100 keV. Neutral atoms or ions with low charge are injected into the nearly monoenergetic beam where they are collisionally ionized and excited. The resulting X-ray emission can be viewed through several ports using crystal spectrometers, and now the X-ray microcalorimeter. The X-ray microcalorimeter has high spectral resolution coupled with high quantum efficiency over a large bandwidth and is well suited to the low fluxes from the EBIT. The spectrometer is based on the Astro-E/XRS engineering model detector, and a portable laboratory adiabatic demagnetization refrigerator developed in our lab.

This work is being carried out in collaboration with Drs. P. Beiersdorfer (LLNL) and S. Kahn (Columbia). LHEA's contribution to this work is being carried out by Drs. Boyce, Kelley, Porter, Brown, Stahle and Mr. Tillotson.

The microcalorimeter has opened up new measurement regimes at the LLNL EBIT. For example, it is possible to measure absolute cross sections for both direct electron impact excitation and dielectronic recombination for relatively low energy Fe L-shell transitions, identify spectral signatures of plasmas which are not in ionization equilibrium, measure the composite X-ray emission from plasmas at a specified Maxwellian temperature, and provide high-resolution measurements of the X-ray emission from low energy charge exchange collisions. During the past year, the absolute cross sections for n = 3 to 2 lines in Li-like Fe 23+ were published. Drs. Brown and Porter presented recent results at the 2002 joint meeting of the American Physical Society and the High Energy Astrophysics Division of the American Astronomical Society in Albuquerque, NM. These include measurements of the absolute cross sections of the L-shell transition in Fe XVII, high-resolution measurements of charge exchange recombination of neutral neon and Ne 9+ and Ne 10+, and improved performance from a newly installed adiabatic demagnetization refrigerator salt pill.

This work will continue on other ionization states of iron and other astronomically important elements. Charge exchange processes in highly charged ions of C, N, Ne, Si and Fe can also be measured. The results will be used to both verify and complement atomic data used in spectral modeling packages that are heavily used in the astrophysics community.

Drs. Mendoza, Palmeri and Kallman with Dr. M. Bautista (IVIC, Venezuela) have calculated energy levels, wavelengths, radiative and Auger rates relevant to model the K-alpha lines in Fe XXV through Fe X. This complete and accurate dataset will be soon available on the TIP/TOP database (http://heasarc.gsfc.nasa.gov/topbase).

Drs. Palmeri, Mendoza, Kallman with M. Bautista (IVIC) have studied the structure of the iron K-edge. They showed that the commonly held view of the sharp Fe K-edge must be modified if the decay pathways of the series of resonances converging to the K thresholds are adequately taken into account. These resonances display damped Lorentzian profiles of nearly constant widths that are rapidly smeared to impose continuity through the threshold. By modeling the effects of K damping on opacities, it is found that the broadening of the K-edge grows with the ionization level of the plasma, and the appearance at high ionization of a localized absorption feature at 7.2 keV is identified as arising from the K-beta unresolved transition array.

5.7 Foil Mirrors for X-Ray Telescopes

The staff of the X-ray Optics Laboratory continue to improve the image quality of segmented thin-substrate X-ray mirrors of conical reflectors with the Wolter I configuration. The reflectors are made of formed thin substrates, and are replicated on smooth Pyrex mandrels. The reflectors are then coated with a layer of gold or platinum to reflect X-rays in the energy band up to 10 keV. At the same time, we have developed a multi-layering technique to reflect X-rays up to 40 keV. This telescope was flown onboard the InFOCμS balloon payload in July 2001 at Palestine, Texas, a collaboration between GSFC, ISAS and Nagoya University in Japan. Work is also being performed to establish X-ray interferometry in a laboratory setting, aiming to achieve an ultimate angular resolution far beyond what specular reflection can offer.

The effort to improve X-ray image quality is being pursued in two directions. The first one is to continue with the existing configuration and to refine proven processes. The focus of the course is on remaking the mirrors for the failed

Astro-E satellite and on approaching the conical limit of the image quality. Some success has been achieved in this effort. The image quality of a completed Astro E2 telescope should be better than 1.3 arc minutes half power diameter. Drs. Chan, Serlemitsos, and Soong lead this effort. The second effort uses new substrates (e.g., thin sheets of glass), more optically precise components (such as precisely ground, highly polished replication mandrels), and seeks new alignment techniques. This effort is to prepare for the fabrication of Constellation X where the telescopes should have resolution of 0.25 arc minute or better. Drs. Zhang and Petre lead this effort.

An instrument for testing the X-ray interferometry is under construction. This consists of a vacuum line of more than 40 m with the X-ray source at one end and the mirror components of centimeter baseline on the other to observe the X-ray interference fringes. Dr. Gendreau is the key developer of this facility.

5.8 International Focusing Optics Collaboration for μCrab Sensitivity (InFOCμS)

The InFOCμS team has flown the first complete hard X-ray, multilayer grazing-incidence telescope with a CdZnTe pixel focal plane and successfully imaged Cyg X-1. This breakthrough combination of technologies yields order-of-magnitude improvements in sensitivity and angular resolution with high resolution spectroscopy. The first InFOCμS mirror is 8 m in focal length and 40 cm in diameter, with 2040 fully multilayered reflectors and an effective area of 40 cm^2 at 30 keV with a measured half power diameter (HPD) point spread function (PSF) of 2.6 arcmin. The measured, in-flight, 3-sigma sensitivity (4.6×10^{-6} ph cm^{-2} s^{-1} keV^{-1}$=600$ μCrab in 8 hours in the $20-40$ keV band) of this initial, one-telescope configuration is already capable of significant new scientific observations. This sensitivity has been directly confirmed by the detection and imaging of Cyg X-1. Crucial to this sensitivity is the low background achieved by the concentration of focusing optics and background suppression with heavy CsI shielding. The InFOCμS focal plane has the lowest reported CdZnTe background of 2.4×10^{-4} cnts cm^{-2} s^{-1} keV^{-1}. A future configuration will be used to map the ^{44}Ti in Cas-A and make a definitive measurement of ^{44}Ti from SN1987A. InFOCμS will also be a superb instrument to follow up the Swift/BAT hard X-ray survey, especially the many newly discovered, highly obscured, nearby AGN. This international collaboration (Drs. Tueller, Babu, Barbier, Barthelmy, Chan, Gehrels, Krimm, Okajima, Owens, Parker, Parsons, Petre, Serlemitsos, Soong, Stahle, and White at GSFC; Dr. H. Kunieda at ISAS in Japan, Drs. A. Furuzawa, Y. Ogasaka, K. Tamura Y. Tawara, and K. Yamashita at Nagoya U.; B. Barber, E. Dereniak, E. Young at U. of Arizona; W. Baumgartner, F. Berense, and M. Leventhal at U. of Maryland) includes world leaders in the development of foil mirrors, multicoated optics, segmented CdZnTe detectors, and balloon payloads with the experience and resources necessary to successfully exploit these promising new technologies for the future Constellation-X mission.

5.9 Nightglow

Following last January's attempt at an ultra-long-duration balloon (ULDB) flight around the world, and in which the balloon failed, the NIGHTGLOW instrument (Dr. Barbier, PI) was returned to GSFC for repairs and upgrades. NASA has provided funds for an additional three-year program to re-fly NIGHTGLOW and include a modest cloud-sensing LIDAR system on board.

The design, fabrication, and integration of the LIDAR system has occurred and the instrument was recently shipped to the National Scientific Balloon Facility in Palestine, Texas for its Mission Readiness Review. Following that, it will be shipped to Australia in anticipation of a late November or early December launch. It will attempt another flight with a ULDB balloon, planning on a 20 day trip around the world.

Nightglow is designed to monitor the ultraviolet light produced in the atmosphere and reflected from the ground. Ultra-high energy cosmic ray particles, with energies greater than 10^{20} eV, are detected by the nitrogen fluorescence they produce in the atmosphere. Nightglow helps to monitor the background light against which that signal would be seen by an orbiting instrument.

5.10 Gamma Ray Burst Coordinates Network (GCN)

The GRB Coordinates Network (GCN), operated by Dr. Barthelmy, continues to deliver locations of GRBs to instruments and observers throughout a distribution of delays, from only seconds after the GRB onset with preliminary localizations (while most events are still in progress), to hours or days later, with refined data. These alerts make possible all multi-band GRB follow-up observations, simultaneous and evolving. This was routine during the GRO-BATSE years and it has resumed with the HETE mission. A primary goal of the GCN was realized with the optical detection of the burst counterpart for GRB990123 by the ROTSE instrument during the several-second duration of this GRB. The GCN system is entirely automatic and is all encompassing: it collects all known information on GRB locations from all sources into a single point and transmits that information to all sites, globally. Thus, each observatory or researcher needs to develop and maintain only one connection for all GRB needs. No humans are involved within the GCN system proper, so the delays are minimized to little over 1 second for HETE events and to several to several tens of seconds delay (after receipt of information) from sources such as RXTE. Currently, the GCN system distributes Notices to 235 locations involving over 400 researchers. These include 65 locations with 80 instruments: 34 optical, 12 radio, 16 gamma-ray, 7 x-ray, 3 gravity wave and 3 neutrino. Also, these include 12 fully automated or robotic instruments. The other recipients are researchers or teams associated with telescopes or activities such as cross-instrument correlation operations. As of Aug 2002, 1468 Circulars were distributed to a list of 530 recipients. At present, about 800 follow-up observations have been made using GCN Notices for about 500 bursts.

5.11 Public and Education Outreach

Under the direction of Dr. Lochner, the Laboratory for High Energy Astrophysics continues its program in education and public outreach through the continuing development of new curriculum support materials, presenting workshops at national and regional educator meetings, and working within the NASA OSS Education Support Network of Education Forums and Broker/Facilitators.

The web site (http://imagine.gsfc.nasa.gov/) Imagine the Universe development continues to bring the Lab's science to the education community. The group is also involved in the Lazarus project, an effort producing approximate models for gravitational waves from binary black hole systems using a combined approach involving numerical simulation together with perturbation theory techniques in the regimes where they are applicable. Mr. C. Wanjek (SP Systems) writes news of discoveries from Chandra, XMM-Newton, RXTE and other missions which are posted on the site monthly. Development of short activities for each of the science topics continued, and the series of profiles of Lab scientists. A special exhibit on the science to be performed by the MAP satellite was developed in colloboration with Ms. L. Bartolone (Adler Planetarium) and Dr. D. Spergel (Princeton).

In January 2002, the 6th edition of the Imagine the Universe! was released. CD-ROM, containing a capture of the Imagine web site, as well as StarChild and Astronomy Picture of the Day for the year 2001. This CD-ROM is distributed free upon request, at teacher conferences, and via NASA CORE. Up to 25,000 of the CDs will be distributed during the course of the year.

Development of the ''Cosmic Journey Trading Card Game'' was completed. This collectible trading card deck features five SEU missions which players try to ''launch'' by acquiring the necessary spacecraft, launch vehicle, technology, and science objective through the play of the game. This deck was developed in collaboration with N. Leon (JPL), who heads the SpacePlace education web site.

While in Antarctica for the TIGER mission, Dr. Christian fielded questions on cosmic ray science and polar living conditions from high school students in three states. Dr. Christian also kept an on-line journal about his experiences. Upon returning, he visited the schools he had taken questions from.

The LHEA outreach group continues to present teacher workshops at a variety of educator meetings, including the National Science Teacher's Association National and Area meetings, the Science Teachers of New York State annual conference, the American Association of Physics Teachers, and numerous smaller educator workshops. Exhibit booths are staffed and workshops presented to train teachers to use our materials in their classrooms. Workshop topics now include using our CD-ROM, using the StarChild web site, the ''Hidden Lives of Galaxies,'' ''Black Holes in a Different Light,'' and ''Life Cycles of Stars.'' These workshop presentations are posted on the Imagine web site for teachers to use with their classes.

The outreach group also continues to work closely with the NASA OSS education effort by supporting the Broker/Facilitators with materials for use in their workshops, and by supporting the SEU Education Forum (Dr. R. Gould, SAO) through staffing of exhibit booths at national meetings, and working with them on a variety of education projects. The ''Anatomy of Black Holes'' poster and booklet, the 6th edition of the Imagine the Universe! CD-ROM, and the second edition of the ''Exploring the Extreme Universe'' CD-ROM were contributed to the SEU Education Kits.

In support of E/PO at the collegiate level and higher, Drs. Harrus and Arnaud organized an ''X-ray Astronomy School,'' held Sept 10-12, for graduate students and post-docs to learn the basics of X-ray astronomy and analyzing X-ray data. Dr. Corcoran continues to lead the team-teaching of an upper undergraduate course on astrophysics from a high-energy perspective at George Washington University.

Dr. Arnaud participated as an invited guest lecturer in a COSPAR capacity-building workshop hosted by INPE, the Brazilian space research center, which educated Latin American astronomers about the Chandra and XMM-Newton observatories, archives, and data analysis systems.

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