NASA Goddard Space Flight Center
Laboratory for High Energy Astrophysics
Greenbelt, Maryland 20771

This report covers the period from July 1, 2002 to June 30, 2003.

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 George Washington U., ISAS in Japan, 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. Dr. Frank Jones served as interim laboratory chief during Dr. White's six-month detail to NASA Headquarters.

The civil service scientific staff includes: Drs. Louis Barbier, Scott Barthelmy, Elihu Boldt, Kevin Boyce, Jordan Camp, Joan Centrella, Thomas Cline, Enectali Figueroa-Feliciano, Keith Gendreau, Alice Harding, Robert Hartman, Stanley Hunter, Keith Jahoda, Frank Jones, Timothy Kallman, Demosthenes Kazanas, Richard Kelley, Frank Marshall, Tom McGlynn, 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 following scientists are National Research Council Associates: Drs. John Baker, Peter Bloser, Gregory Brown, Analia Cillis, Jean Cottam, Markos Georganopoulos, Kenji Hamaguchi, Timothy Hamilton, Thomas Hams, Kouichi Hirotani, Claudio Mendoza, Tarek Saab, 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, Robin Corbet, Michael Corcoran, Jay Cummings, Georgia de Nolfo, Fred Finkbeiner (SSAI), Philip Deines-Jones, Stephen Drake, Ilana Harrus, Stephen Henderson, Hans Krimm, John Krizmanic, Jeongin Lee, John Lehan, James Lochner, Thomas McGlynn, Paul McNamara, Alex Moiseev, Koji Mukai, James Reeves, Nadine Saudraix, Chris Shrader, Steven Snowden, Yang Soong, Martin Still, Steve Sturner, and Vigdor Teplitz.

The following investigators are University of Maryland Scientists: Drs. Keith Arnaud, David Band (UMBC), Simon Bandler, Patricia Boyd (UMBC), John Cannizzo (UMBC), David Davis (UMBC), Ian George (UMBC), Masaharu Hirayama (UMBC), Una Hwang, Yasushi Ikebe (UMBC), Kip Kuntz (UMBC), Mark Lindeman, Michael Loewenstein, Craig Markwardt, Julie McEnery (UMBC), Igor Moskalenko (UMBC), Chee Ng, Patrick Palmeri, Dirk Petry (UMBC), Christopher Reynolds, Ian Richardson, and Jane Turner (UMBC).

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

Graduate Students doing their thesis research in this Laboratory are: from the U. of Maryland, Wayne Baumgartner, David Fiske, Derek Hullinger, Breno Imbiriba, Barbara Mattson, Giridhar Nandikotkur, Luis Reyes, Andy Tillotson, and David Wren; from ISAS in Japan, Goro Sato; and from George Washington U., Alaa Ibrahim.

2. RESEARCH PROGRAMS

2.1 Sun and Solar System

The relative roles of resonant stochastic acceleration in flares and shock acceleration by CME-driven shocks in producing solar energetic particle (SEP) events is undergoing active debate. Events dominated by the former are known as impulsive events, whereas events dominated by the latter are known as gradual events. The issue is to what extent events exist which are hybrids of the two. The GSFC Low Energy Cosmic Ray Group has recently contributed to both sides of this argument. It had been expected, based on shock acceleration theory and the fact that Fe is only partially stripped of its electrons, that gradual events would have Fe/O rolling off at higher energies. Observations from ACE/SIS have shown, however, that many apparently gradual events have Fe/O above the solar system value at high energies, whereas others show the expected Fe/O roll-off. Various means have been invoked to resolve this issue, including measurements of velocity dispersion of electrons and heavy ions and the possibility of remnant particles from preceding impulsive events being injected into interplanetary shocks. This topic will soon be addressed by the ACE/WIND/RHESSI Workshop.

Dr. Snowden with Drs. M. Collier (Code 692) and I. Robertson (U. Kansas) studied the soft X-ray background produced in the solar system by charge exchange between the solar wind and interstellar atoms. This was the dominant non-cosmic background observed by *ROSAT* in the $\frac{1}{4}$ keV band, and could reach levels equal to or exceeding those of the cosmic background. By understanding the temporal history of this emission (referred to as long-term enhancements, LTEs) an estimate of the residual unmodeled and therefore unsubtracted background of the *ROSAT* All-Sky Survey can be derived.

Drs. Reames and Ng studied, for the first time, angular distributions of energetic Fe and O ions in large solar energetic-particle events. They found that the distributions required reflections of the ions in magnetic ‘‘bottles’’ extending out beyond Earth. Drs. Ng and Reames collaborated with Dr. Tylka (NRL) to produce an extensive model of particle acceleration at shock waves and their transport through self-generated Alfven waves in the inner heliosphere.

2.2 Stars

Dr. Corcoran helped organize a worldwide observing campaign to monitor the extremely massive, luminous star Eta Carinae during its X-ray eclipse in mid-2003. Dr. Corcoran led the monitoring of the X-ray emission variations using the *Rossi XTE*, *Chandra*, and *XMM-Newton*. Drs. Corcoran and Kallman with Drs. B. Boroson and S. Vrtilek (CfA) analyzed X-ray grating spectra from *Chandra* of the X-Ray binary 4U 1700-37 in a flaring state. Dr. Corcoran with Drs. A. Naze and J. Manfroid (IAG, U. Liege), J. Hartwell and I. Stevens (U. Birmingham), S. Marchenko (Western Ky U.), and A. Moffat, and G. Skalkowski (U. Montreal) published their investigation of the X-ray emitting field population near the NGC 346 cluster in the Small Magellanic Cloud.

Drs. Hamaguchi and Corcoran with Dr. K. Imanishi (Kyoto U.) analyzed two sets of *Chandra* data of the young B3 star Rho Oph S1, which has polarized radio nonthermal emission. Both spectra do not show any apparent line emission, and therefore the metal abundance is less than 0.1 solar if they fit the spectra by an absorbed thin-thermal model. The spectra can be reproduced by an absorbed power-law model, as well. They discussed the possibility to make a small abundance plasma, or non-thermal X-ray emission.

2.3 Galactic Binaries

Dr. Mukai with Drs. A. Kinkhabwala, J. Peterson, S. Kahn, and F. Paerels (Columbia U.) studied the *Chandra* HETG spectra of seven cataclysmic variables. These spectra are unambiguously divided into two distinct types. One type can be fitted with a simple cooling flow model, first developed for clusters of galaxies; the other exhibit a hard continuum and low energy lines that are characteristics of photoionized plasma.

Dr. Mukai with Drs. C. Hellier (Keele U.), G. Madejski (SLAC), J. Patterson (Columbia U.), and D. Skillman (Center for Backyard Astrophysics) performed a series of *Rossi XTE* observations of the magnetic cataclysmic variable, V1432 Aql, and the Seyfert Galaxy, NGC 6814, separated on the sky by $\sim 37'$. Combining these and archival X-ray data, NGC 6814 is shown to be X-ray bright on many occasions and highly variable, suggesting a Narrow-line Seyfert 1 subclassification. They were also able to settle the debate over the nature of the deep dips seen in V1432 Aql: they are due to eclipses by the secondary. Moreover, they were able to use the high quality eclipse light curves to place constraints on the size and the apparent motion of the accretion regions on the white dwarf surface.

Dr. Ebisawa with Drs. P. Zycki (Copernicus Center), A. Kubota (ISAS), T. Mizuno (Stanford) and K. Watarai (Kyoto U.) studied accretion disk spectra of the Ultra-Luminous X-ray sources (ULXs) in nearby spiral galaxies and Galactic superluminal jet sources. These sources share the same spectral characteristics such that the accretion disk disk temperatures are significantly higher than accretion disks of ordinarily Galactic black hole candidates. They pointed out that the inclined Kerr disk, not Schwarzschild disk, may explain the hard spectra of Galactic superluminal jet sources. On the other hand, ULXs are explained as slim disk (advection dominant optically thick disk) shining at super-Eddington luminosities around a few tens of solar mass black holes. ‘‘Intermediate mass black holes’’ are not required to explain the high luminosity of ULXs.

Drs. Angelini and White analyzed the *XMM-Newton* data of the LMXB and black hole candidate 4U1755-33 to study the quiescent phase. The source was not detected with an upper limit of the luminosity $5\times10^{31} d^2_{4kpc}$ ergs s^{-1} in the $2-10$ keV band, consistent with other black hole candidates in quiescent state. An unexpected result is the discovery of a narrow $7'$ long X-ray jet centered on the position of 4U1755-33. The spectrum of the jet is similar to that of jets observed from other galactic and extragalactic sources, and may have been ejected from 4U1755-33 when it was bright. Jets are a feature of accreting black holes, and the detection of a fossil jet provides additional evidence supporting the black hole candidacy of 4U1755-33.

Dr. Arzoumanian with Drs. E. Splaver and D. Nice (Princeton U.), F. Camilo (Columbia U.), A. Lyne (U. Manchester), and I. Stairs (NRAO) reported on continued pulse timing measurements of the binary radio pulsar system J0621+1002. Chief among their results was a measurement of the masses of the neutron star (1.7 $M_\odot$) and its white-dwarf companion (0.97 $M_\odot$). The large neutron star mass value supports the prevailing scenario for the formation of rapidly-rotating pulsars through spin-up during accretion in a low-mass X-ray binary phase. Other results included the first estimates of the pulsar’s age and magnetic field, and a measurement of the systemic proper motion, all of which constrain the binary system’s origin.

Dr. Strohmayer with Dr. E. Brown (U. Chicago) have studied the spectrum and energetics of a ‘‘superburst’’ from the low mass X-ray binary (LMXB) 4U 1820-30 observed with the proportional counter array (PCA) onboard the *Rossi XTE*. This burst released upwards of 10^{43} ergs of energy in a thermonuclear event which likely involved a 10^{24} gram layer of carbon deposited after several years of accretion and subsequent thermonuclear processing. Steady helium burning when the accretion luminosity is high, and no normal, short bursts are observed, is the likely source of most of the carbon required for the explosion. Perhaps most of the energy involved escapes detection as neutrinos or is conducted into the star and released over timescales longer than the 3–4 hour burst duration. Discrete spectral components, including an Fe K emission feature and accompanying edge were observed throughout the burst and likely result from reprocessing of the thermal burst flux off of the accretion disk in 4U 1820-30.

Dr. Strohmayer has been exploring the X-ray timing of the two candidate double degenerate binaries; RX J1914.4 +2456 and RX J0806+1527, with archival *ROSAT*, *ASCA*, and new *Chandra* observations. The archival *ROSAT* and *ASCA* data indicate that the X-ray frequency of the system is increasing at a rate consistent with the loss of gravitational radiation from a system with the size inferred if the X-ray period is indeed the orbital period. The observed frequency increase is not expected if the system is powered in the X-ray by accretion onto a degenerate secondary. A model which can account for the frequency increase attributes the X-ray flux to an electric current driven by a slight asynchronicity between the orbital and rotation rates of the stars. Long term monitoring of the X-ray period combined with future, direct observations, with LISA, of the gravitational wave signal will both confirm the compact nature of the sources and provide powerful new ways to study compact binary evolution.

Drs. Cannizzo and Gehrels, with Dr. J. 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. Shrader and Titarchuk have undertaken a study to model the broad-band high-energy continuum of low-hard State Galactic black holes in the context of Comptonization in a wind outflow. An analytic model has been developed, coded, and imported into the ''XSPEC'' spectral analysis package for application to observational data. Thus far, preliminary results based on observational data from RXTE, CGRO and publicly available data from the INTEGRAL spectrometer have been encouraging.

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, has been 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. In addition, algorithms and software have been developed to construct frequency-dependent spectra. In preliminary results, there appears to be a low-frequency component which peaks towards the highest energy channels.

Dr. Shrader, with Drs. R. Hynes (UT-Austin), C. Haswell (The Open University) and W. Cui (Notre Dame) are continuing to conduct a multiwavelength observational program to study bright X-ray nova outbursts. Target of opportunity programs are in place for RXTE, HST, and several ground-based facilities. In addition, Dr. Shrader, with Drs. Swank, Markwardt, and Gehrels, is involved with an INTEGRAL target of opportunity program for study of rising-phase X-ray nova outbursts.

2.4 Pulsars and Magnetars

Dr. Arzoumanian, with Drs. S. Chatterjee, J. Cordes, and W. Vlemmings (Cornell U.), M. Goss (NRAO), and J. Lazio (NRL) reported on the first pulsar astrometry carried out at 5 GHz with the Very Long Baseline Array – at this frequency, ionospheric and tropospheric effects are mitigated, but the typical steep radio spectrum of pulsars poses significant challenges. Parallaxes and proper motions for two objects, PSRs B0355+54 and B1929+10, were derived. The resulting distance estimates provided new insights into the high-energy emissions of these pulsars: they imply an emitting area for thermal X-rays from B1929+10 consistent with the canonical size of a heated magnetic polar cap, and require that the gamma-ray luminosity of B0355+54 must be low, consistent with predictions that its beam is directed away from our line of sight.

Dr. Arzoumanian with Drs. D. Lorimer and M. McLaughlin (U. Manchester), K. Xilouris (U. Va), J. Cordes (Cornell U.), A. Lommen (Franklin & Marshall College), A. Fruchter (STScI), A. Chandler (Caltech), and D. Backer (UC Berkeley) reported the discovery and initial timing observations of a new 55.7 ms pulsar, J0609+2130. Its relatively weak magnetic field suggests that this pulsar had its origin in a high-mass X-ray binary system that was disrupted by the supernova explosion of the mass donor star.

Drs. Strohmayer, Markwardt, and Swank with Dr. in't Zand (SRON/Utrecht), have studied a sample of X-ray bursts from the recently discovered accreting millisecond pulsar XTE J1814-338. This pulsar has a 314.4 Hz spin frequency. A total of 27 thermonuclear bursts were observed during an extensive *Rossi XTE* monitoring campaign in June and July, 2003. All the bursts show coherent oscillations (burst oscillations) at the known spin frequency. The frequency and phase of the burst oscillations is locked to that of the persistent pulsations. It seems likely that this phasing results from the magnetic field of the neutron star. The large oscillation amplitude during bursts confirms that the burst flux is spin modulated. This is only the second pulsar to show burst oscillations at the known spin frequency (SAX J1808.4-2456 being the other). For the first time, significant harmonic structure is detected in burst oscillation pulse profiles. The strength of the harmonic suggests that the burst flux may be beamed, perhaps a result of a magnetic field stronger than that found in non-pulsing low mass X-ray binaries.

Dr. Harding with Dr. A. Muslimov (DoD) are developing a physical model for particle acceleration and high-energy emission from the pulsar Slot Gaps (SGs). Preliminary study of primary acceleration, generation of electron-positron pairs, and gamma-ray emission fron SGs shows that theoretical high-energy luminosities of pulsars are in good agreement with the corresponding empirical relationships for gamma-ray pulsars. They are trying to investigate the possibility of particle acceleration and high-energy emission up to very high altitudes in SGs.

2.5 Supernovae and Supernova Remnants

Dr. Hwang with Dr. J. M. Laming (NRL) carried out studies of the explosion asymmetry and Fe nucleosynthesis in the Cassiopeia A supernova remnant using *Chandra* observations. They applied models that treat the supernova remnant hydrodynamics and the relevant atomic and plasma physics to compute measurable physical quantities for comparison to the observations and infer mass coordinates for the ejecta. This approach allowed them to constrain the density profiles of the ejecta in various azimuthal directions and interpret the results in terms of the implied directional asymmetry in the release of explosion energy. In the second part of this project, they identify a nearly pure Fe knot in the remnant as the site of complete Si-burning, and infer the mixing of Fe out from the innermost layers of the progenitor.

Drs. Hwang and Petre with Mr. G. Cassam-Chenai and Drs. A. Decourchelle, J. Ballet (Saclay), and J. Hughes (Rutgers U.) analyzed X-ray imaging and spectral data for Kepler's supernova remnant from the *XMM-Newton* observatory. The observations show the distribution of the Fe and Si line emission, and constrain the relative amount of nonthermal emission compared to thermal emission from the forward shocked gas.

Drs. Hwang and Petre with Drs. S. Holt (Olin C.), and E. Schlegel (CfA) studied the source population of the galaxy NGC 6946 using *Chandra* observations. They examined the correlation of the X-ray sources with sources at other wavelengths, and found the galaxy's ultraluminous supernova remnant to have an unusual spectrum devoid of the expected thermal line emission.

Drs. Kuntz and Petre with Dr. R. Shelton (JHU) have analyzed *Chandra* images of the Galactic mixed morphology supernova remnant W44 and have found that the X-ray emission profile is mediated by a radial change in depletion/abundance. They have found some confirmation of the entropy mixing (thermal conduction) model of mixed-morphology remnants, but have found no evidence for evaporating cloudlets.

Drs. Petre and Kuntz with Dr. R. Shelton (JHU) have analyzed a *Chandra* observation of PSR B1853+01 and its related wind nebula in W44. They convincingly separated the emission from the wind nebula ($\Gamma=2.2$) from that of the pulsar ($\Gamma=1.4$) and from that of the supernova remnant, and were thus able to calculate the physical properties of the wind nebula. Despite the high velocity of the pulsar and the peculiar morphology of the wind nebula, this wind nebula has properties typical of other pulsar wind nebulae.

Drs. Gehrels, C. Laird (U. of Kansas), C. Jackman (Lab. for Atmospheres, GSFC), and Cannizzo, together with B. Mattson and Dr. Wan Chen (Sprint) have completed a study of the effect of nearby supernovae on the ozone layer of the Earth. As first shown by Dr. 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 effects 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 Nicolaidis (U. of 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. Although this approach is limited and does not produce the apparent return to lighter elements that is observed at even higher energies, further work will take cognicence of the fact that the hadronic core of a typical air shower at shower maximum contains only a few percent of the energy. Furthermore, leading baryon effects must be included. The cosmic-ray group at the University of Utah has shown interest in this project and will contribute their expertise in air shower modeling. Jones will present this work at the 2th International Cosmic Ray Conference in Tsukuba in August of 2003.

Dr. Moskalenko with Drs. A. Strong (MPI-Extraterrestrischephysik, Germany), S. Mashnik (LANL), and J. Ormes (Code 600) used a realistic cosmic ray propagation code GALPROP to study secondary antiprotons in cosmic rays. The measured antiproton flux and boron/carbon ratio have been used to fix the diffusion coefficient and other propagation parameters. This led to a conclusion that the spectra of primary nuclei as measured in the heliosphere may contain a fresh local ''unprocessed'' component at low energies perhaps associated with the Local Bubble, thus decreasing the measured secondary to primary nuclei ratio. The independent evidence for supernova activity in the solar vicinity in the last few Myr supports this idea. The model reproduces antiprotons, boron/carbon ratio, and elemental abundances from H up to Ni ($Z\leqslant 28$). Calculated isotopic distributions of Be and B are in perfect agreement with cosmic ray data. The abundances of three ''radioactive clock'' isotopes in cosmic rays, ^{10}Be, ^{26}Al, ^{36}Cl, are all consistent and indicate a Galactic halo size ~ 4 kpc based on the most accurate data taken by the ACE spacecraft.

Dr. Moskalenko, with Drs. Strong (MPI, Germany) and Mashnik (LANL), made improvements of the cosmic ray propagation code GALPROP resulting in more accurate calculation of isotopic production cross sections. This allows for more reliable determination of the interstellar propagation parameters.

2.7 Black Hole Astrophysics

Dr. Centrella, Dr. Choi, B. Imbiriba and D. Fiske are applying the techniques of numerical relativity to carry out more refined gravitational wave source modeling. They have 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 are currently applying this code to studies of black holes, 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 binary black hole systems using a combined approach involving numerical simulation together with perturbation theory techniques in the regimes where they are applicable.

The X-ray dark nuclei of nearby bulge-dominated galaxies are quasar remnants harboring supermassive black holes. Drs. Hamilton, Boldt and Loewenstein have examined a sample of 149 such galaxies for their stellar velocity dispersions, bulge luminosities, color, and metallicity properties. From these they derive the associated bulge and black hole masses, as well as the age of each galaxy–the time since its last major merger. Due to accretion, the mass of the central black hole grows with galaxy age. By measuring this growth they expect to estimate the fraction of the present black hole mass gained from accretion occurring after (not during) the initial galaxy merger interaction.

2.8 Our Galaxy

Drs. Kuntz and Snowden are analyzing *XMM-Newton* spectra taken in the direction of Baade's Window and the Galactic Bulge. Although the spectra towards Baade's Window are quite complicated, due to multiple emission/absorption components along the line of sight, there is some evidence of a temperature gradient in the bulge.

Dr. Kuntz and Dr. R. Shelton (JHU) are analyzing *XMM-Newton* spectra taken along several lines of sight in order to characterize the thermal state of hot gas in the Local Hot Bubble and the Galactic Halo. These lines of sight have complementary FUSE observations of O VI.

2.9 Normal Galaxies

Drs. Kuntz and Snowden have analyzed a deep *Chandra* observation of the diffuse X-ray emission from M101. They found that the emission traces the star formation in the spiral arms. In accord with recent theoretical work, find no evidence for an axisymmetric X-ray halo, at least at radii greater than 7 kpc. The spectrum of the diffuse emission does not change significantly with radius or surface brightness, indicating that the relative mixture of emission components is the same throughout the disk.

Drs. Kuntz, Snowden, Mukai, and Pence have embarked on a program to identify the optical counterparts of X-ray point sources in M101 using deep BVI images from the HST ACS. The current *Chandra* observations allow detection of sources to $\sim 10^{36}$ ergs s^{-1} (i.e., all HMXB and many LMXB) and scheduled *Chandra* observations will push the detection limit lower by a factor of at least three, to include most of the LMXB. The HST data will allow detection of nearly all the X-ray emitting background AGN, the HMXB with O and early B companions, and LMXB in globular clusters. The optical identification of X-ray sources is crucial to understanding the population of point sources and tracking the star formation history of M101, with obvious implications for the Milky Way.

XMM-Newton's EPIC detectors were used by Drs. Strohmayer and Mushotzky to discover the first quasiperiodic oscillation (QPO) in an ultra-luminous X-ray source (ULX) in an external galaxy. The source is in the starburst galaxy M82. The QPO had a centroid frequency of 54.3 1 0.9 mHz, a coherence of about 5, and an amplitude (rms) in the 2–10 keV band of 8.5%. The X-ray spectrum requires a curving continuum, with a disk blackbody at T = 3.1 keV providing an acceptable fit. A broad Fe line centered at 6.55 keV is required in all fits, but the equivalent width is sensitive to the continuum model. It appears likely that the QPO is associated with the most luminous object in the central region of M82, CXO M82 J095550.2+694047; however, *XMM-Newton* imaging alone is not sufficient to unambiguously confirm this. Although galactic black hole candidates can sometimes show QPOs with a similar frequency, we argue that the presence of QPOs and an Fe line suggest beaming cannot be very significant. Given the factor of 50–100 in the luminosity compared to galactic black hole sources, the evidence against beaming argues for an intermediate mass black hole as the source of the QPO.

2.10 Starburst Galaxies

Dr. Weaver with Drs. M. Dahlem (ESO), M. Ehle, F. Jansen (ESTEC), T. Heckman, and D. Strickland (JHU) published a study of the hot gas in the halo of the starburst galaxy NGC 1511. *XMM-Newton* data reveal the presence of a previously unknown extended hot gaseous phase of its ISM, which partly extends out of the disk plane. The emission distribution is asymmetric, being brightest in the eastern half of the galaxy, where also radio continuum observations suggest the highest level of star formation. Together with the X-ray data, *XMM-Newton* obtained UV images of NGC 1511, tracing massive stars heating the ambient gas, stars heating the ambient gas. UV, Hα and near-infrared imagery suggest that NGC 1511 is disturbed, most likely by its two small companion galaxies.

2.11 Active Galaxies

Dr. Hamilton with Drs. S. Casertano (STScI) and D. Turnshek (U. Pittsburgh) have found a fundamental plane for nearby quasars. This plane is a relationship between a quasar host galaxy's effective radius and effective surface magnitude and the nuclear luminosity (in either optical or X-ray bands). Within the phase space formed by these three parameters, quasars are found to lie within a thin plane. This plane appears to have different slopes for different classes of quasars, and it may be that the slope is a characteristic of the particular black hole fueling mechanism for each class. The equation of the plane explains 95% of the variance in the overall sample, and the versions of the plane for different classes of quasars can explain as much as 98% of the subsample variances. Dr. Hamilton has found a similar relationship for Low-Luminosity Active Galactic Nuclei, and work is continuing to discover if this rule applies to other classes of active galaxies as well.

Dr. Reeves with Drs. P. O'Brien and M. Ward (U. Leicester) analyzed the *XMM-Newton* observation of the most luminous nearby quasar, PDS 456. The hard X-ray spectrum of PDS 456 exhibited a series of blue-shifted Fe K-shell absorption edges, whilst the RGS spectrum displayed a blend of L-shell Fe lines. An outflow velocity of 50000 km s^{-1} and a column density of 10^{24} cm^{-2} were required to model the absorber. A mass outflow rate of 10 solar masses per year was calculated, the kinetic energy of the flow being a substantial fraction of the total bolometric output of the quasar. This represented one of the largest AGN outflows known, placing PDS 456 towards the most extreme end of the broad absorption line quasar population.

Dr. Reeves with Dr. D. Porquet (MPE) discovered an unusually strong and broad iron line in luminous quasar Q0056-363 with *XMM-Newton*. The was found to originate from low ionization iron, with a velocity width of 25000 km s^{-1}, correspond to a radius of 30 gravitational radii from a supermassive black hole, of mass $>10^8$ solar masses. Q0056-363 was found to be the most luminous AGN known to exhibit such a broad and intense Fe Kα line profile from near neutral iron. It was found that a patchy hard X-ray corona covering a large part of the inner disk surface is needed to reproduce the X-ray spectrum of Q0056-363.

Dr. Weaver with Drs. N. Levenson (U. Kentucky), J. Krolik and T. Heckman (JHU), P. Zycki (Copernicus Astronomical Center), H. Awaki (Ehime U.) and Y. Terashima (ISAS, UMd) published a study of *Chandra* observations of heavily obscured active galaxies, concentrating on the iron Kα fluorescence line. The large equivalent widths suggest that the geometry of an obscuring torus of material near the active galactic nucleus determines the Fe emission. Active galaxies with starbursts require small torus opening angles and generally present few direct lines of sight to their central engines.

Drs. Weaver and Mushotzky with Drs. E. Colbert and J. Krolik (JHU) and J. Mulchaey (Carnegie Observatories) published a study of the X-Ray reflectors in the nucleus of the Seyfert galaxy NGC 1068. They reported a flare in the 6.7 keV Fe K line while other line components (6.21, 6.4, and 6.97 keV) remained steady. The X-ray data indicate that the 2-10 keV continuum emission is dominated by reflection from a previously unidentified region of warm, ionized gas located less than or equal to 0.2 pc from the central AGN. The properties of the warm reflector are most consistent with an intrinsically X-ray-weak AGN. The optical and UV emission that scatters from the warm reflector is required to suffer strong extinction, which can be reconciled if our line of sight skims the outer surface of the obscuring torus.

Dr. Stecker has continued work of the absorption of very high energy gamma-rays by pair production interactions with intergalactic IR, optical and UV photons. This work has led 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 Dr. 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 have applied the bulk-motion Comptonization model and physical parameter estimation mehods to a subclass of AGN, the narrow-line Seyfert-1 galaxies (NLS1s). The NLS1s are known to exhbit unusually steep X-ray spectra and rapid, energy-dependent variability. It has been speculated that they may represent the extragalactic analog of the high-soft spectral state seen in Galactic black-hole X-ray binaries where the soft X-rays. Preliminary evidence suggests that the central object masses in NLS1s may typically be lower than those of the broader Seyfert subclass. Similar work on the apparent new class of accreting ''intermediate mass'' black holes, using data with improved spatial resolution has also been undertaken.

2.12 Gamma Ray Bursts

Dr. Reeves with Drs. D. Watson, J. Hjorth, P. Jakobsson and K. Pedersen (U. Copenhagen) discovered delayed X-ray line emission from Mg, Si, S, Ar, and Ca in the X-ray afterglow of Gamma Ray Burst 030227. The lines appeared in the last 10 ks of an *XMM-Newton* follow-up observation, twenty hours after the burst event. The line emission was found to contain twice as many detected photons as any previous detection of GRB X-ray lines. There was no evidence for Fe, Co or Ni – the ultimate iron abundance being a tenth that of the lighter metals. A continuing, sporadic power output after the burst, of 5×10^{46} ergs s^{-1}, was required to power the X-ray line emission, if the burst and supernova events occur simultaneously.

Drs. Band, Norris and Bonnell have constructed a burst database with redshifts, peak fluxes and spectra using the lag-luminosity relation. A key question is whether this relationship should be modified to include the sub-luminous GRB980425; such a modification results in a population of nearby, low luminosity bursts. Different luminosity functions can be tested with this database.

Dr. Band has been comparing the burst detection sensitivities of different detectors using the threshold peak flux (integrated over a fiducial energy band) as a function of the spectral hardness. Comparisons between detectors show that CZT-based detectors (e.g., Swift and EXIST) will be significantly more sensitive to soft bursts compared to scintillator-based detectors (e.g., BATSE).

Drs. Band, Norris and Bonnell have been developing burst trigger algorithms for GLAST's LAT detector that use both spatial and temporal information. With GLAST's GBM team Dr. Band is performing trade studies for the GBM's burst trigger.

Drs. Cannizzo and Gehrels, with Dr. E. Vishniac (JHU) studied the evolution of a relativistic blob propagating through a uniform medium, as representing a ''fireball'' that produces a gamma-ray burst. This project was carried out by utilizing a 3D relativistic hydrodynamics code written by Cannizzo. The primary finding was that the material in front of the blob does not adhere to it, and therefore the decelerating power of the circumstellar medium through which the blob propagates must be greater than inferred by previous workers.

2.13 Clusters

Drs. Mushotzky, Figueroa-Feliciano, Loewenstein, and Snowden derived the temperature, density, entropy, gas mass, and total mass profiles for groups of galaxies out to one-third the virial radius from *XMM-Newton* spatially resolved X-ray imaging spectroscopy. They find a diversity of mass-fractions and entropy profiles that are indicative of a complex thermal history in the intracluster medium involving both cooling and heating.

Mr. Baumgartner and Drs. Loewenstein and Mushotzky with Dr. D. Horner (Amherst U.) derived the average abundances of intermediate elements (including Fe, Si, S, Ar, Ca, and Ni) in the intracluster medium on various cluster mass scales by performing a stacked analysis of all the galaxy clusters in the *ASCA* archive. In general, Si and Ni are overabundant with respect to Fe, while Ar and Ca are very underabundant. It is found that ''alpha'' elements do not behave homogeneously as a single group, and that the abundance patterns are not consistent with any combination of Type Ia and Type II supernova having standard yields. An additional source of metals, most plausibly explosions of massive and/or metal-poor primordial stars may be required.

Drs. Davis and Mushotzky are currently analyzing a long 53 ksec XMM observation of the NGC 2300 group. The XMM observations of this group confirm that the hot gas in the group has very low elemental abundances. The high throughput of XMM allows spatially resolved spectra to be extracted. These data show that the group gas is isothermal and has a flat abundance profile. These spectra also allow us to determine the 3-dimensional structure of the hot gas which includes the entropy profile of the gas. Using this information we can constrain the theories of group formation and investivate the origin of the diffuse gas

2.14 Instrumental Background

Dr. Kuntz is analyzing the temporal and spatial variation of the spectral shape of the *XMM-Newton* EPIC particle background. The particle background is composed of a ''quiescent'' component that varies over periods of months, as well as a ''flare'' component. He is analyzing the background data for all publicly available *XMM-Newton* observations to construct a tool that will allow the removal of both components of the particle background from observations of diffuse emission. This project continues similar work done by Dr. Kuntz with the *Chandra* background.

2.15 Theoretical Astrophysics

Drs. Palmeri and Kallman with Drs. C. Mendoza and M. Bautista (IVIC, Venezuela) have carried out calculations of the decay properties of the fine-structure K-vacancy levels in Fe X-Fe XVII. A large set of level energies, wavelengths, radiative and Auger rates, and fluorescence yields has been computed using three different standard atomic codes, namely Cowan's HFR, AUTOSTRUCTURE and the Breit-Pauli R-matrix package. This multi-code approach is used to study the effects of core relaxation, configuration interaction and the Breit interaction, and enables the estimate of statistical accuracy ratings. The Kα and KLL Auger widths have been found to be nearly independent of both the outer-electron configuration and electron occupancy keeping a constant ratio of 1.53+/-0.06. By comparing with previous theoretical and measured wavelengths, the accuracy of the present set is determined to be within 2 mÅ . Also, the good agreement found between the different radiative and Auger data sets that have been computed allow us to propose with confidence an accuracy rating of 20% for the line fluorescence yields greater than 0.01. Emission and absorption spectral features are predicted finding good correlation with measurements in both laboratory and astrophysical plasmas.

Drs. Palmeri and Kallman with Drs. C. Mendoza and M. Bautista (IVIC, Venezuela) have carried out a detailed analysis of the radiative and Auger de-excitation channels of the K-shell vacancy states in Fe II-Fe IX. Level energies, wavelengths, A-values, Auger rates and fluorescence yields have been calculated for the lowest fine-structure levels populated by photoionization of the ground state of the parent ion. Different branching ratios, namely Kα(1)/Kα(2), Kβ/Kα, KLM/KLL, KMM/KLL, and the total K-shell fluorescence yields, omega(K), obtained in the present work have been compared with other theoretical data and solid-state measurements, finding good general agreement with the latter. The Kα(2)/Kα(1) ratio is found to be sensitive to the excitation mechanism. From these comparisons it has been possible to estimate an accuracy of 10% for the present transition probabilities.

Drs. Palmeri and Kallman with Drs. C. Mendoza and M. Bautista (IVIC, Venezuela) have computed photoabsorption cross sections across the K-edge of Fe XVII-Fe XXIII and electron impact K-shell excitation effective collision strengths in Fe XVIII-Fe XIII with the Breit-Pauli R-matrix method. The target models are represented with all the fine-structure levels within the n=2 complex, built up from single-electron orbital bases obtained in a Thomas-Fermi-Dirac statistical model potential. The effects of radiation and spectator Auger dampings are taken into account by means of an optical potential. In photoabsorption, these effects cause the resonances converging to the K thresholds to display symmetric profiles of constant width that smear the edge, with important implications in spectral analysis. In collisional excitation, they attenuate resonances making their contributions to the effective collision strength negligible.

All these atomic data will be soon available in TIPTOPbase (http://heasarc.gsfc.nasa.gov/topbase) and will also be included in the XSTAR database.

2.16 Gravitational Wave Astrophysics

Drs. Camp and Cannizzo, with the LIGO Scientific Collaboration (LSC), are 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 burst sources and inspiraling binary neutron star systems, the LSC has begun a preliminary study of LIGO data.

Dr. J. Baker and collaborators 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 finding that during this time nearly 3% of the system's mass-energy is lost, corresponding to a peak gravitational wave luminosity of roughly 5×10^{56} erg 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 $a\sim0.7m$.

3. OPERATING ORBITAL FLIGHT MISSIONS

3.1 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. The SAMPEX mission will come to an end during the coming year. SAMPEX data have enabled many discoveries and accomplishments: SAMPEX proved the existence of a magnetospheric belt composed of trapped anomalous cosmic rays (ACRs), thus confirming their origin as interstellar neutrals which are ionized close to the sun and are subsequently accelerated at the heliospheric termination shock; SAMPEX documented the build-up of energetic electrons in the magnetosphere which frequently accompany satellite failures; a very successful model was developed for predicting these MeV electron fluxes at geosynchronous orbit based solely on solar wind measurements as input; measurements of Fe charge states 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.

3.2 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 GSFC. Dr. Marshall is the director of the SOC. Dr. Corbet manages the Science Operations Facility, which carries out the observation planning and monitoring and instrument commanding. Dr. Boyd this year took over from Dr. Alan Smale as the manager of the Guest Observer Facility (GOF) The GOF is responsible for making the RXTE data available to observers and for fielding questions asked by the observers.

Operating since 1996, RXTE has transitioned to an extended mission phase. Cycle 8 observations are being carried out until 1 March 2004, when observations of the cycle 9 will begin. Cycle 9 proposals will be due in the fall of 2003. 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 continues to carry out both preplanned and target of opportunity proposals. 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 21 accreting neutron stars. In 10 of them, thermonuclear flash bursts have revealed oscillations probably coherent, but of slightly varying frequency. The discovery of two new millisecond accreting pulsars this year has raised the number to five. This year another transient outburst of SAX J1808.4-3658 was successfully observed and this time, not only were bursts observed, but pulsations in the bursts at the neutron star rotation frequency were seen, implying that the oscillations seen in bursts are indeed based on the rotation period. This was a key discovery for RXTE.

RXTE result highlights may be found at the web site: http://hea-www.harvard.edu/xrt2003/.

3.3 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 (U. Maryland) 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 Cosmic Ray (ACR) component, Corotating Interaction Regions and ^{3}He-rich events have been possible. Multiple studies have utilized this high sensitivity to observe composition changes as a function of time during individual solar energetic particle events, to discover trans-Fe element enhancements in impulsive events, to observe acceleration by inter-planetary shocks, and to observe temporal variations of the ACRs. Extensive work has been done on modeling particle cceleration by a coronal/interplanetary shock, including the effects of wave-particle nteractions where the waves are produced primarily by protons interacting with the shock.

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

Konus is a gamma-ray burst (GRB) monitor on the ISTP/Wind spacecraft, launched in November 1994 and still (in late 2003) operating perfectly. Drs. E. P. Mazets of the Ioffe Physico-Technical Institute in St. Petersburg, Russia and Cline of Goddard are the co-Principal Investigators. Konus is providing isotropically sensitive GRB coverage in its location well outside the magnetosphere that is actively varied in distance up to the first Lagrangian point, 5 light-seconds away. In the interplanetary GRB network (see IPN section), with Ulysses and Mars Observer at great distances, Konus is thus the primary near-Earth GRB monitor, with HETE-2 and RHESSI in low Earth orbit and INTEGRAL in cislunar space, also with GRB capabilities. Data recovery from the Wind spacecraft is being maintained, although with a reduced operating budge, and new software techniques are enabling GRB data to be automatically analyzed soon after each download. Konus and the IPN have provided many GRB alerts to the GRB afterglow community in recent years, including the most distant GRB source ever, at $z=4.5$. It is anticipated that Konus may now continue to provide this critical support for some time.

3.5 Interplanetary Gamma-Ray Burst Timing Network (IPN)

The Interplanetary GRB network (IPN) now involves a full complement of space missions at mutually great separations. The Ulysses solar orbiter is at distances of up to 6 AU (K. Hurley, UC Berkeley, PI) and the Mars Odyssey is in Martian orbit with both a gamma-ray-sensitive neutron detector (I. Mitrofanov, IKI, Moscow, PI) and a gamma-ray spectrometer (W. Boynton, Arizona, PI). The near-Earth IPN vertex combines INTEGRAL in cislunar space, HETE-2 and RHESSI in low Earth orbit, and Konus (see Konus section) outside the magnetosphere. Dr. Cline is co-I for the IPN, which is now functioning at full capability, with Mars Odyssey having effectively replaced the NEAR mission last year. The precise (several-arc-minute) GRB source localizations are delivered to the community on receipt by the Goddard GCN (see GCN section). This IPN service has provided a great many GRB localizations and improvements on the precision of the localizations from BeppoSAX and HETE-2, thus enabling a considerable variety of follow-on GRB afterglow studies. Since data recovery for the Ulysses and GGS/Wind missions have recently been extended, the IPN should be able to provide these services until at least 2006, fully overlapping the activity of Swift, the next-generation GRB mission.

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

The ESA *XMM-Newton* X-ray observatory launched in 1999 December continues to operate well and is in its Guest Observer phase of operations, which also includes Target of Opportunity observations. *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).

XMM-Newton data are flowing to the community both through the GO program (where US scientists have been rather successful) and through the project archive. All calibration, performance verification, and science verification data sets are public, and both GT and GO data sets are becoming public as their proprietary periods expire. Archive data are available through the SOC as well as a mirror site at GSFC. New data are typically delivered to Guest Observers within a few weeks of the completion of the observation.

The current version of the data reduction software is both robust and complete although improvements continue to be made. The instrument calibrations are quite good (typically good to within 15%), and also continue to be improved.

The NASA/GSFC *XMM-Newton* Guest Observer Facility supports US participation in the project. This includes supporting the submission of science observing proposals (the project is currently in its third GO cycle), providing help in the analysis of the science data, and managing the GO grant process. The GOF also participates in the continued development of 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 on calibration issues and software development teams, both in the US and in Europe.

3.7 Advanced Composition Explorer (ACE)

The Advanced Composition Explorer (ACE) was successfully launched on August 25, 1997. LHEA scientists involved include Drs. De Nolfo 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. Analysis of these measurements indicates that the source abundances of 18 heavy isotopes (Mg-Ni) are strikingly like solar system abundances despite the fact that the observed cosmic rays are much younger than the solar system. The Solar Isotope Spectrometer (SIS) has measured isotopes in the Galactic Cosmic Rays, Anomalous Cosmic Rays, and in solar energetic particle events. The large collection power and resolution of SIS has allowed it to observe 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. For example, in the event of 3 August 2002, the ratio of $^{26}Mg/^{24}Mg$ is enhanced relative to the solar system abundance ratio by a factor of approximately 8, whereas other events have this ratio consistent with the solar system ratio. The ACE mission has recently been extended for an additional three years.

3.8 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 successful launch took place on 17 October 2002. INTEGRAL is an observatory class mission performing high-resolution spectroscopy and imaging in the 20 keV to 30 MeV region. It has two main instruments, a spectrometer and an imager. By taking advantage of new technology, the INTEGRAL has 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. NEW FLIGHT MISSIONS

4.1 Gamma-ray Large Area Space Telescope (GLAST)

Drs. Gehrels, Hartman, McEnery, 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, the GLAST LAT 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 late 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 J. Ormes (Code 600) 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, McEnery, 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 and Mr. Reyes are U. of Maryland Ph.D. students 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. Dr. McEnery is also involved in mission-level science planning. The GLAST Science Support Center (GSSC) 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.

4.2 Astro-E2

The Astro-E2 mission is being developed jointly by NASA/Goddard and the Institute of Space and Astronautical Science in Japan to provide astrophysicists with high resolution, high sensitivity x-ray spectroscopy over a wide range of photon energies. The core instrument, the high resolution X-Ray Spectrometer (XRS) is based on the x-ray microcalorimeter, a device that detects individual x-ray photons thermally and measures their energies with very high precision and sensitivity. The XRS is a cryogenic instrument and the cooling system has been designed to last at least 2 years in orbit. The microcalorimeter array consists of 32 pixels, each with a size of 625 microns, or about 30 arcsec. One of the pixels is out of the field of view of the x-ray mirror and will be illuminated by a 55Fe x-ray source to provide constant gain calibration data. The energy resolution of the array is about 6 eV and the overall effective area of the instrument is about 150 cm^2 over much of the 0.3-10 keV band. This 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 other instruments on Astro-E2 include a set of four CCD cameras (developed jointly by MIT and various institutions in Japan) and a combination photo-diode/scintillator detector system (developed primarily by the University of Tokyo and ISAS) that will extend the band pass up to nearly 700 keV. A significant feature of Astro-E2 is that all of the instruments are coaligned and operated simultaneously. The observatory will be launched into low earth orbit on a Japanese M-V rocket in early 2005.

Major accomplishments were achieved this year as all of the flight hardware instrumentation for the XRS was fabricated, tested, and integrated into the cryostat. Dr. Stahle was responsible for the detector array, including extensive flight qualification, testing, and evaluating for cosmic ray sensitivity. Dr. Porter was responsible for the detector assembly and the test equipment necessary to operate the detector assembly prior to integration in the He cryostat. Dr. Boyce was responsible for the microcalorimeter electronics and flight software. The flight electronics have been sent to Japan, while the XRS He cryostat system will be sent to Japan in early 2004 following calibration. The calibration plans and instrumentation have been developed and tested by Drs. Brown and Cottam and are ready for use. The entire calorimeter group contributed to a 10-week long operational test of the XRS detector system that provided extremely valuable data on the performance characteristics of the detector system prior to going into the instrument calibration.

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. Chan, Lehan, and Soong. The first two of the five mirror modules have been completed and are now on their way to Japan.

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.

4.3 Solar-TErrestrial RElations Observatory (STEREO)

Drs. von Rosenvinge and Reames are Coinvestigators for the IMPACT investigation on the STEREO mission. Dr. J. Luhmann of the U. of California at 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 2005.

4.4 Swift

The Swift gamma-ray burst MIDEX proposal was selected by NASA October 14, 1999. The observatory will be launched in April 2004 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. J. 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 saw the delivery of the spacecraft and the narrow-field instruments to Goddard for integration on the spacecraft and testing. The wide-field gamma-ray camera is in final stages of completion.

Mr. G. Sato, a graduate student from ISAS (Japan), has been working at the GSFC LHEA analyzying Swift BAT (Burst Alert Telescope) ground calibration data in association with Dr. Parsons and Mr. Hullinger. Now back at ISAS, Mr. Sato continues his work on the BAT spectral response in collaboration with the BAT team.

4.5 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 2004 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 and serves as a member of the International Program Committee. Dr. Streitmatter is a member of the Scientific Committee and Dr. Moiseev is involved in instrument modeling. PAMELA integration has been completed. Following beam calibrations at CERN in September 2003, PAMELA will be shipped to Russia for integration with the spacecraft and flight.

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 ($E/\Delta E \sim 300-1500$) 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. The science goals are to study the effects of extreme gravity, the formation and evolution of black holes, the formation of the elements, and to trace dark matter. The *Constellation-X* mission is part of the ''Beyond Einstein'' program that has been proposed as part of the President's FY2004 budget, which provides full implementation funding to support launches in 2013/14. In 2003, the *Constellation-X* Project Team completed a successful Technology Readiness and Implementation Review and hosted the NASA review panel at a site visit to GSFC. Technical progress continues at a good pace, and the technology funding continues to ramp up. Plans to demonstrate the required angular resolution of a flight-sized reflector pair in flight-like housing are underway. A small array of microcalorimeter devices has been fabricated that meets the design requirements.

There is substantial participation by LHEA in the *Constellation-X* project. Dr. White serves as the Project Scientist and Dr. Weaver serves as the Deputy Project Scientist. Dr. Petre is one of two Mission Scientists (along with Dr. 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. Bandler, Boyce, Figueroa-Feliciano, Finkbeiner, Lindeman, Porter, Saab, and Stahle, and collaborators from NIST, Stanford, SAO, and Lawrence Livermore Natl. Laboratory (LLNL). Drs. Petre, Zhang, Tueller, Gehrels and Parsons are members of the Hard X-ray Telescope (HXT) team, which is led by F. Harrison (CalTech) and includes collaborators from Columbia, LLNL, SAO, MSFC, Danish Space Research Institute, and Observatoria Astronomica de Brera.

LHEA is the leading organization for developing the technology to fabricate the X-ray optics for the *Constellation-X* mission. A number of issues are being worked on: mirror substrate development, replication procedure, and alignment and integration methods. Drs. Zhang and Petre have found in the last year that mirror segments can be made to faithfully replicate the figure of the forming mandrel. They have identified a new technique to minimize stress introduced by the replication process. They have also devised a new alignment scheme based on precision diamond turning technology. They will further investigate it and implement it in the next year.

LHEA is continuing its development of high-resolution detectors for the *Constellation-X* mission. *Con-X* requires detectors with an energy resolution of 4 eV at 6 keV in an array capable of $5'' - 10''$ imaging over a field of view of at least $02.5'$. This requires 0.25 mm 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, 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.

4.7 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 will reach the sensitivity to observe low frequency gravitational radiation from likely sources out to cosmological distances, and will be an important complement to the ground-based experiments already being constructed. 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 Beyond Einstein Program. The NASA scientists involved in LISA are: Drs. Teegarden (Gravity Group leader), Stebbins (LISA Project Scientist), Centrella (Numerical Relativity Group Leader), Camp, Merkowitz, McNamara and K. Numata, an NRC associate starting July 2003.

4.8 Energetic X-ray Imaging Survey Telescope (EXIST)

The Energetic X-ray Imaging Survey Telescope (EXIST) is a mission being proposed for the Black Hole Finder Einstein Probe in NASA's ''Beyond Einstein'' Program. The primary objective is to survey the gamma-ray sky in the $5 - 600$ keV energy band. 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. Jonathan Grindlay (Harvard) is the EXIST Principal Investigator. At Goddard, Dr. Gehrels is the Study Scientist and Drs. Barthelmy, Parsons, and Tueller with C.M. Stahle and S. Babu (Code 553) are team members.

4.9 The Energetic Trans-Iron Composition Explorer (ENTICE)

Dr. Barbier is the NASA lead Co-investigator on the Small Explorer proposal for the Energetic Trans-Iron Composition Explorer ENTICE. (Dr. R. Binns, Washington U., St. Louis, PI). ENTICE studies heavy ($Z>26$) cosmic ray particles in the galactic radiation, iron through curium - atomic mass 56 through 247.

ENTICE 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).

Work is currently underway for a new Explorer proposal in response to an Announcement of Opportunity expected in 2004.

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 U. of Maryland. BESS combines the largest geometric acceptance of any balloon-borne magnetic-rigidity spectrometer ($0.3\,m^2\,sr$) with powerful particle identification, using an advanced superconducting magnet and precision time-of-flight (TOF), Cherenkov, and tracking systems. It has had nine successful balloon flights since 1993, measuring the spectra of cosmic ray antiprotons and light nuclei, and performing a sensitive search for antihelium. A new BESS-Polar instrument is being developed for an Antarctic flight program beginning in 2004/2005 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 (ACC), and Dr. Mitchell is responsible for the TOF system. Drs. Hams and Sasaki will test prototypes of the ACC and TOF at KEK in July 2003. BESS-Polar will conduct a short test flight from Palestine, TX, in September 2003. Full integration for the 2004/2005 Antarctic flight will take place at GSFC beginning in October 2003.

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, Dr. Barbier (GSFC Lead Co-I), Dr. de Nolfo (NRC), Dr. Mitchell, and Dr. Streitmatter are participants. Goddard supports the Cherenkov detector subsystems in the TIGER instrument. Dr. W. 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.), Dr. S. Geier (Caltech), Dr. R. Mewaldt (Caltech), Dr. S. Schindler (Caltech), Dr. E. Stone (Caltech), Dr. J. Waddington (U. of Minnesota), and Dr. E. Christian (NASA HQ).

After its record breaking balloon flight from Antarctica during December 2001 and January 2002, becoming the first payload to circumnavigate Antarctica twice and make a record-breaking 31.5 days at the top of the atmosphere, TIGER was returned to the US and refurbished. It is now being shipped back to Antarctica for another flight in December of 2003.

A paper was presented at the 28th International Cosmic Ray Conference in Japan in August reporting on the data from the first flight. The main results of that flight are that cosmic-rays with charge equal to 30 and 32 have abundances in agreement with the volatility models of cosmic ray production and propogation, while charge 31 agrees better with the FIP models. Charge peaks with Z greater than 34 were not clearly resolved due to lack of statistics (the ultra-heavy particles being so rare). The upcoming flight will hopefully double the number of particles in this charge range.

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 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: (1) the total volume of archival high-energy data has reached 3.0 Terabytes (TB), including 1.0 TB of *Rossi XTE* data, 0.5 TB of *ASCA* data, 0.4 TB of *XMM-Newton* data, 0.2 TB each of *BeppoSAX* and *Compton* data, and 0.7 TB of data from 18 other gamma-ray, X-ray, or extreme-ultraviolet satellite observatories; (2) record amounts of data, software, images, and web pages were downloaded by HEASARC users: 3.2 TB via anonymous ftp and/or the ftp server, and 1.6 TB via the Web (http) server, with the most popular missions (based on the amount of data downloaded as a fraction of the mission archive size) being *Rossi XTE*, *ROSAT*, *Compton*, and *XMM-Newton*; (3) a record number (2,560,000) of queries were made using the HEASARC's web-based multi-mission database and catalog service, Browse, an increase of $>100\%$ compared to the previous 12-month period; (4) there was continued heavy usage of the HEASARC's Web-based SkyView utility (a tool to display images of selected portions of the sky in various projections and in any of a wide range of wavelengths), with the number of generated images exceeding 1 million (for the first time ever); in addition, SkyView was designated as one of the top 50 science Web sites by Scientific American for the second year in a row; (5) 15,000 more entries in the bibliographic code/dataset identification correlation tables for HEASARC archival datasets were created in this 12-month period: users of the NASA Astrophysics Data System (ADS) can thus link immediately from the ADS bibliographic record of a paper for which this correlation has been made to the HEASARC high-energy datasets which were analyzed in that paper, e.g., most papers which have presented *ROSAT* and *XMM-Newton* analyses now have the ADS/HEASARC link in place; (6) in July 2002, a beta version of the Gamma-Ray Burst Catalog (GRBCAT) Web site was released: GRBCAT contains a new compilation of 4677 gamma-ray bursts (GRBs) which were detected over the period from 1967 to mid-2001, and will soon be updated to include GRBs detected by *BeppoSAX* and *HETE 2*; and (7) the continuation of an 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, multi-wavelength datasets so as to allow users to classify samples of X-ray sources based on a large number of scientific criteria.

5.4 Laboratory Astrophysics

A LHEA microcalorimeter has continued to operate as part of the Laboratory Astrophysics program centered at LLNL's electron beam ion trap EBIT-I. EBIT-I operates at electron densities of $\sim 10^{12}$ cm^{-3} and in the 10^6-10^8 K temperature range, parameters similar to many astrophysical plasmas. The resulting X-ray emission can be viewed through several ports using crystal and grating spectrometers, high-purity solid state detectors, and the X-ray microcalorimeter array. The X-ray microcalorimeter has high spectral resolution coupled with high quantum efficiency over a large bandwidth making it well suited to the study of weak atomic processes. The spectrometer is based on the Astro-E/XRS engineering model detector, and a portable laboratory adiabatic demagnetization refrigerator developed in our lab. Before the end of 2003, a new detector will be installed in the portable system with a resolution of $\sim$6 eV, i.e, similar to that of the XRS to be flown on *Astro-E2*.

This work is being carried out in collaboration with Drs. P. Beiersdorfer and H. Chen at LLNL and S. Kahn at Stanford. LHEA's contribution to this work is being carried out by Drs. Boyce, Brown, Kelley, Porter, and Stahle.

The microcalorimeter has continued to open up new measurement regimes at the LLNL EBIT-I. For example, the first ever measurement of an absolute cross section of an Fe L-shell line was completed. Absolute cross sections of L shell emission from Fe XVII-XXII have also been measured and are being analyzed.

The relative line strength of the 2p-3s to 2p-3d lines in Fe XVII has been a long standing problem in X-ray astronomy because no plasma model has been able to reproduce observations from sources such as the Sun, Capella, or Procyon. Uncertainties associated with the models made it impossible to determine if the disagreement was a result of unknown source physics or problems with the atomic models. Measurements using the microcalorimeter, along with several other spectrometers, at EBIT-I agree with observations, proving that theory has not yet achieved the accuracy necessary to reproduce astrophysical data.

Charge exchange recombination is the source of X-ray emission from comets. However, the atomic data necessary to reliably model charge exchange reactions is far from complete. Taking advantage of the fact that the calorimeter is a non-dispersive spectrometer, we are able to measure the X-ray emission from low-energy charge exchange between neutral atoms and molecules and highly charged ions. These data were used to developed a charge exchange emission model that successfully reproduced the soft X-ray spectrum of comet Linear C/1999 S4, observed with *Chandra*.

In the next year, a permanent EBIT Calorimeter Spectrometer (ECS) built at LHEA will be installed at the LLNL EBIT-I. The ECS will be designed for minimum servicing and high operational duty cycle, with integration times of several days, and have a factor of two better resolution. Also, part of the array will be dedicated to thicker absorber material in order to measure X-rays with energy $>$60 keV.

5.5 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. Present members of the LHEA microcalorimeter team include Drs. Bandler, Boyce, Brown, Cottam, Figueroa-Feliciano, Finkbeiner, Kelley, Lindeman, Porter, Saab and Stahle. During the last year, Dr. Saab joined our group as a NASA/NRC Research Associate to work on TES microcalorimeters and anticoincidence techniques.

Work is continuing on improving devices with ion-implanted Si thermometers and superconducting transition edge thermometers. Most significantly, new 36 pixel microcalorimeter arrays (with 32 read out in flight) have been successfully developed for the *Astro-E2* program with an energy resolution of 6 eV. This is a factor of two better than what would have flown on *Astro-E*. Drs. Stahle and Porter have also installed one of these new arrays in our X-ray spectrometer used for laboratory astrophysics studies at the Lawrence Livermore National Laboratory in collaboration with Dr. P. Beiersdorfer. The central focus of our work in this area now is in improving arrays especially designed for low energy work for upgrading our sounding rocket payload. This instrument is a joint effort between our group and Prof. D. McCammon at the U. Wisconsin to study the X-ray emission from the diffuse X-ray background below about 1 keV.

In the past year, we have produced the first functional TES devices with pixels designed to meet the *Constellation-X* requirements for size, quantum efficiency, etc. The results are extremely good for this stage of the program (e.g., 5-7 eV). We have also fabricated and tested TES devices with a variety of thermistor geometries with the goal of studying the affect this has on TES noise. We have verified that a specific geometry significantly lowers the detector noise and we are now incorporating this design into the next lot of arrays. Our group has also initiated work on magnetic calorimeters. These devices use a paramagnetic material in a magnetic field to measure temperature changes as variations in magnetization. Work on these and TES microcalorimeters will continue in parallel to achieve the highest spectral resolution and establish which is the most reliable and robust for future flight applications.

5.6 Gas Micro-Structure Detectors

Imaging micro-well proportional counters and related gas micro-structure devices are being developed in the LHEA (Drs. Black, Deines-Jones, and Jahoda) for large-format X-ray imaging and for electron tracking in X-ray polarimeters. Gas micro-structure detectors exploit narrow-gap electrodes, rather than thin anodes, to achieve gas amplification and are capable of diffusion limited imaging. Work in the LHEA is concentrated on fabrication techniques and readout electronics that are readily extensible to large areas (thousands of square centimeters). Current applications include the microwell detectors which are suitable for use as the focal plane detectors for the Lobster-ISS all sky monitor and Gas Electron Multiplier (GEM) foils which can be used as the multiplication stage in a photo-electric polarimeter. To date these devices have been produced with a UV laser ablation process.

Micro-well detectors are a simple and inexpensive means of high-resolution (micron) imaging over large areas. We have demonstrated that this detector geometry offers: 1) Subpixel resolution: detectors with 400 m pixel spacing having 85 m 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. Two dimensional imaging is provided by reading out the anodes and cathodes as crossed strips. The Lobster-ISS payload requires 2400 square cm of instrumented area; we are developing 100 square cm panels which can be mounted in tilted pyramids which approximate the focal surface.

GEMs create charge multiplication through similar processes, but are typically used only for multiplication and not readout. Deines-Jones and Black, with Drs. S. Ready and R. Street (Palo Alto Research Center) have coupled LHEA produced GEMs to a thin film transistor array and created images of the photo-electron track created after the absorption of an X-ray. For polarized sources, there is an asymmetry in the directions of the tracks, and this effect has been exploited to measure X-ray polarization. This is only the second time that a photo-electric measurement of polarization has been made, and the first time that an intrinsically large (and expandable) readout, the thin film transistor, has been employed. This enables the possibility of X-ray polarimetry detectors large enough to cover the focal plane of a modern X-ray telescope or large collimated detector. Further development of these detectors is a high priority.

5.7 Foil Mirrors for X-Ray Telescopes

The image quality of segmented, thin-substrate X-ray telescopes has been improved continuously throughout years. The conical approximation of the Wolter I configuration is the baseline design of the *BBXRT*, *ASCA*, and the future *Astro-E2* optics. The substrate of the reflector is of 152 μm aluminum alloy which is replicated on smooth Pyrex mandrels. The finished mirrors reflect X-ray specularly in the energy band up to 10 keV with a layer of gold or of platinum. The response can be elevated to a higher energy band if multi-layering techniques is applied to the same configuration. Telescopes that image up to 40 keV photons will be flown onboard the *InFOCμS* balloon payload for the second time in the summer of 2004. This is a collaborative effort between GSFC and ISAS/Nagoya U. in Japan.

The effort to improve the X-ray image quality is divided into two directions. The first one is to continue with the existing configuration, to quantify the error terms, and to minimize them as their origins are better understood. The current focus is on fabricating the *Astro-E2* telescopes, and to reach the conical limit of the image quality in the near future. There are extensive efforts proceeding in searching for a new substrate material with better structural integrity as it goes through the fabrication processes, and to improve precision of optical elements in the processes (such as the replication mandrels). We are also seeking ways to improve the alignment scheme. Drs. Chan, Serlemitsos, Soong, Lehan, and Okajima lead these efforts.

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 HPD 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. The InFOCμS team is preparing to fly the telescope again in Spring, 2004. This flight will include a new mirror with improved sensitivity and effective area, and a completely redesigned attitude control system including the use of differential GPS for daytime pointing. Crucial to the sensitivity of the telescope 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}. In a future configuration we expect to be able 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 followup 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

In December 2002 NIGHTGLOW was shipped to Alice Springs Australia and prepared for a second attempt at an ultra-long-duration balloon (ULDB) flight around the world (Dr. Barbier, PI) After integration there was a 2.5 month delay in waiting for proper launch conditions. A beautiful launch was achieved on March 17th at approximately 8:38 AM local time. During the ascent phase of the mission, an anomaly was seen in the balloon shape and internal pressure. After repeated attempts to correct the situation, it was determined that the flight should be terminated. After a trip of less than 300 miles from the launch site, the instrument was cut down and landed in the Australian Outback (in a shallow lake!). Recovery was difficult, taking just over one week and some damage occur to the payload, both during the landing and on the recovery trip.

Currently, the instrument is back at Goddard for repairs and upgrades in hope of a third launch attempt in early 2005.

On the bright side, the design, fabrication, and integration of the LIDAR system was successful, giving NIGHTGLOW the capability to monitor cloud cover as well as measure the near ultra-violet emissions in the atmosphere.

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, such as EUSO or OWL.

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 Three-dimensional Track Imaging Micro-Well Detectors for Gamma-Ray Telescopes

Three-dimensional track imaging gas micro-well detectors are being developed in the LHEA (Drs. Bloser and Hunter) in collaboration with the Center for Thin Film Devices at the Pennsylvania State U. (Prof. T. Jackson) for Compton scattering and pair-production gamma-ray telescopes with high polarization sensitivity. The micro-well detectors, which exploit narrow-gap electrodes, rather than thin anodes, to achieve gas amplification, are a demonstrated, mechanically simple means of high-resolution ($\sim$50 m) imaging over large areas. We (with Drs. Deines-Jones and Black) have demonstrated that this detector geometry offers: 1) Sub-pixel resolution: detectors with 400 micron pixel spacing having 85 m 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.

Micro-well detectors are arrays of proportional counter pixels with a well-like geometry. Each well 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 drift 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.

The three-dimensional electron track imagers for gamma-ray telescopes consist of micro-well detectors with two-dimensional pixelized readout augmented with measurement of the ionization charge drift time to provide the third coordinate. The two-dimensional pixelized micro-well readout uses an active transistor array to isolate the anode pads from each other. Asserting the gates of the transistors, connected in columns, shifts the avalanche charge stored on the anode pads column-by-column onto charge integrating amplifiers. The pixelized readout is significantly different from the simple two-dimensional crossed strip readout being developed for X-ray applications (e.g. the Lobster-ISS X-ray all-sky monitor). Efficient track imagers for telescopes optimized for high polarization sensitivity must also be made of optically thin (low Z) materials so that the photons interact predominately in the gas rather than in the inactive materials (metal electrodes, support structure, and electronics) and to minimize Coulomb scattering of the electrons. We are developing optically thin, rugged amorphous silicon thin-film transistor (TFT) arrays on polyimide substrates along with techniques to fabricate the micro-well electrode structure as an integral part of the array. These techniques are extendable to tens of square meters in area. Several 8×8 arrays of TFTs with different geometries have been tested. The best configuration shows excellent electrical performance: mobility ~1 $cm^2\ V^{-1}$ s, $I_{on}/I_{off}=108$, low threshold voltage $0.8-2.5$ V, and low leakage current ~0.3 pA.

The current goals of this high priority work, motivated by the requirements of the medium-energy (0.5-30 MeV) Advanced Compton Telescope (ACT) mission, are to fabricate 16 cm $\times16$ cm three-dimensional track imaging detectors, assemble these detectors into a prototype medium-energy (Compton scatter) gamma-ray telescope, and test this telescope at an accelerator in the next 2-3 years. The goals of the ACT missionare to study the emission from SNRs, pulsars, black holes, and the EGRET unidentified gamma-ray sources with high polarization sensitivity and sufficient energy resolution to study emission lines.

We are also developing a concept for a high-energy (~50 MeV $-$ ~1 GeV, i.e., pair production) Advanced Pair Telescope (APT). This instrument would be valuable for the study of high-energy pulsars, active galactic nuclei, supernova remnants, and gamma-ray bursts. The pixelized three-dimensional micro-well detectors combine high spatial resolution with a large, nearly continuous low-density gas volume that permits many thousands of measurements per radiation length. This allows the electron and positron directions to be accurately determined before multiple scattering masks their original directions, providing superior angular resolution and good polarization sensitivity. We have performed GEANT4 simulations to estimate the polarization sensitivity of a simple telescope geometry. We will extend these simulations and use the results to optimize the design of this telescope.

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 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.

We continue to develop the Imagine the Universe! (http://imagine.gsfc.nasa.gov/) web site to bring the Lab's science to the education community. Mr. Wanjek writes news of discoveries from *Chandra*, *XMM-Newton*, *Rossi XTE* and other missions which are posted on the site monthly. We also continued development of short activities for each of the science topics, and our series of profiles of Lab scientists. We included a new article about the research done by the Gravitational Wave Astrophysics group and the LISA mission.

In January 2003, we prepared and released the 7th 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 2002. This CD-ROM is distributed free upon request, at teacher conferences, and via NASA CORE. We expect to distribute 20,000 of the CDs during the course of the year.

We completed the development of our new curriculum support material on the cosmic origin of the chemical elements. Entitled ''What is Your Cosmic Connection to the Elements?'' the poster and booklet provide information on the various astrophysical processes that give rise to the chemical elements. Classroom activities were developed by participants in the ''Elements 2002'' workshop held at GSFC in Aug 2002. The poster, activities, and booklet material were field tested this past fall and spring. We premiered a teacher workshop based on this material at the national convention of the National Science Teachers Association in April 2003.

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. We staff exhibit booths and present workshops which train teachers to use our materials in their classrooms. Our workshops topics now include using our CD-ROM, using the StarChild web site, the ''Hidden Lives of Galaxies,'' ''Black Holes in a Different Light,'' ''Life Cycles of Stars,'' and our new workshop on ''What is Your Cosmic Connection to the Elements?'' These workshop presentations are posted on the Imagine web site for teachers to use with their classes.

We also participate in a number of teacher workshops that are held at NASA/GSFC during the summer. Drs. Lochner, Corcoran, and de Nolfo participated in the Anne Arundel County Public School Summer Academy. Dr. Lochner presented the ‘‘Cosmic Elements’’ material and activities to the ‘‘Exceptional Space Science Materials for Exceptional Students’’ workshop, participating in discussion as to how the materials could be adapted for students with special physical and learning needs.

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. In May we participated in the SEUEF retreat to develop a SEU E/PO strategy and begin the development of a SEU Short Course on ‘‘Modeling the Universe,’’ which will be presented at next year’s teacher conferences.

Drs. Lochner and Pence developed an education interface for the Hera software, enabling high school students to analyze X-ray timing data using a subset of the FTOOLS software. This will be extended to projects using imaging data.

Coordinating with Dr. Lochner, cosmic ray education and public outreach continued under the direction of Ms. B. Jacob. Drs. Thompson, Christian, and Mukai gave presentations on high-energy astrophysics at a Norfolk State U. (NSU) teacher workshop. NSU is a partner minority university. We also provided the teachers and the NSU planetarium with a large number of NASA educational materials. During the three-month Australian balloon campaign, two NIGHTGLOW scientists and an engineer kept journals, answered student questions, and provided hundreds of photographs for the website. Ms. Jacob assisted in the development and presentation of the annual Cooperative Satellite Learning Program student conference at GSFC. We recruited eleven new ACE scientists to answer questions from the public for the Cosmic and Heliospheric Learning Center website.

5.13 Workshops and Classes

Drs. Arnaud and Harrus organized the second US X-ray astronomy school for graduates and young postdocs. This ran from 18-22 August 2002 in Berkeley Springs WV and was deemed to be a success by the participants. Dr. Arnaud also participated as an invited guest lecturer in a COSPAR capacity-building workshop in Udaipur, India, which educated Asia-Pacific region astronomers about the *Chandra* and *XMM-Newton* observatories, archives, and data analysis systems.

Dr. Corcoran continues to lead the team-teaching of an upper undergraduate course on astrophysics from a high-energy perspective at George Washington U.

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