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, 2000 to June 30, 2001.

This Laboratory's scientific research is directed toward experimental and theoretical investigations in the areas of X-ray, gamma-ray, 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, and the extragalactic background radiation. 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., Stanford 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 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, Joan Centrella, Thomas Cline, 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, Jonathan Ormes (now Director of Space Sciences, Code 600), Ann Parsons, William Pence, F. Scott Porter, Reuven Ramaty (deceased), Donald Reames, Steven Ritz, Peter Serlemitsos, Caroline Stahle, Robin Stebbins, Floyd Stecker, Robert Streitmatter, Tod Strohmayer, Jean Swank, Andrew Szymkowiak (now at Yale), Bonnard Teegarden, David Thompson, Jack Tueller, Tycho von Rosenvinge, Kim Weaver, and William Zhang.

The following scientists are National Research Council Associates: Drs. Zaven Arzoumanian, Gregory Brown, Georgia de Nolfo, Kouichi Hirotani, Taro Kotani, Mark Lindeman, Igor Moskalenko, Sergei Nayakshin, Daniel Proga, Olaf Reimer, Alfred Stephens, Rosa Williams, and Bing Zhang.

The following researchers are University Space Research Association Scientists: Drs. Lorella Angelini, Matthew Baring, Kevin Black (Forbin), Jerry Bonnell, Kai-Wing Chan, Dae-ll Choi, Eric Christian, Nicholas Cummings, Robin Corbet, Michael Corcoran, Philip Deines-Jones, Seth Digel, Joseph Dodoo, Stephen Drake, Ken Ebisawa, Michael Harris, Ilana Harrus, Hans Krimm, John Krizmanic, James Lochner, Natalie Mandzhavidze (deceased), Thomas McGlynn, Alex Moiseev, Sandor Molnar, Koji Mukai, Kirpal Nandra, Scott Owens, Hideki Ozawa, 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), Patty Boyd (UMBC), James Chiang (UMBC), Fred Finkbeiner, Ian George (UMBC), Una Hwang, Kip Kuntz (UMBC), Michael Loewenstein, Craig Markwardt, Chee Ng, Ian Richardson, Jane Turner (UMBC), and Tahir Yaqoob (now JHU).

Visiting scientists from other institutions:Hilary Cane (U. Tasmania), Ralph Fiorito (Catholic U.), Tae Furusho (JSPS) Thomas Hams (U. Seigen), Benzion Kozlovsky (U. Tel Aviv), Masaki Mori (Miyagi U.), 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, Donald Horner, Derek Hullinger, Breno Imbiriba, Giridhar Nandikotkur, and David Wren; from George Washington U., Alaa Ibrahim; from Drexel U., Orhan Donmez; and from Stanford U., Enectali Figueroa-Feliciano.

2. RESEARCH PROGRAMS

2.1 Sun and Solar System

Dr. Reames has discovered that small impulsive events can enhance the abundances of nuclei heavier than iron by factors of several hundred to several thousand relative to normal solar abundances. Impulsive events are solar flare particle events which are known to enhance ^3He relative to ^4He by similar factors. Normal solar abundances of elements fall off by orders of magnitude above about iron. Trans-iron elements had been reported once in 1973 in a non-refereed paper; there were no subsequent such reports until the recent report by Dr. Reames. The new observations were made using the Low Energy Matrix Telescopes, part of the EPACT investigation on-board NASA's WIND spacecraft, launched in 1994. These telescopes were designed to have particularly large collection power and to have dynamic range sufficient to be able to observe trans-iron elements. Confirming observations have been recently reported from the ULEIS instrument on NASA's Advanced Composition Explorer (ACE). These enhancements pose a major challenge to any model attempting to explain the acceleration of particles in solar flare events.

2.2 Stars

Dr. Kuntz, using the Besançon model of stellar populations in the galaxy, new *ROSAT* derived X-ray luminosity functions for different stellar age groups/spectral classes, and new spectral energy distributions derived from *ROSAT* spectra, has constructed a model for the stellar contribution to the diffuse X-ray background. The greatest uncertainties in this model are due to the youngest stars; work continues to improve the model to apply it to the study of the diffuse X-ray background within the plane of the Milky Way.

Drs. Ebisawa, Kotani, and Mukai in collaboration with Drs. K. Asai, T. Dotani, F. Nagase (ISAS), H. W. Hartmann, J. Heise (SRON), P. Kahabka (U Amsterdam) and A. van Teeseling (U Getteingen), have observed the super-soft X-ray sources CAL87 and RX J0925.7-4758 with ASCA, and studied their X-ray spectral characteristics by comparing them with theoretical spectral models of super-soft sources. They have estimated the white-dwarf mass of CAL87 to be 0.8-1.2 $M_\odot$, and found that the white dwarf is permanently hidden by the accretion disk surrounded by an accretion disk corona whose column density is $\sim 1.5 \times 10^{23}$ cm^{-2}. They found RX J0925.7-4758 requires an extremely high temperature and a large mass for the white dwarf to explain the observed X-ray spectrum.

Drs. Corcoran, Swank, Petre, Drake, and Ishibashi with Drs. K. Davidson (U. Minnesota), A. Damineli (I. Astronomico e Geofisico, U. Sao Paulo), L. Townsley (PSU), R. Smith (CfA), and R. Viotti have recently obtained a high resolution 0.5-10 keV X-ray spectrum of the extremely massive star Eta Carinae using the HETGS on Chandra. These data show that the unresolved hard X-ray source is non-isothermal, and that the line forming region lies far from the stellar photosphere, consistent with current models of the system as a colliding wind binary.

Drs. Corcoran and Mushotzky and Ms. Brenneman with Drs. A. Moffat, S. Marchenko, A. Muecke, G. Skalkowski (Montreal), A. Ptak (CMU), I. Stevens (Birmingham), W. Brandner (Hawaii), J. Pittard (Leeds), A. Pollock (C&S Ltd), B. Koribalski (ATNF) have recently completed a preliminary analysis of an X-ray image of the massive star forming region NGC 3603 (the most massive and luminous visible supergiant HII region in the Milky Way) obtained by the ACIS camera on Chandra. Preliminary results suggest the detection of about 100 cluster members to an X-ray flux limit of 10^{-15} ergs cm^{-2} s^{-1}, with at least 30 associated with massive cluster members. The brightest X-ray sources appear to be colliding wind binaries. There are a significant percentage of X-ray sources with no obvious optical counterparts.

Dr. Corcoran and Ms. Carson have correlated X-ray sources with optical sources visible in digitized sky survey plates. Corcoran is also continuing work as moderator of the XMEGA group, a collaboration of scientists interested in problems regarding the X-ray emission from massive stars. In addition to the Chandra observation of NGC 3603, this group has been awarded a Chandra observation of NGC 346, a star forming region in the SMC, and an XMM-Newton observation of the colliding wind binary HD 5980.

Drs. Corcoran, Nandra, Harrus, Christian, and Yaqoob have continued to teach a course on high energy space astrophysics at the George Washington U.

Dr. Drake in collaboration with Drs. R. Osten, A. Brown, T. Ayres, and J. Linsky (U. Colorado), Dr. M. Gagne (West Chester U.), and Dr. R. Stern (LMSAL) studied the coronal structure, variability, and abundances of the well-known short-period binary star TZ CrB using simultaneous RXTE, ASCA, and VLA observations, and earlier epoch EUVE observations. They observed flares in both radio and X-ray spectral ranges that were well-correlated, with the X-ray peak preceding the radio peak by up to 1.4 hours. Plasma as hot as 100 million K was detected during the rise phase of a large flare observed by ASCA. The ASCA X-ray spectra that were obtained during quiescence exhibit coronal metal abundances that are 0.25 to 0.5 times their solar photospheric values, while the metal abundances during the flare rise phase are inferred to be near solar.

Drs. Drake and White and Ms. Brenneman with Drs. T. Simon (Hawaii), M. Guedel (PSI, Switzerland), R. Mewe and J. Kaastra (SRON), and K.P. Singh (TIFR, India) have been studying Chandra grating spectra of the active binaries Algol and UX Ari. The observation of Algol caught a moderate flare on the secondary star, the spectrum of which was analyzed separately from the remainder of the observation when the system was quiescent. As in the case of TZ CrB, the flare plasma was hotter and more metal-rich than the quiescent coronal plasma. A weak (3-sigma) feature was detected in the flare spectrum at 6.4 keV which appears to be due to fluorescent emission from cool iron in the photosphere of the secondary star being irradiated by the hard X-ray tail of the flare plasma. As has been found from analysis of Chandra and XMM-Newton grating spectra of other active stars, the coronal Ne abundances in Algol and UX Ari are close to solar, while all other elements are significantly subsolar.

2.3 Pulsars and Magnetars

Drs. Bertsch and Thompson have been studying the highest energy gamma radiation seen with EGRET from pulsars. They find that the shape of the light curve changes from double peaks to single peaks above 5 GeV and that pulsed emission is seen from several pulsars above 10 GeV.

Dr. Harding, with Dr. A. Muslimov (Emergent), has been investigating pulsar polar cap heating and the resulting thermal X-ray emission from the neutron star surface. They have self-consistently computed the dynamics of electron-positron pairs produced by high energy radiation from accelerated primary particles and the effect of electric field screening by returning positrons. Pairs from both curvature and inverse Compton radiation provide heating to the neutron star polar cap. They find that the X-ray luminosity due to polar cap heating is significant in older pulsars and should be observable.

Dr. Harding with Dr. B. Zhang (NRC) proposed a unified model for high field pulsars and magnetars, arguing that they are all rotating high-field neutron stars but that their magnetic axes have different orientations with respect to their rotation axes. In strong magnetic fields where photon splitting suppresses pair creation near the surface, the high-field pulsars can have active inner accelerators while the anomalous X-ray pulsars cannot. This can account for the very different emission characteristics of the anomalous X-ray pulsar 1E 2259+586 and the high-field radio pulsar PSR J1814-1744.

Dr. Harding with Dr. B. Zhang (NRC) investigated whether gamma-ray pulsars viewed at large angles to the magnetic pole could contribute to the new population of unidentified Galactic EGRET sources in the Gould Belt. The faint, soft nature of these sources is distinctly different from both the properties of unidentified EGRET sources along the Galactic plane and the properties of the known gamma-ray pulsars. Within the polar cap model, some of the sources could be emission from pulsars seen at lines of sight that miss both the bright gamma-ray cone beam and the radio beam. They estimated that the relative detectability of the off-beam emission is about a factor of 4-5 higher than the on-beam emission.

Dr. Harding and Dr. Baring (USRA) explored the possibility of a radio pulsar death line at high magnetic fields, due to a suppression of magnetic pair creation by photon splitting. The death line occurs for pulsar surface magnetic fields exceeding B $\sim 4.4\times10^{13}$ G. They found that pair production is effectively suppressed only if all three modes of photon splitting allowed by QED are operating in high fields.

2.4 Galactic Binaries

Drs. Shrader and Titarchuk are exploring self-consist-ent approaches towards modeling the spectral and temporal properties of accreting black holes. The now well known trend for high-frequency $\sim 10^2$ Hz QPOs to be associated with relatively hard (but high-state) broad-band X-ray spectra is explained naturally in the context of the bulk-motion Comptonization model, but is very difficult to explain for hot coronae models. Trends in the derived parameters, namely an apparent correlation between the appearance and strength of the QPOs and the illumination fraction of the bulk-inflow site have been identified, further strengthening this picture.

Drs. Shrader and Kazanas, with Drs. W. Cui (Purdue U.), C. Haswell and R. Hynes (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 Schwarzchild 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. Additionally, quasi-periodic oscillations at a common frequency ~ 0.08 Hz at optical, UV and X-ray energies. The cross-spectrum sign and amplitude bracketting this feature are of interest in identifying its origin.

Dr. Still with Prof. K. Horne (St. Andrews), Drs. K. O’Brien (Amsterdam), B. Boroson (Wooster), S. Vrtilek (CfA), H. Quaintrell (Open U.), and H. Fiedler (Munich), and Mr. D. Hudson (UMBC) have performed simultaneous X-ray, EUV, UV, and optical monitoring during the short-high state of Hercules X-1, finding evidence for enormous azimuthally-extended curtains of absorbing material above the accretion disk plane.

Dr. Still with Prof. Horne and Dr. C. Knigge (Southampton) have employed HST and Gemini-North in an attempt to directly image propeller ejecta from the nearby cataclysmic variable AE Aquarii. None was found providing useful physical constraints for propeller models to satisfy.

Dr. Smale analyzed a bright X-ray burst from X2127+119 observed in 2000 September, only the second such event ever detected from this globular cluster binary (in M15 = NGC 7078). The RXTE data showed that the burst had a multi-peaked profile, a total integrated energy of 2×10^{40} ergs, and significant photospheric radius expansion. The luminosity-temperature relation during this expansion allows a derivation of the gravitational redshift at the neutron star surface and an estimate of the neutron star mass.

Dr. Smale with Drs. L. Homer, P. Charles, and S. Shih (Oxford), P. Hakala and P. Muhli (U. Helsinki), and G. Ramsay (MSSL) have obtained high-quality contemporaneous fast photometry of the dipping source XB1916-053 from a comprehensive RXTE/optical campaign. These data have allowed them to refine the X-ray period of the system to 3000.6 ± 0.2 s, the optical period to 3027.555 ± 0.002 s, and the timescale of repeating evolution of the obscuring X-ray dip structure to 4.74+/-0.05 d.

Dr. Smale with Drs. M. Church, M. Balucinska-Church, and R. Barnard (Birmingham) continued analysis of RXTE data from the 21-hr dipping source X1624-490 and have produced the counterintuitive result that the emitting region contracts during flares. The most likely scenario is that the high radiative flux of the flaring blackbody removes the upper and lower parts of the inner accretion disk, reducing the accretion rate and terminating the flare.

Drs. Mukai, Smale, and Stahle with Drs. E. Schlegel (CfA) and R. Wijnands (MIT) have analyzed an ASCA observation of a high-latitude X-ray source, MS 1603.6+2600 (UW Corona Borealis). The nature of this source was uncertain, except that it was a 111-min eclipsing binary as determined through optical observations. The ASCA data show a burst, probably of Type I (thermonuclear) origin, orbital modulation, and probably dips due to azimuthal structure in the accretion disk. They favor a model in which MS 1603.6+2600 is a low-mass X-ray binary (LMXB) containing a neutron star.

2.5 Supernovae and Supernova Remnants

Dr. Harrus with Drs. P. Slane, R. Smith (CfA), and J. Hughes (Rutgers) published studies of the supernova remnant G272.2-3.2. They studied the spectral properties of this remnant and examined the possible explanations for its unusual morphology.

Drs. Harrus, Hwang, Petre, Stahle, and Szymkowiak with Dr. S. Holt (Olin C.) presented a study of the shock front in Kepler SNR. They found that the remnant shell can be separated into regions of distinct emission ranging from almost featureless emission to one dominated by contributions from Si, S, and Fe lines.

2.6 Cosmic Rays

Dr. Kazanas with Dr. Becker (George Mason U.) have studied the properties of cosmic ray modified astrophysical shocks in the standard two fluid approximation. They were able to provide novel exact analytic expressions relating the pre- and post-shock conditions. Such expressions were known to exist before, however they could be found only through numerical searches of the available parameter space.

Dr. Kazanas with Dr. Nicolaidis (U. Thessaloniki) have argued that the ‘‘knee’’ in the cosmic ray spectra at energies $10^{15.5}$ eV is due to ‘‘New Physics,’’ in particular a novel channel in the high energy interactions which should become operative at energies just beyond those of the current accelerators. The key element of this proposal is that this channel provides for ‘‘missing energy,’’ i.e., energy that does not trigger the cosmic ray detectors. This proposal is consistent with most theories of high energy collisions and it should be testable with the next generation of accelerator experiments.

2.7 Black Hole Astrophysics

Dr. Strohmayer used archival RXTE observations to analyze the timing properties of the hard X-ray flux above 12 keV from GRO J1655-40. The study revealed the presence of a 450 Hz quasi-periodic oscillation (QPO), the highest frequency QPO yet seen from a stellar mass black hole. The new QPO was detected at times when a previously discovered 300 Hz QPO was also seen, demonstrating for the first time that black hole systems can show pairs of high frequency QPOs as well as neutron star binaries. The 450 Hz frequency provides strong evidence for significant black hole spin in GRO J1655-40.

Drs. Strohmayer and Nath modeled oscillations observed during thermonuclear X-ray bursts from neutron stars. They developed a hot spot model which describes the flux observed from a rotating neutron star with an expanding hot spot. They use this model to fit data from the onset of thermonuclear bursts from 4U 1636-53 and 4U 1728-34, two low mass X-ray binaries (LMXB). Using four bursts from 4U 1636-53 and assuming the modulations are produced by a pair of antipodal spots they conclude that the mass to radius ratio, M/R, has to be less than 0.18 (99% confidence).

Dr. Strohmayer with Dr. E. Brown (Chicago) studied a remarkable three hour long thermonuclear burst observed with RXTE from the LMXB 4U 1820-30. This burst produced 1000 times more energy than typical bursts from this source. The shorter, more common bursts from 4U 1820-30 are fueled by helium, but the giant burst was likely fueled by the carbon ashes which result from the steady burning of helium accreted onto the neutron star from its degenerate helium dwarf companion.

2.8 Our Galaxy

Drs. Kuntz and Snowden have more tightly constrained the existence of the hot, X-ray emitting Galactic halo. Using the *ROSAT All-Sky Survey* they have isolated two X-ray emitting components that are located either in or beyond the Galactic halo. There is a low temperature ($T \sim 10^6$ K) spatially variable component that is likely to reside in the lower Galactic halo and may be the result of galactic chimneys or super-bubble break-out. There is also a higher temperature ($T \sim 10^{6.45}$ K) component that is spatially uniform, of which some fraction may be a truly extragalactic component. Study of the halo of M101 (a nearby face-on Milky Way analogue), suggests that if the Milky Way halo is like that of M101, only a small fraction of this uniform component will be due to the Galactic halo.

Dr. Boldt with Dr. A. Levinson (Tel Aviv) have suggested that the enhanced cosmic ray flux at 10^{18} eV from the general vicinity of our own galactic center could be due to a compact dynamo associated with the Sgr A* black hole ($\sim 2.5 \times 10^6 M_\odot$) and that the resulting gamma-ray curvature radiation expected in this case at $\sim$ 100 GeV should be observable with GLAST.

2.9 Normal Galaxies

Drs. Snowden, Kuntz, Pence, and Mukai have analyzed their *Chandra* observation of the nearby face-on galaxy M101. They have 1) created a catalog of X-ray sources, 2) disproved the previous identification of several sources as hypernova remnant candidates, 3) studied the X-ray emission from the binary population including that from an extremely bright and variable source, and 4) studied the extensive diffuse emission. These studies continue.

Drs. Loewenstein, Mushotzky, Angelini, and Arnaud with Dr. E. Quataert (I. for Advanced Study) analyzed the Chandra data on the central regions of the giant elliptical galaxies NGC 1399, NGC 4472, and NGC 4636. All of these galaxies are likely to have supermassive black holes, yet no nuclear point sources were found with Chandra. The severe upper limits proved inconsistent with basic advection-dominated accretion flow models for NGC 1399 and NGC 4472, indicating accretion onto the black hole at 10% of the Bondi rate.

Since the largest supermassive black hole nuclei ($>10^8 M_\odot$) generally reside in non-active galaxies their lack of compact core X-ray emission precludes spectral line-shape determination of spin, expected to be feasible for active (Seyfert) galaxies. Drs. Boldt, A. Levinson (Tel Aviv) and Loewenstein have pointed out that to obtain evidence for such holes being spun-up we should search for TeV gamma-ray curvature radiation characteristic of the putative compact dynamo production of the highest energy cosmic rays ($\geqslant 10^{20} eV$) by these otherwise dark nuclei of giant elliptical galaxies.

2.10 Starburst Galaxies

Dr. Weaver with Drs. D. Strickland, T. Heckman (JHU), and M. Dahlem (ESTEC), presented arcsecond-resolution X-ray imaging of the nearby starburst galaxy NGC 253. Chandra data reveal a well-collimated, strongly limb-brightened, kiloparsec-scale conical outflow from the central starburst region. The outflow is similar in morphology to the known H-alpha outflow cone, on scales down to $\sim$ 20 pc. This provides, for the first time, robust evidence that both X-ray and H-alpha emission come from low volume filling factor regions of interaction between the fast energetic wind of SN ejecta and the denser ambient interstellar medium and not from the wind fluid itself.

2.11 Gamma Ray Bursts

Drs. Norris, and J. Bonnell with Dr. J. Scargle (NASA/ARC) have continued to utilize Bayesian analysis algorithms to characterize pulse distributions in gamma-ray burst (GRB) temporal profiles.

Analyzing BATSE time-tagged event (TTE) data for short GRBs durations <2 s and the cross-correlation function between energy bands, they determine an average lag 20 times shorter than for long bursts. The short burst lag distribution is close to symmetric about zero - unlike long bursts. They further find an order of magnitude fewer pulses than found in previous studies of long bursts. These results indicate that short bursts are not representable as a continuation of long bursts' characteristics, and appear to be a distinct phenomenon.

Using BATSE 64-ms data for long GRBs (durations >2 s), their brightness-independent analysis of pulse characteristics adds to the emerging picture of an intimate connection between pulse width, spectral lag, and peak luminosity for bursts with known redshifts (e.g., Norris, Marani, and Bonnell): the lower-luminosity bursts tend to have fewer episodes of emission - essentially wider pulses with longer spectral lags.

In work with M.F. Morales (UCSC), Drs. Norris and Bonnell are exploring the use of BATSE 16 energy channel data to determine corrected luminosities from energy dependent time lags for GRBs of known redshift.

2.12 Active Galaxies

Drs. Shrader and Titarchuk are exploring 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 ‘‘middle-weight’’ black holes, using data with improved spatial resolution is also being undertaken.

Dr. Weaver with Drs. H. Netzer (Tel Aviv), R. Sambruna, S. Kaspi, N. Brandt, G. Chartas, G. Garmire, and J. Nousek (PSU) reported results from a Chandra HETG Spectrometer observation of the nearby Seyfert 2 galaxy Circinus. The spectrum shows a wealth of emission lines at both soft and hard X-rays, including Ne, Mg, Si, S, Ar, Ca, and Fe, and a prominent Fe K-alpha line at 6.4 keV. The zero-order image constrains the size of the emission region to be 20-60 pc, suggesting that emission within this volume is almost entirely due to the reprocessing of the obscured central source.

Dr. Weaver with Drs. N. Levenson and T. Heckman (JHU) published a detailed study of the X-ray properties of Seyfert 2 galaxies known to possess starbursts, based on their optical and UV characteristics. These composite galaxies exhibit extended, soft, thermal X-ray emission, which is attributed to their starburst components. The ratio of the hard X-ray luminosity to the far-infrared and [O III] lambda 5007 luminosity distinguishes most of these composites from ‘‘pure’’ Seyfert 2 galaxies, while their total observed hard X-ray luminosity distinguishes them from ‘‘pure’’ starbursts.

Dr. Weaver with Drs. J. Gelbord and T. Yaqoob (JHU) presented the variability properties of the Fe K-alpha line in Seyfert 1 galaxies using data from the ASCA archive. They found that variability of the iron line is common in Seyfert 1 galaxies. About 70% show variability in centroid energy, intensity, and/or equivalent width. In most cases changes in the line do not appear to track changes in the continuum. In some cases, this clearly implies an origin for the line in a region larger than the putative accretion disk around the central, supermassive black hole.

Drs. Yaqoob, George, Nandra, Turner, Serlemitsos, and Mushotzky reported the discovery of a narrow iron K emission line using Chandra. This is the first unambiguous detection of the hypothesized narrow component of the iron line in a Seyfert 1 galaxy. The narrow line likely originates far from the black hole and such measurements with Chandra will be important for deconvolving that component of the iron line thought to originate close to the putative black hole.

Drs. Yaqoob and Serlemitsos reported measurements of the broad iron K line in the quasar 3C 273 from all of the observations of this source made by ASCA during its entire lifetime (more than eight years). The iron line was found to be variable. The broadening is likely to be due to gravitational and Doppler energy shifts in the vicinity of a black hole. 3C 273 is the most luminous active galaxy in which such a line profile has been observed.

Dr. Yaqoob with Drs. B. McKernan, M. Carson, and D. Fegan (University College, Ireland) presented an time-variability analysis of ASCA and Whipple (TeV gamma-ray) data for the Blazars Mkn 421 and Mkn 501. From the analysis they were able to place limits on the local change in lepton density and magnetic field strength in the Blazar jets.

Dr. Kazanas with Dr. S. Nayakshin (NRC) have produced models of various aspects of the variability of Active Galactic Nuclei. They have produced models of the correlated optical - X-Ray variability of NGC 3516 in an attempt to reproduce the results of a recent multiwavelength campaign, as well as the expected correlated X-Ray continuum Fe K-alpha line under a number of assumptions concerning the source of ionizing X-Ray continuum in AGN.

Dr. Kazanas along with Drs. Nandra and Papadakis (U. Crete) have computed the time lags between different energy bands in the light curve of the active galactic nucleus of NGC 7469, obtained in a multiwavelength campaign of this object a number of year ago. It was found that these lags are very similar in form to those observed in galactic black hole candidates, thus providing an additional similarity between these classes of objects.

Dr. Kazanas along with Drs. Becker (GMU) and Subramanian (NRL) derived analytic self similar solutions of Advection Dominated Inflow-Outflow Solutions (ADIOS) onto black holes using the approximate potential of Paczynski and Wiita, thus extending the existing solutions which were valid only for accretion onto objects with Newtonian potentials.

Dr. Hartman led a successful campaign of multi-epoch multi-wavelength spectral observations of Blazar 3C 279. Covering radio through gamma-ray observations at eleven epochs spanning nine years, this campaign demonstrated that a consistent model could describe the dramatic range of variations in the spectra, with only a small number of adjustable parameters.

2.13 Sky Background Radiation and Cosmology

Drs. Kuntz and Snowden have deconstructed the spectrum of the diffuse soft X-ray background into its various components. They have placed an upper limit on the surface brightness of the putative diffuse extragalactic background in the $\frac{3}{4}$ keV background of 7.5 keV s^{-1} cm^{-2} sr^{-1} keV^{-1}, slightly larger than some theoretical predictions. The model temperature of the spectral component that may contain emission due to the diffuse extragalactic background is $\log T \sim 6.45$, again similar to that of theoretical predictions. They have also measured the autocorrelation function of the diffuse soft X-ray background and find a significant signal on scales $10' < \theta < 20'$.

Dr. Loewenstein investigated the possibility that hypernovae associated with Population III stars may significantly contribute to the heating and metal enrichment of the intracluster medium (ICM). He found that a reasonable number of such hypernovae can help account for the abundance anomalies discovered in the ICM and would be a non-negligible source of preheating. A similar mechanism may also explain some of the energy and enrichment puzzles in the Lyman-alpha forest clouds.

2.14 Statistical Methods

Dr. Arnaud has extended the popular Cash maximum-likelihood statistic used in parameter estimation when fitting models to X-ray spectra. The new statistic works in the presence of a background spectrum subtracted from the source. It is of particular use with Chandra and XMM-Newton data.

3. OPERATING ORBITAL FLIGHT MISSIONS

3.1 Compton Gamma Ray Observatory (CGRO)

The Compton Gamma Ray Observatory (CGRO) was de-orbited on June 4, 2000. The de-orbit was controlled to place the spacecraft in the Pacific Ocean. The reason for this end of mission was the loss of a gyroscope in December 1999. The four instruments onboard covered an unprecedented six orders of magnitude in energy, 30 keV to 30 GeV, with an order of magnitude improvement in sensitivity over previous missions. The scientific theme of CGRO was the study of physical processes taking place in the most dynamic sites in the Universe, including supernovae, novae, pulsars, black holes, active galaxies, gamma-ray bursters, and solar flare. The first 15 months of the mission (Phase 1) were dedicated to a full-sky survey. A Guest Investigator program was implemented and a Science Support Center established at the Goddard Space Flight Center to support the Guest Investigators. Dr. Gehrels is Project Scientist and Drs. Bertsch and Norris are Deputy Project Scientists. The CGRO Project is funded through September 2002. 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.

3.2 EGRET

The EGRET instrument continued functioning until the end of the mission. In the last month, the Crab and Geminga pulsars were viewed along with the Sun in hopes of detecting a major solar flare. The pulsars provided valuable end of mission calibration information since the instrument efficiency had decreased very significantly due to spark gas contamination effects. A complete analysis of the degradation since the last gas exchange in September, 1995 has been completed, and all exposure and intensity maps have been regenerated. All of the standard EGRET data products and software in final form are available in the Compton Gamma Ray Observatory archive.

3.3 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 at 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.

3.4 Advanced Satellite for Cosmology and Astrophysics (ASCA)

The joint Japanese-U.S. ASCA mission re-entered the Earth's atmosphere on 2001 March 2, after more than 8 years in orbit. ASCA carried X-ray foil mirrors produced at Goddard, and used CCD cameras as position-sensitive, spectroscopy detectors, a first for X-ray astronomy satellites. More than 3,000 observations were carried out over the course of the mission, resulting in over 1,000 publications in refereed journals to date. The bulk of the data are now available in the public archive. The ASCA GOF continues to support the data analysis needs of the community, primarily for archival research, and the instrument teams' effort to update the calibration, such as that of secular changes of the CCD performances due to radiation damage.

3.5 Rossi X-ray Timing Explorer (RXTE)

The Rossi X-ray Timing Explorer (RXTE) operations have been stable during the last year. NASA's Senior Review in the summer of 2000 rated RXTE highly for results achieved and the promise of continued scientific value. On that basis it was authorized to continue operations certainly through 2002 and through 2004 subject to confirmation in the next Senior Review in 2002. The collimated Proportional Counter Array (PCA) and High Energy X-ray Timing Experiment (HEXTE), that cover the 2-200 keV band for measurements on time-scales from microseconds to years, and the All Sky Monitor (ASM) that obtains long term light-curves of sources brighter than a few microJanskys as well as detecting new sources or changes in known sources all continue to operate. As much as 25% of the pointed detectors observing time is for targets of opportunity (TOOs), that is, made in response to discoveries of either the ASM, or other space or ground based observatories. Of the non-TOO time another 25% is coordinated with other space or ground-based observations, including the Chandra and XMM-Newton Observatories. There is a large data base of public data. Information on the detectors, data access, data analysis tools, and results of the mission are available on the Web at http://xte.gsfc.nasa.gov/docs/xte/xte_1st.html.

During the first 5 years of operation, RXTE observations showed that almost all of the low-mass X-ray binaries that are called Z sources and the atoll sources that are sources of thermonuclear flash bursts are sources of high frequency quasiperiodic oscillations (QPO) in the frequency range of 0.5 to 1.4 kHz, consistent with the frequencies that would be expected within a few radii of the neutron star surface. Frequency changes correlated with luminosity and spectral changes have been subject to several interpretations. Very long observations are now being undertaken, particularly of sources with strong signals, in the search for systematic dependences and lower amplitude signals.

The number of bursters with frequencies seen in the bursts is certainly 9, and probably 10, based on BeppoSAX detection of pulses in 1 of 3 bursts detected from SAX J1808-369 in 1996. Efforts are underway to observer bursters especially when they are burst active, to better study the relation of the burst oscillation frequency to the difference between the two main high frequency oscillations. Between BeppoSAX and RXTE, at least 4 sources have exhibited bursts as long as hours in duration, possibly the result of carbon burning. This type of burst has a recurrence time on the order of a year.

Active galaxies continue to be monitored over the lengthening baseline, which should identify the break frequency of low state power spectra and in a few special cases possibly characteristic frequencies, as well as find cases when the AGN's X-ray activity cuts off, facilitating studies of correlation between the Fe line flux and the continuum.

3.6 Transient Gamma-Ray Spectrometer (TGRS) on the GGS/Wind Spacecraft

The Transient Gamma Ray Spectrometer (TGRS) is a high-resolution gamma-ray astronomy experiment aboard the WIND spacecraft. The team, consisting of Drs. Teegarden, Cline, Gehrels, Harris, and Weidenspointer along with K. Hurley (Space Sciences Laboratory, UC Berkeley), has continued to analyze the data returned from TGRS. A high resolution spectrum of positron annihilation radiation from the Galactic center has been obtained using an on-board occulter. When the occulter is not used, the entire southern sky is observed by the detector, enabling useful survey work to be done. Dr. Kurczynski has recently completed and successfully defended his PhD thesis on a thorough search for narrow gamma ray lines in the spectra of a large number of gamma rays. Drs. Harris and Weidenspointner in collaboration with scientists at the U. of Southhampton have recently undertaken a thorough modelling of the background production in TGRS. These results will be used to place limits on, or hopefully detect, structure in the diffuse cosmic background radiation such as is expected from supernovae. Dr. Harris has recently completed another paper on a search for gamma-ray lines from novae.

3.7 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 coinvestigator. 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

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

Konus, a gamma-ray burst (GRB) monitor launched on the Wind spacecraft in November 1994, is the first Russian scientific experiment on a NASA mission. Dr. E. Mazets of the Ioffe Physico-Technical Institute in St. Petersburg, Russia is the PI and Dr. Cline of Goddard is the co-PI. The Konus experiment provides an uneclipsed near-Earth vertex in the long-baseline interplanetary GRB network (see IPN section). This network, in the year 2000, produced between one-third and one-half of the accurate GRB source localizations that were rapid enough to enable optical and radio counterpart studies, yielding, among others, the most distant GRB source at $Z = 4.5$. In addition to the IPN work, Konus is contributing recent advances in the studies of soft gamma repeaters (SGRs), giant SGR flares, and other hard X-ray transients. These efforts are continuing and production of a 7-year GRB catalog is in progress

3.9 Interplanetary Gamma-Ray Burst Timing Network (IPN)

The interplanetary GRB network presently involves three space probes at mutually great separations: Ulysses (Dr. K. Hurley, UC Berkeley, PI), the Konus experiment on the GGS-Wind (see Konus section), and the Mars Odyssey 2001, with both a neutron detector (Dr. I. Mitrofanov, Moscow, PI) and a gamma-ray detector (Dr. W. Boynton, Arizona, PI). This new IPN has already experienced SGR events from sources with accurately known locations, enabling its precise intercalibration. In the past, experiments additionally contributing to the IPN have included those on Rossi-XTE, BeppoSAX, TGRS on GGS-Wind, and, until their recent terminations, several on the Compton-GRO and on the NEAR (asteroid rendezvous) missions. The IPN provides precise (several arc-minute) GRB localizations with a 1- to 1.5-day delay, necessitated by the recovery of data from the deep-space missions. Its prompt GRB alerts, using the Goddard Gamma-Ray Burst Coordinates Distribution Network (see GCN section), even without BeppoSAX and/or Compton-GRO participation, have enabled numerous optical and radio counterpart observations and redshift studies - in fact, over one-third of the total in the year 2000 alone. With Mars Odyssey 2001 replacing the NEAR mission as the necessary second vertex at distances up to several AU, the renewed IPN will continue to provide this service for some additional years, and should augment GRB data from the HETE-2 and the European INTEGRAL missions as well.

3.10 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, Guest Observer, and Target of Opportunity targets. XMM-Newton covers the 0.1 - 15 keV energy range with large effective area, moderate angular resolution (15″), 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, data are flowing to the community both through the GO program and through archived calibration, performance verification, and science verification data sets. Archive data are available through the SOC as well as a mirror site at GSFC.

The NASA GSFC XMM-Newton Guest Observer Facility has continued 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 Dr. Mushotzky, have worked closely with both the instrument hardware teams and software development teams, both in the US and in Europe. A major effort was also spent on the NASA budget proposal process for US investigators.

3.11 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. of 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 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 mid-term mission in the NASA Structure and Evolution of the Universe division for launch in 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.

4.3 International Gamma-Ray Astrophysics Laboratory (INTEGRAL)

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 1995. The launch is scheduled for Oct. 2002. It will be an observatory class mission that will perform high-resolution spectroscopy and imaging in the 20keV 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 times better energy resolution and 10 times better angular resolution than the Compton Observatory. GSFC is participating in the mission planning and in the development of the scientific data analysis software for the spectrometer. The Goddard scientists involved are Drs. Teegarden (NASA Project Scientist), Gehrels (Mission Scientist), Shrader, Sturner and Weidenspointner.

4.4 Gamma-ray Large Area Space Telescope (GLAST)

Drs. Digel, Gehrels, Hartman, Moiseev, Norris, Ormes, 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 $>10{,}000 cm^2$, greatly improved point spread function <0.15 degree 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 greater than a factor 50 better sensitivity than the existing 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 black holes and active galactic nuclei; gamma-ray bursts; supernova remnants; and searches for new phenomena such as supersymmetric dark matter annihilations and primordial black hole evaporation. The proposed instrument consists of a large effective area Si-strip precision 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 ACD, including all hardware and readout electronics. Dr. Ormes, the ACD subsystem manager, and Drs. Moiseev, Thompson and Hartman 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. A prototype custom Calorimeter front-end electronicschip was also designed (in collaboration with Dr. W.N. Johnson (NRL) and tested by Goddard for the engineering model tower, demonstrating the analog capabilities needed for flight. This same tower will be used in a balloon flight in 2001, for which Dr. Thompson is the leader.

Drs. Digel, Moiseev, and Ritz are performing instrument and science simulations to optimize the design of the instrument. Under Stanford leadership, Drs. Digel and Norris are helping to coordinate the LAT team science software preparation. Drs. Gehrels, Ormes, Ritz and Thompson are members of the GLAST Senior Scientist Advisory Committee, which is chaired by Dr. Gehrels. Dr. Ritz is the LAT Instrument Scientist. 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. Kotani works on both ACD design and science analysis software.

LHEA scientists also work with the GLAST project office, which is located at Goddard. Dr. Ormes is the GLAST project scientist and chair of the Science Working Group, and Drs. Gehrels and Ritz are deputy project scientists. During the AO competition, the project scientist was Dr. Bertsch.

The GLAST Science Support Center (SSC) is located at Goddard, and is lead by Dr. Norris. 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.

4.5 PAMELA/Timing Experiment Modules for PAMELA Observations (TEMPO)

In order to understand the nature of the dark matter that pervades the universe and the apparent absence of cosmological antimatter, sensitive measurements of cosmic ray anti-proton and positron spectra are crucial. PAMELA will measure these spectra from 50 MeV to over 100 GeV using a magnetic 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 a flight in late 2002 or early 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 HECR group 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. of Siegen (Germany). Dr. Streitmatter is a member of the Scientific Committee and Dr. Moiseev is involved in instrument definition and modeling. Design of the TOF detectors and fabrication of prototype electronics has been completed at GSFC and engineering models of these systems are currently being fabricated in Italy.

4.6 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.

4.7 Orbiting Wide-angle Light-collectors (OWL)

A collaboration led by Dr. Streitmatter is working on the design of an instrument for detecting the highest energy cosmic rays by observing from space the fluorescence light due to giant air showers produced when particles with energies greater than 10^{20} eV interact with the atmosphere. OWL is in the NASA mid-term Strategic Plan. At GSFC, work on computer simulation of the OWL baseline instrument has been carried out by Dr. Krizmanic. The simulation code has been significantly upgraded and now includes: a sophisticated physics model for atmospheric interaction and cascade development; the fluorescence photon spectrum; dark-sky UV background; atmospheric effects including a model atmosphere, Rayleigh scattering and ozone absorption. The instrument simulation includes photocathode spectral response, with Poisson fluctuated photoelectron detection; trigger modes involving multiple pixels; reconstruction of events using the stereoscopic event generation information from two satellites. As a result of this effort, the baseline OWL has evolved toward larger effective apertures, of the order 4×10^5 km^2 sr. The OWL collaboration includes groups and individuals from GSFC, Columbia, NASA/MSFC, University of Alabama, U. of Utah, UCLA, Washington U. in St. Louis, and Vanderbilt.

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 1Hz 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 lowfrequency 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 $5x10^6$ km on a side. It is a NASA/ESA mission that is part of the NASA SEU roadmap for the latter half of the next decade. Dr. Merkowitz joined Goddard in Sept., 2000 and is currently working on characterizing the micro-newton thrusters that will be part of the LISA Disturbance Reduction System. Prof. Centrella of Drexel U. joined Goddard in April, 2001 and is instituting a program in numerical relativity. Part of her effort will involve modelling gravitational radiation wave forms of the sort that LISA might detect. Dr. Stebbins from the U. of Colorado joined Goddard in May 2001 and has become the LISA Project Scientist.

4.9 SWIFT

The Swift gamma-ray burst MIDEX proposal was selected by NASA October 14, 1999. It will fly in September 2003 for a nominal three 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 $\sim$300 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 PI, Dr. White is the Science Working Group Chair and Dr. J. Nousek is the lead scientist at Penn State. Key hardware contributions are made by international collaborators in the UK and Italy. The mission has passed its Critical Design Review and is proceeding to hardware fabrication.

4.10 The Heavy Nuclei Explorer(HNX)

Dr. Barbier is the NASA lead Co-investigator on the successful Small Explorer proposal for the Heavy Nuclei Explorer (HNX). HNX (Dr. R. Binns, Washington U., St. Louis, PI) 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 study will last until November 2001 at which time a report will be submitted for review. Two missions will be selected for flight.

HNX is a shuttle launched and retrieved free-flyer and 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 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).

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

5.1 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 (LHEA) and the Associate Director is Dr. S. Murray (CfA). HEASARC provides the astrophysics community access to archival data from extreme-ultraviolet, X-ray, and gamma-ray missions. In order to provide the maximum 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., WebSPEC, a tool for simulation of X-ray spectra) and also for more general astronomical purposes (e.g., WebNH, a tool to calculate the galactic hydrogen column density in any direction).

Highlights from the past 12 months of HEASARC operation include (i) a total volume of archival data reaching 2.4 Terabytes (TB), (ii) record annual amounts of data downloaded by users via anonymous ftp (2.1 TB) and of images, webpages, and data downloaded via the Web (1.3 TB), (iii) a record 670,000 queries to the HEASARC's multi-mission database and catalog Web service, Browse, which now contains more than 300 tables, (iv) continued heavy usage (more than 400,000 images served to users) of the Web-based SkyView facility (a tool which allows users to display images of selected portions of the sky in various projections and in any of a wide range of wavelengths based on a large number of existing large-area surveys which it incorporates); (v) the opening in January 2001 of the US XMM-Newton Data Archive, the volume of which had reached 56 Gigabytes (GB) of public and proprietary data by June 2001; (vi) the continuing export of copies of the ASCA Data Archive to the U. Leicester (UK), the BeppoSax Data Center (SDC) in Italy, the European Space Agency XMM-Newton facility at ESTEC, and the Integral Data Center in Switzerland; (vii) the continuing ingest of BeppoSAX Narrow-Field Instrument (NFI) data from the SDC; (viii) the creation of a mirror archive at the HEASARC of the HETE-2 Raw Data Archive at MIT, the data in which will start becoming available to the public in early 2002; (ix) the completion of the move of the HEASARC's data holdings from magneto-optical jukeboxes to more fail-safe RAID (Redundant Array of Inexpensive Disks) system; (x) a major revamping of the HEASARC's Browse Web software that will allow access to thousands of tables maintained at the Strasbourg Astronomical Data Center (CDS); (xi) the continuing AISRP-funded development of a Web software package, dubbed Hera, which will provide all the capabilities of the current HEAsoft package (which combines the previously separate FTOOLS and XANADU software) in a Web interface, thereby enabling users to seamlessly browse for data in the HEASARC archive, and then to immediately reduce and analyze the data using the same integrated Web interface; and (xii) the commencement of another AISRP-funded effort called ClassX to develop a prototype National Virtual Observatory (NVO) utility, namely 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 criteria.

5.2 X-Ray Quantum Calorimeter (XQC) Sounding Rocket Program

Drs. Porter, Szymkowiak, Kelley, Stahle, Figueroa-Feliciano with Prof. D. McCammon and other collaborators at U. Wisconsin-Madison, have been developing high resolution, high throughput X-ray spectrometers for astrophysical observations. The techniques on which we have been focusing involve single photon calorimetry, which requires cryogenic operation. One important testbed for this technology has been our X-ray Quantum Calorimeter (XQC) sounding rocket payload.

On March 28th, 1999, we flew this payload from the White Sands Missile Range, configured to observe a $\sim$1 sr section of the soft diffuse X-ray background. The instrument functioned well, and we were able to collect data from all 34 active detectors. We have been refining the data analysis from this flight and finalizing the results for submission to ApJ. The results from this flight show, for the first time, bright line emission from H-like O VIII, He-like O VII, and H-like C VI. We see no evidence for either L shell Fe emission from Fe XVII, XVIII or higher charge states or M shell emission from Fe IX,X below 100 eV. This suggests a low Fe abundance relative to solar. Finally, irrespective of global fitting, the line emission alone is sufficient to constrain the diffuse emission from intergalactic diffuse gas. This constraint can be greatly improved by further observations.

We are planning to fly the experiment again in the next year with an improved detector system. The goal is to increase the collecting area by a factor of 4 by moving from 34, 1 mm^2 detectors to 34, 4 mm^2 with improved resolution. A new type of "deep" implant semiconductor calorimeter developed in our laboratory during the past year shows greatly improved noise performance which limited the resolution of both the sounding rocket and Astro-E/XRS detector systems. We will use our sounding rocket experiment as a test bed for these new detectors, and will acquire unique data on the soft X-ray background accessible to no other instrument.

5.3 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. We are also developing the instrument electronics that will be required for large arrays of microcalorimeters. Members of the LHEA microcalorimeter team include Drs. Boyce, Figueroa-Feliciano, Finkbeiner, Gendreau, Kelley, Lindeman, Porter, and Stahle. Dr. A. Szymkowiak recently left our group for a research position in the department of physics at Yale. Dr. Furusho (Tokyo Metropolitan U.) has received a fellowship from the Japanese Society for the Promotion of Science to work in our group for two years.

We are working on improving devices with ion-implanted Si thermometers and superconducting transition edge thermometers. The implanted Si detectors have near-term applications in our sounding rocket program, laboratory astrophysics with an electron beam ion trap, and possibly on a rebuild of the Astro-E mission. We have fabricated test devices 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. We are now characterizing these devices for thermal conductance, heat capacity and mechanical properties, after which we will design new arrays that are optimal for specific energy bands. It is anticipated that an energy resolution of $\sim$6 eV is achievable. We have also completed a 16 channel test facility for characterizing the implanted silicon microcalorimeters down to below 50 mK.

For the Constellation-X mission, an energy resolution of 2 eV at 6 keV and below is required in an array capable of $5'' - 10''$ imaging over a field of view of at least $2.5'$. This requires $\sim 250 \mu$m pixels in close-packed arrays that are of the order 30×30, 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, we are pursuing microcalorimeters with superconducting transition edge thermometers, or transition edge sensors (TES).

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, the energy resolution has been improved to 2.4 eV (FWHM at 1.5 keV) using a Mo/Au bilayer ($T_c \sim 100$ mK) on a low stress silicon nitride membrane.

We have achieved a significant breakthrough in the area of small pixel array technology. TES pixels designed to have a systematic range of thermal conductances have been fabricated and tested. Pixels with a 300 and 150 μm sensor area (appropriate for Constellation-X) and 5 μm beams spaced around the perimeter gave a suitably low thermal conductance. In fact, the thermal conductance is on the low side of optimal, which will allow an optimum pixel design to be realized that also has better mechanical properties.

5.4 Future Hard X-ray Detector Development

The research and development of new detector and optics technologies for future hard X-ray astrophysics instrumentation has long been an important endeavor in the LHEA. Drs. Parsons, Barbier, Barthelmy, Gehrels, Krimm, Teegarden and Tueller of the Low Energy Gamma-Ray Group (LEGR) have continued their highly successful technology development program to produce new cadmium zinc telluride (CdZnTe) and cadmium telluride (CdTe) detector arrays and focal plane sensors for balloon and spacecraft applications. Improvements in the availability of high quality room temperature semiconductors such as CdZnTe and CdTe have made it possible to produce large, convenient, light-weight detector arrays for hard X-ray imaging and spectroscopy. The advantages of CdZnTe and CdTe detectors include good energy resolution in the 5-300 keV energy range without the complexity of cooling and high-Z for greater stopping power with a thinner, more compact instrument. Working with Dr. C. Stahle and P. Shu in the GSFC Detector Systems Branch (Code 553), B. Parker in the Materials Engineering Branch (Code 541), and J. DuMonthier, J. Odom, M. Smith, and G. Winkert from the Microelectronics and Signal Processing Branch (Code 564), the LEGR group has developed the capability to design, process and package CdZnTe and CdTe detectors with Application Specific Integrated Circuits (ASIC) readout electronics for a variety of space applications. The packaging of the detectors and electronics for the 32,768 element ($5200 cm^2$) CdZnTe detector array for the Swift Burst Alert Telescope (BAT) is this team's current CdZnTe development task.

Detector systems fabricated in the past include double-sided CdZnTe strip detectors with 100 micron pitch that would allow fine (arcsecond) imaging of hard X-ray sources and gamma-ray bursts. A 6x6 array of such strip detectors has been assembled at GSFC with over 500,000 separate resolution elements. The LEGR group has also flown CdZnTe detectors at balloon altitudes to investigate the CdZnTe detector background dependence on the active shielding configuration. The baseline detector systems for many future missions described elsewhere in this report depend on detector technologies that were developed through this program. Examples include the BAT on the Swift Gamma-Ray Burst Explorer due for launch in September 2003; InFOCμS, a balloon-borne hard X-ray focusing telescope; and the Hard X-ray Telescope for the Constellation-X program.

Future thrusts in the development of these technologies will be to improve spectroscopic performance throughout a more extended energy range (1-600 keV) with the use of both thicker CdZnTe detectors and stacked Si and CdZnTe detector arrays. As the angular resolution of hard X-ray optics improves, the trend in the development of future hard X-ray focal plane sensors will also be toward finer pitch detector arrays with an increasingly large number of pixels that must be read out within a physically small space. Small ASICs provide each pixel with its own readout electronic circuit. One of the challenges of ASIC design is to fit the readout circuits with the required functionality into a space less than 400 microns square.

5.5 Micro-Well Pixel Proportional Counter Development

Imaging micro-well proportional counters 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. Micro-well detectors are one of a new generation of finely segmented, pixel proportional counters that exploit narrow-gap electrodes, rather than thin anodes, to achieve gas amplification. Work in the LHEA is concentrated on fabrication techniques and readout electronics that are readily extensible to large areas (thousands of square centimeters).

Micro-well detectors are a simple and inexpensive 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 μm pixel spacing having 85 μm 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% 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. To take full advantage of the micro-well as an electron tracker requires orienting the detector such that the tracks are basically parallel to the micro-well plane, so that the track is sampled at the frequency of the pixel spacing. This scheme, however, requires instrumenting the individual pixels to avoid ambiguities.

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 cm^2 micro-well arrays, 2) demonstrating thin, large-area, sealed silicon nitride windows, 3) modifying a readout system developed by MPE for double-sided silicon detectors. For electron tracking, a large area charge-integrating pixel readout based on thin-film transistors is being developed in collaboration with Penn State U.

5.6 Laboratory Astrophysics

We have assembled a microcalorimeter spectrometer 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.

This work is being carried out in collaboration with Dr. P. Beiersdorfer (LLNL) Prof. S. Kahn (Columbia). Our contribution to this work is being carried out by Drs. Boyce, Gendreau, Kelley, Porter, Brown, and Stahle.

Using this EBIT/microcalorimeter, we measure absolute cross sections for both direct electron impact excitation and dielectronic recombination, 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 measure X-ray emission from low energy charge exchange collisions. 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. 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.

The unit and instrument electronics were brought to the EBIT in the summer of 2000 and successfully operated for six weeks. A number of interesting results have already been obtained. Many of these were presented at the 2000 HEAD meeting held in Honolulu, and several papers are in preparation for publication. These include the measurement of excitation cross sections for n = 2 to 3 transitions from Fe XXIV (Chen *et al.* 2001), and an independent measurement of the Lyman alpha to Lyman beta ratio of oxygen. We are now operating the unit again with a new adiabatic demagnetization refrigerator that will improve the operating efficiency. This work will continue on other ionization states of iron and be extended to other astronomically important elements. We will also measure charge exchange processes in highly charges ions of C, N, Ne, Si and Fe.

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. We are also working to establish X-ray interferometry in a laboratory setting, aiming to achieve an ultimate angular resolution far beyond what specular reflection can offer.

The first telescope that can do imaging up to 40 keV is currently onboard the InFOCμS balloon flight at Palestine, Texas. This is the result of a collaboration between GSFC, ISAS, and Nagoya U. in Japan. The first flight is to be flown on July 2001. Drs. Serlemitsos and Owens are leading the work.

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 our 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. We expect the image quality of a completed telescope to 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 to seek 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)

InFOCμS is a balloon-borne instrument incorporating recent breakthroughs in hard X-ray focusing optics and detectors to achieve order of magnitude improvements in both sensitivity (100 μCrabs in 12 hours, 20 μCrabs for long duration ballooning) and imaging resolution (1 arcmin), with high-resolution spectroscopy (2 keV FWHM). Very low backgrounds achievable with this configuration will produce systematics-free results for very long, high sensitivity observations. Most traditional sources are so bright that background subtraction would be unnecessary. Exciting new results are expected, such as direct imaging of cosmic ray acceleration and nucleosynthesis (44Ti lines) in the Cas A supernova remnant and the first measurement of intergalactic magnetic field strengths by measuring the upscattering of the cosmic black-body radiation by electrons in the radio lobes of AGN. This international collaboration (Drs. Tueller, Barthelmy, Gehrels, Krimm, Palmer, Parsons, Petre, Serlemitsos, Stahle, Teegarden, White, and Mr. P. Shu at GSFC; Drs. H. Kunieda, Ogasaka, Y. Tawara, K. Yamashita at Nagoya U.; B. Barber, E. Dereniak, D. Marks, 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. Current activity includes analysis of Cyg X-1 observations from the first flight of InFOCμS in July 2001.

5.9 Gas Micro-Structure Detector SR&T

Drs. Black, Deines-Jones, Hunter have continued their development of large area, high spatial resolution, two-dimensional micro-well detectors (MWDs), a new type of gas proportional counter. These charge-sensitive detectors are being developed for astrophysical instrument applications requiring large area, low-power, two-dimensional position sensing and polarization sensitivity. The cathode of a MWD is raised above the anode, separated by a thin dielectric. The well, concentric with a hole in the cathode, is micro-machined through the dielectric to expose the anode. This electrode geometry allows for two-dimensional readout if the anode and cathode electrodes are segmented into orthogonal strips. The avalanche, or gas multiplication, region of the MWD is determined by the depth of the well. This aspect of the MWD geometry makes for a very robust, spark-tolerant construction. Further segmentation of the anode into pads allows for true pixel MWDs. The readout of a pixelized MWD requires an array of FET switches. The FET array for these detectors is being developed using thin film transistor technology at Pennsylvania State University. We have demonstrated 1) fabrication of 5 cm 5 cm detectors with 400 um pitch, 2) stable proportional operation at a gas gain $>$30,000 in Ar- and Xe-based gases, 3) ability to sustain repeated breakdown with no performance degradation, 4) nominal proportional operation and good electron collection efficiency with FWHM energy resolution of 20% with 6 keV X-rays, and 10% resolution with 20 keV, and 5) $<85 um$ X-ray spatial resolution.

5.10 Nightglow

The Nightglow balloon instrument (Dr. L. Barbier, PI) had an aborted around-the-world balloon flight from Alice Springs, Australia in February 2001. 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 is seen.

Nightglow was launched on February 24th, 2001 on a newly designed, long-duration balloon (nicknamed a ''pumpkin'' balloon because of its shape). The flight was terminated at an altitude of approximately 85,000 feet due to a leak in the balloon. The payload was recovered two days later, 115 nautical miles downrange. It suffered very little damage. The flight was supposed to take Nightglow around the world in about 20 days at a constant altitude of 110,000 feet. The instrument has been returned to the National Scientific Balloon Facility in Texas and is undergoing repairs. We hope to attempt another around-the-world flight in December 2002.

5.11 Gamma Ray Burst Coordinates Network (GCN)

The GRB Coordinates Network (GCN), operated by Dr. Scott Barthelmy of GSFC, 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 routine during the GRO-BATSE years 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 BeppoSAX or RXTE. Currently, the GCN system distributes Notices to 204 locations involving over 350 researchers. These include 55 locations with 75 instruments: 34 optical, 12 radio, 16 gamma-ray, 7 x-ray, 3 gravity wave and 3 neutrino. Also, these include 11 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 2001 June 01, 1063 Circulars were distributed to a list of 520 recipients. At present, about 600 follow-up observations have been made using GCN Notices for about 450 bursts.

5.12 Public and Education Outreach

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

During this time, the redesign of the Imagine the Universe! education web site was completed. C. Wanjek writes news of discoveries from Chandra, Newton, RXTE, and other missions which are posted on the site monthly. We also continue our series of profiles of Lab scientists and special exhibits on science results from other SEU missions such as CGRO and MAP. We prepared and released the 5th edition of the Imagine the Universe! CD-ROM, containing a capture of the Imagine web site, as well as StarChild and Astronomy Picture of the Day for the year 2000. This CD-ROM is distributed free upon request, at teacher conferences, and via NASA CORE.

Working with Ms. L. Williamson and Ms. E. Fitzhugh (Drew-Freeman MS) we produced the next in our series of posters and information/activity booklets with a set entitled ‘‘The Hidden Lives of Galaxies,’’ which discusses optical and X-ray properties of galaxies, and the hidden mass problem. New to this set is a set of transparencies for use with some of the classroom activities.

Under the direction of Ms. Jacob, we also prepared the second edition of our ‘‘Exploring the Extreme Universe’’ CD-ROM, a collection of LHEA mission web pages and other education web sites, such as The Cosmic and Heliospheric Learning Center, the RXTE Learning Center, and the Cosmic Distance Scale. Among its uses in the scientific and education communities, this CD-ROM is used as part of the Earth and Space Science curriculum in a local Maryland school district.

The LHEA outreach group continues to support the Structure and Evolution of the Universe Theme at a variety of educational and scientific meetings, including the National Science Teacher’s Association National and Area meetings, the Science Teachers of New York State annual conference, American Astronomical Society and its High Energy Astrophysics Division meetings, and numerous smaller educator workshops. We staff exhibit booths and present workshops on using our CD-ROM, the ‘‘Hidden Lives of Galaxies’’ materials, and our ‘‘Life Cycles of Stars’’ materials.

We also continue 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.

5.13 Workshops

During October 5-6, 2000, Dr. Stecker, together with Dr. D. Cline (UCLA) ran a workshop at Goddard on the science of ultrahigh energy cosmic rays in preparation for the OWL (Orbiting Wide-angle Light collectors) project (see 4.7 in this report). The stress was on how to determine the origin of ultrahigh energy hadrons, i.e., protons and heavy nuclei.

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