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

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This report covers the period from July 1, 1997 to June 30, 1998.

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

1. PERSONNEL

Dr. Jonathan F. Ormes is the Chief of the Laboratory for High Energy Astrophysics. Dr. Neil Gehrels is Head of the Gamma Ray & Cosmic Ray Astrophysics Branch and Dr. Nicholas White is Head of the X-Ray Astrophysics Branch.

The permanent scientific staff includes: Drs. Louis Barbier, David Bertsch, Elihu Boldt, Kevin Boyce, Thomas Cline, Alice Harding, Robert Hartman, Stanley Hunter, Keith Jahoda, Frank Jones, Timothy Kallman, Demosthenes Kazanas, Richard Kelley, Frank Marshall, Richard Mushotzky, Jay Norris, Theodore Northrop, Ann Parsons, William Pence, Robert Petre, Reuven Ramaty, Donald Reames, Peter Serlemitsos, Caroline Stahle, Floyd Stecker, Robert Streitmatter, Tod Strohmayer, Jean Swank, Andrew Szymkowiak, Bonnard Teegarden, David Thompson, Jack Tueller, Tycho von Rosenvinge, and William Zhang.

The following scientists are National Research Council Associates: Drs. Pijushpani Bhattacharjee, Steven Bloom, Andrew Chen, Ed Colbert, Stanley Davis, Philip Deines-Jones, Moshe Elitzur, Pranab Ghosh, Sunil Gupta, Xin-Min Hua, Craig Markwardt, Alex Muslimov, Kirpal Nandra, Andrew Peele, Alak Ray, Samar Safi-Harb, Robin Shelton, Vincent Tatischeff, and Barbara Williams.

The following researchers are University Space Research Association Scientists: Drs. Glenn Allen, Lorella Angelini, Matthew Baring, Paul Barrett, Scott Barthelmy, Kevin Black (SAC), Jerry Bonnell, Patricia Boyd, William Bridgman, John Cannizzo, Kaiwing Chan, Eric Christian, Robin Corbet, Michael Corcoran, Stephen Drake, Ken Ebisawa, Joseph Esposito, Mark Finger, Ian George, Eric Gotthelf, Michael Harris, John Krizmanic, James Lochner, Daryl Macomb, Wilhelm Mandl, Natalie Mandzhavidze, Thomas McGlynn, John Mitchell, Alex Moiseev, Koji Mukai, Juan Naya, David Palmer, Francois Pelaez, Chris Shrader, Alan Smale, Steven Snowden, Yang Soong, P. Sreekumar, Steve Sturner, Toshiaki Takeshima, Jane Turner, Ken Watanabe, Laura Whitlock, and Tahir Yaqoob.

The following investigators are University of Maryland Scientists: Drs. Keith Arnaud, Manuel Bautista, Wan Chen, Fred Finkbeiner, Keith Gendreau, Una Hwang, Michael Loewenstein, Greg Madejski, F. Scott Porter, Ian Richardson, Caleb Scharf, Michael Stark, and Azita Valinia.

Visiting scientists from other institutions: Drs. Vadim Arefiev (IKI), Hilary Cane (U. Tasmania), Peter Gonthier (Hope College), Thomas Hams (U. Seigen), Donald Kniffen (Hampden-Sydney College), Benzion Kozlovsky (U. Tel Aviv), Richard Kroeger (NRL), Hideyo Kunieda (Nagoya U.), Eugene Loh (U. Utah), Masaki Mori (Miyagi U.), Robert Nemiroff (Mich. Tech. U.), Hagai Netzer (U. Tel Aviv), Yasushi Ogasaka (JSPS), Lev Titarchuk (George Mason U.), Alan Tylka (NRL), Robert Warwick (U. Leicester) and Andrzej Zdziarski (Copernicus Astr. Cen.).

Graduate Students doing their thesis research in this Laboratory are: from the U. of Maryland: Angela Ahearn, Damian Audley, Jennifer Catelli, Warren Focke, Sven Geier, Donald Horner, Kip Kuntz, Peter Kurczynski, Nicolas Pereyra, Glenn Piner, Andrew Ptak and Jason Taylor; from the U. of Minnesota, Jonathan Keohane; from Catholic U., Charles Hall; and from Stanford U., Enectali Figueroa-Feliciano.

2. RESEARCH PROGRAMS

2.1 Sun and Solar System

Drs. Richardson and Cane, in collaboration with Dr. C. St Cyr (Computational Physics, Inc.) have investigated the relationship between coronal mass ejections (CMEs), detected by the LASCO coronagraph on SOHO, and the energetic particle signatures of CMEs. The particle depressions were well-correlated with earth-directed CMEs observed by LASCO. High-energy particle enhancements were associated with flares and CMEs. They have also studied the particle and solar wind features associated with the large geomagnetic storm in November, 1978, which was caused by CME-associated material incorporating southward magnetic field interacting with a corotating interaction region. Dr. Richardson, in conjunction with Prof. G. Mason (U. Maryland) and Dr. J. Mazur (Aerospace Corp.), has also compared observations of a few MeV ion enhancements corotating with the Sun made at Earth by the IMP 8 and SAMPEX spacecraft, and by the Ulysses spacecraft during passage over the poles of the Sun in 1994-1996. The enhancements observed at Ulysses, even at high latitudes, can be related to those at Earth by considering simple corotation delays. Their intensities near polar passage were $<$ 0.1% of the corresponding enhancements at Earth.

2.2 Stars

Drs. Corcoran, Swank, Petre with Dr. K. Davidson and Mr. K. Ishibashi (U. Minnesota) studied the X-ray variations from the extremely massive star Eta Carinae using RXTE, ASCA, and ROSAT. The most recent data show that the X-ray ''low state'' last seen in mid-1992 has repeated in late 1997, in good agreement with the 5.52-year period derived from observations of the He I 1083 nm line. The X-ray data show that the observed X-ray low states are probably periodic and strongly support the idea that Eta Carinae is in reality a massive binary system in which the observed periodic variations are caused by interactions between the wind from the primary and its companion. Periodic ''flaring'' every 85 days was also discovered in the RXTE data; this ''flaring'' may be related to pulsations of the primary star.

2.3 Pulsars

Dr. Ghosh studied the diagnostic potential of models of quasiperiodic oscillations (QPO) in X-ray pulsars for probing the inner accretion disks in these systems, and for mapping out the accretion torques on the pulsars. He suggested that the magnetospheric beat-frequency model may not be applicable to all QPOs observed in X-ray pulsars. Dr. Ghosh with Drs. M. Abramowicz (U. Goteborg), N. Anderssen (Washington U.), and M. Bruni and S. Sonego (SISSA) showed that the optical-geometry viewpoint offers a unified, powerful description of the general-relativistic w-modes of neutron stars and ultracompact stars, stressing the role of the oscillations of the metric. That the basic eigenspectrum of trapped w-modes can be calculated by this method with little effort, and that the result compared favorably with that obtained by large supercomputer calculations, underscores the potential of the method.

Drs. Lochner, Marshall, Corbet, and Whitlock discovered and monitored five transient pulsing sources near SMC X-3 in the Small Magellanic Cloud between November 1997 and March 1998 using RXTE. With periods ranging between 45 and 170s, and outbursts lasting between 14 and 30 days, each of these sources is likely to be a Be-neutron star system. One of the sources, AX J0051-722, exhibited a second outburst in March 1998, suggesting a possible binary orbital period of $\sim$ 110 days. These 5 pulsars have significantly increased the number of such systems studied in the SMC, making possible a meaningful comparison of the SMC pulsar population relative to the Galaxy.

Dr. Kazanas with Drs. J. Contopoulos (U. Crete) and C. Fendt (Astrophysical I., Potsdam) have produced the first exact, continuous, axisymmetric model for a pulsar magnetosphere, in the context of ideal magnetohydrodynamics. Such a solution has eluded previous researchers who produced solutions which are only piece-wise continuous. The importance of such a solution lies in the fact that it can serve as a background model for investigations of realistic non-axisymmetric solutions and the associated emission of radiation.

Dr. Thompson and visiting scientist Dr. P.V. Ramanamurthy completed a study showing that the Crab pulsar does not show variability at energies above 50 MeV on time scales of seconds to hundreds of seconds. Dr. Thompson, in collaboration with a group of radio, X-ray, and gamma-ray astronomers, completed a multiwavelength study of PSR B1055-52 indicating complex emission from this pulsar.

Drs. Baring and Harding have identified a simple physical explanation for radio quiescence in highly magnetized pulsars such as soft gamma repeaters and anomalous X-ray pulsars. This quiescence is expected due to the effectiveness of photon splitting in the strong neutron star fields in strongly inhibiting the production of electron-positron pairs. The boundary for the onset of the suppression of radio emission lies at period derivatives above those of known radio pulsars but below those of the anomalous sources and SGR 1806-20, thereby defining a clean division between these classes of pulsars.

Drs. Harding and Muslimov have been studying particle acceleration above pulsar polar caps. They have modeled the electrostatic field, due to relativistic intertial frame dragging, which accelerates electrons to very high energies, the radiation from these particles and the electron-positron pair formation that will screen the accelerating field at some height. Incorporating inverse Compton scattering of the electrons by thermal surface X-rays, they found that screening of the electric field also near the neutron star surface by backflowing positrons drives the acceleration zone to altitudes of several stellar radii.

2.4 Galactic Binaries

Dr. Mukai with Drs. C. Hellier (Keele U.) and J. Osborne (Leicester U.) have studied the Fe K lines in magnetic cataclysmic variables using archival ASCA data. They have concluded that, at least in some systems, the thermal lines from H-like and He-like Fe (but probably not the fluorescent line) are significantly broadened. They suggest Compton broadening is the most likely mechanism for this.

Dr. Mukai with Drs. A. Beardmore (Keele U.), A. Norton (Open U.), Osborne, and Hellier have compared the X-ray light curves of the intermediate polar FO Aqr over a 10 year time span, using EXOSAT, Ginga, and ASCA data. They find that the spin-folded light curves are highly variable from epoch to epoch, suggesting that changes in accretion geometry is rather frequent in this system.

Dr. Mukai has proposed a new model (a white dwarf whose spin period is $\sim$ 4040 s) for the variable source V1432 Aql (RX J1940.1-1025), whose $\sim$ 12,000 s periodicity was once claimed to originate from the Seyfert galaxy, NGC 6814. Drs. Mukai and Madejski with Dr. Hellier have begun a campaign of XTE observations to test this theory and to monitor the behavior of NGC 6814.

Dr. Smale analyzed data from an RXTE observation of Cygnus X-2, in which the source mapped out a new, pronounced up-turn on the Horizontal branch of its color-color diagram. During this up-turn a bright X-ray burst was observed. The detection of photospheric-radius expansion during the burst rise and spectral cooling in its decay proves that the bursts from Cygnus X-2 are ''standard'' Type I, removing the former ambiguity about the nature of these uncommon events and providing an independent estimate of its distance.

Dr. Smale with Dr. S. Wachter (U. Washington) performed a campaign of simultaneous X-ray and optical observations of the LMXB X1254-690 using RXTE and CTIO. They have shown that the source did not display its usual regular deep dipping during the time of the observations. The upper limit of 2% on any X-ray orbital variation indicates a dramatic reduction in the size of the vertical structure on the disk edge. From the accompanying reduction in optical variability, they deduce that this bulge usually provides 40% of the contribution to the overall optical modulation.

Dr. Focke (U. Maryland, Dr. Swank advisor) successfully defended his Ph.D. dissertation. Using data from RXTE, he demonstrated that the time scales of shots in the light curve of Cygnus X-1 in the hard state exhibit a broad distribution. Also using data from RXTE, and new Comptonization spectral models developed with Dr. Titarchuk, he showed that the power law tail in the photon spectrum of Cygnus X-1 in the soft state varies on time scales at least as small as one minute.

Drs. Focke, Swank, and Markwardt are analyzing RXTE data from the new transient galactic black hole candidate XTE J1748-288. This source appears to be a microquasar, similar to GRS 1915+105, GRO J1655-40, and Nova Muscae 1991.

Drs. Shrader and Titarchuk conducted tests of the Bulk-Motion Comptonization (BMC) model for black-hole accretion through its application to observational data obtained with CGRO and RXTE. The results are strongly supportive of the basic features the BMC model, namely that the high-energy power law is produced through Comptonization of photons from matter within about 3 Schwarzchild radii of the black hole.

Dr. Shrader with Drs. Macomb, K.P. Singh, and F. Sutaria (Tata I.) studied the high-energy spectral and temporal properties of the accreting Be Star - neutron star binary GRO J1008-57. Evidence for iron line emission and possible cyclotron resonance absorption was explored, as was the pulse-profile dependence on energy and intensity. The outburst history of this system, and its frequency history, support the notion of ''normal'' and ''super'' outbursts in certain Be systems, and the formation of a transient disk in the case of the super outbursts.

Drs. White and Ghosh reported the implications of a time-variable cosmic star-formation rate for resolving the long-standing puzzle about the discrepancy between the birth rates of low-mass X-ray binaries (LMXB) and millisecond radio pulsars (MRP), showing that steady-state arguments are in general inadequate, and that evolving LMXB and MRP populations can account for the observations. They argued further that the X-ray luminosity distribution of normal galaxies should show strong evolution with redshift.

Drs. Titarchuk and T. Zannias (U. Micharana, Mexico) formulated and solved the problem of the X-ray spectral formation in the converging inflow into a black hole. The solution was done in the full relativistic framework. Seed photons from the disk scatter off the electrons in the converging inflow producing the hard power law tail which extends to 400-500 keV. An extended power law up to 500 keV, formed as a result of bulk motion Comptonization, is an inevitable stamp of Black Hole systems.

Drs. Shrader and Titarchuk demonstrated that the new X-ray observations of the superluminal sources GRO 1655-40 and GRS 1915+105 from RXTE and CGRO are well fitted by the converging inflow model, and that these results strongly support the converging inflow hypothesis.

Drs. Titarchuk and Muslimov with I. Lapidus (I. Astronomy, Cambridge) developed a theory of the origin of QPO phenomena in binary systems where there is an unavoidable adjustment of the Keplerian disk to the inner boundary conditions of the central object (a neutron star or black hole). In the process of the adjustment the vertical, azimuthal and radial oscillations occurs in certain part of the disk where the centrifugal barrier effect takes place.

Dr. Chen with Drs. S. Zhang (MSFC) and C. Wei (MIT) reported the discovery of two extremely fast spinning black holes in the Galactic superluminal jet sources, GRO J1655-40 and GRS 1915+105. The black hole spin rates obtained by using the X-ray spectroscopic method agree well with those obtained by measuring the ''frame-dragging'' precession frequency, a unique prediction of general relativity, in the form of a stable, high frequency QPO. Other black hole binaries in their sample, including Cyg X-1 and GS 1124-68, seem to contain only slowly or at most modestly spinning black holes.

Drs. Chen and Shrader with Dr. M. Livio (STScI) completed a comprehensive work on the morphological classification and astrophysical properties of the X-ray and optical light curves of all X-ray nova outbursts detected in the last two decades. Using data derived from this work, they found that the distinction between the neutron stars and black holes proposed by Narayan *et al.*, completely vanishes when one includes data from a larger sample.

Dr. Zhang and collaborators have uncovered further evidence for the marginally stable orbit in the X-ray binary system 4U 1820-30. The evidence suggests that the neutron star has about 2.2 solar masses. If confirmed, this result would make it possible to test the theory of general relativity and other variant gravity theories in the strong gravity regime.

Dr. Kazanas with Drs. Hua, W. Cui (MIT), and E. Grove (NRL) have continued their study of the combined spectral-timing properties of galactic X-ray binaries. They analyzed the light curves of a number of black hole candidates in two different energy bands and estimated the size of the X-ray emission region. They determined that the time lags between the hard and soft X-ray bands imply that the X-ray emission region is not located near the compact object and that they are more than a thousand times larger than previously thought.

Drs. Shrader and Barrett with Dr. K.P. Singh (Tata I.) used the ultraviolet spectrometers on IUE in low dispersion mode to make observations of the ROSAT-discovered magnetic cataclysmic variable V844 Her (RX J1802.1+1804). Given the seemingly rich spectrum of helium and oxygen emission lines, and the known relationship between He II Ly-alpha and the oxygen lines, i.e. the Bowen fluorescence mechanism, they could, in principle, constrain the size and thermodynamics of the emitting region. The physical scale is consistent with the line-emission originating in the accretion column rather than in the hot spot on the white dwarf surface.

2.5 Supernovae and Supernova Remnants

Dr. Shelton with Dr. D. Cox, Mr. Maciejewski, and Mr. Pawl (U. Wisconsin), Dr. R. Smith (CfA), and Drs. Plewa and Rozyczka (Copernicus I.) completed their multifrequency analysis of supernova remnant W44. They demonstrated that thermal conduction or other energy mixing phenomena take place within the remnant's interior, that much of the radio synchrotron emission derives from cosmic rays which are swept up and adiabatically heated by the shockfront, and that the periphery of the supernova remnant is forming a cool, HI shell.

Drs. Hwang and Petre obtained a new, deep ASCA observation of the young supernova remnant N103B that reveals a previously undetected Fe K blend. The success of a Sedov model in describing this remnant indicates that its interaction with a nearby H II region is driving part of the remnant quickly to the adiabatic phase.

Dr. Petre with Dr. J. Rho (UCSB) investigated the thermal and nonthermal X-ray emission from ''mixed morphology'' SNRs, those with radio shells but centrally peaked, thermal X-ray emission. They used ROSAT and ASCA data to demonstrate that these remnants represent a true physical class, not merely a morphological one.

Dr. Shelton has shown via modeling that the X-ray properties arise from enhanced conduction in the interior of a remnant in the momentum conserving stage, that has propagated into an interstellar medium with a higher than average density. Drs. Shelton and Petre are currently applying this model to ROSAT data from G65.3+5.7, a nearby example of this class.

Drs. Petre, Hwang, Allen, Gotthelf, and Keohane are engaged in the continuing search for non-thermal X-ray emission from SNR shells, a sign of shock acceleration of TeV cosmic rays. Detailed studies continue of SN1006. RXTE data provide a detailed measure of the electron synchrotron spectrum in the 10-20 keV band; ASCA data provide a spatially resolved measure of the spectral slope.

Dr. Allen has shown that the Lupus Loop has a nonthermal spectrum that extends to energies at least as high as about 20 keV. This non-thermal emission may be produced by bremsstrahlung radiation from a non-thermal distribution of electrons. Studies of relatively old remnants, such as the Lupus Loop, may help determine how particle acceleration processes evolve in supernova remnants and what fraction of the electrons are accelerated to non-thermal energies.

Dr. Safi-Harb has used ROSAT, ASCA, and XTE data to study the emission processes in the eastern lobe of W50, the SNR associated with SS 433, and has found non-thermal X-ray emission over ~ 3 orders of magnitude in energy. This emission probably results from synchrotron radiation of relativistic particles produced by the interaction of the SS 433 jet with the surrounding SNR shell.

Dr. Keohane (U. Minnesota, Dr. Petre advisor) completed his Ph.D. dissertation on comprehensive search for nonthermal X-ray emission from the shells of the supernova remnants with the highest radio brightness. He uses limits he places on the nonthermal X-ray flux to constrain the maximum energy of the shock accelerated particles. He finds that SNRs are in general only responsible for cosmic rays with energies no higher than a few hundred TeV.

Drs. Gehrels and Jacques Paul (Saclay, France) published a paper in Physics Today on recent developments in gamma-ray observations of supernovae and other sources. The paper reviews results from CGRO and GRANAT/SIGMA and describes future promise from INTEGRAL and GLAST.

2.6 Cosmic Rays

Dr. Digel together with Drs. Hunter, I. Grenier (CEA-Saclay), T. Dame (Center for Astrophysics), and Prof. P. Thaddeus (Center for Astrophysics), has been studying the diffuse gamma-ray emission observed by EGRET toward the outer Milky Way in Monoceros. Differential rotation of the Galaxy allows the distances of interstellar clouds in Monoceros to be estimated from the doppler shift of their CO and HI emissions. This in turn permits the gradient of cosmic-ray density in the outer Galaxy to be determined using the EGRET data. Preliminary results indicate a monotonic gradient, consistent with earlier results for the Cepheus region, and inconsistent with models of cosmic ray propagation that assume they are coupled to the spiral arms.

Dr. Baring, in conjunction with Drs. D. Ellison and S. Reynolds (NCSU), and Drs. I. Grenier and P. Goret (CEA,Saclay, Paris), has been applying the Monte Carlo shock acceleration model to study gamma-ray emission from supernova remnants. The model fully incorporates the nonlinear acceleration effects that are crucial to the understanding of SNRs. They have made predictions that can accommodate the constraining Whipple upper limits to EGRET unidentified sources with remnant associations, and have identified the conditions required for gamma-ray bright sources and those for cosmic ray generators.

Drs. Jones and Baring, together with Prof. R. Jokipii (U. Arizona), have performed a formal derivation of the theorem that states that charged particles in an arbitrary electromagnetic field with at least one ignorable spatial coordinate remain forever tied to a given magnetic field line. Such a situation contrasts the significant motions normal to the magnetic field that are expected in most real three-dimensional systems. This theorem has important consequences for plasma simulations of acceleration of cosmic rays by astrophysical shocks.

Drs. Jones and Baring, in conjunction with Dr. Ellison (NCSU), have developed a model for the acceleration of anomalous cosmic rays (ACRs) at the solar wind termination shock. This model applies their Monte Carlo shock acceleration code to the case of quasi-perpendicular shocks. They found that the observed ACR intensities are consistent with the measured abundances of pick-up ion populations in the heliosphere and the complete absence of any pre-acceleration mechanism for injecting ions into the Fermi process. Diffusion near the Bohm limit is found to provide high acceleration efficiencies so that pick-up ion components are then (and only then) unnecessary to explain the ACR intensities.

Dr. Streitmatter leads the High Energy Cosmic Ray (HECR) research group (Drs. Barbier, Christian, Gupta, Krizmanic, Mitchell, Moiseev, Ormes and graduate student S. Geier) in pursuing a broad-based investigative program seeking to unravel the processes of galactic cosmic-ray propagation and acceleration, as well as characterizing the cosmic-ray sources themselves.

The HECR group has developed the Isotope Magnet Experiment (ISOMAX), a superconducting magnetic rigidity spectrometer which can measure light isotopes (notably the radioactive clock ^{10}Be) to about 3.5 GeV/nucleon. A successful first flight of ISOMAX was made this summer. Measurements on this and future flights will allow crucial tests of standard galactic cosmic-ray transport models. As the Instrument Scientist Dr. Mitchell has played a leading role in ISOMAX development. The ISOMAX project is carried out in collaboration with groups at University of Siegen, Germany (Prof. M. Simon) and Caltech (Drs. S. Schindler, R. Mewaldt, and G. deNolfo.)

Dr. Streitmatter and Dr. A. Stephens (Tata I. of Fundamental Research) have published in Astrophysical Journal a study of techniques used in computations of cosmic ray transport. They confirmed quantitatively that traditional approaches lead to errors at low energy, and put forward a technique for obtaining exact solutions to the leaky box model.

Drs. Krizmanic, Ormes and Streitmatter have edited the AIP Conference Proceedings for the workshop on Observing Giant Cosmic Ray Air Showers From $> 10^{20}$ eV Particles from Space which was held in November 1997.

The HECR group is a member of the WiZard/CAPRICE collaboration, which is headed by Dr. S. Stochaj (New Mexico State U.), and is carrying out a program of measuring antimatter fluxes and limits in the 0.1 - 40 GeV range.

Drs. Ormes, Mitchell, Moiseev and Streitmatter participate in the Balloon-Borne Superconducting Solenoid (BESS) collaboration led by a group of Japanese investigators (Dr. S. Orito *et al.*). This instrument has made five flights measuring antiproton fluxes and antihelium flux limits at low energies. The recently reported results from this work have improved the limits on the flux of antihelium by more than an order of magnitude.

Dr. Ramaty, in collaboration with Drs. Lingenfelter (UCSD) and Kozlovsky (Tel Aviv U.), has been studying the relationship between the problem of cosmic ray origin and the origin of the light elements (Li, Be and B) in the early Galaxy. They have shown that the erosion products of freshly formed grains in supernovae play a central role in accounting for both the observed abundances of the refractory metals in the cosmic rays (primarily Mg, Al, Si, Ca, Fe and Ni) and the production of Be in the early Galaxy by cosmic ray interactions. Both C and O can be found in the dust grains, primarily as oxides and graphite. Their work has thus established a strong link between the current epoch direct cosmic ray observations and the atomic spectroscopy studies of abundances in old halo stars.

Drs. Boldt and Ghosh suggested that the highest energy cosmic rays (i.e., those observed at energies $\sim 10^{20}$ eV) may be accelerated to such energies near the event horizons of spinning supermassive black holes associated with presently inactive quasar remnants, the required emf being generated by the rotation of the (externally supplied) magnetic field threading the hole's horizon.

2.7 Interstellar Matter and Molecular Clouds

Mr. Kuntz and Dr. Snowden with Dr. F. Verter (GSFC/LASP) continue their work on X-ray absorption techniques for determining N(H_2) in molecular clouds. Their current work focuses on reconciling the discrepancies in N(H_2) measured using different energy X-ray bands.

Dr. Harris and co-workers on the Transient Gamma Ray Spectrometer (TGRS) mission measured the spectrum of positron annihilation radiation from the region of the inner Galaxy. Thanks to TGRS's excellent spectral resolution, details of both annihilation line and continuum spectrum were resolved, allowing inferences to be made about the sites of positron annihilation in the interstellar medium.

Dr. Digel with Dr. R. Mukherjee (Barnard College), Prof. E. Aprile, and Dr. F. Xu (Columbia U.) has been studying the diffuse gamma-ray emission observed by EGRET in the Orion region, which contains the nearest giant molecular cloud complex and massive star-forming regions. The present work updates a previous study with significant additional exposure that is now available. No evidence for cosmic-ray gradients or gamma-ray point sources has been found.

2.8 Our Galaxy

Dr. Shelton has determined that the high stage ions of C IV, N V, and O VI observed within the first kiloparsec of the disk at high latitudes can be attributed to a population of supernova remnants. Recently she has found and currently she is in the process of demonstrating that the high latitude 1/4 keV X-ray emission originating above the HI layer can also be attributed to the population of supernova remnants.

Mr. Kuntz and Dr. Snowden studied the small-scale fluctuations in the 1/4 keV background and have worked characterize the nature of the fluctuations observed at high and low galactic latitudes. Mr. Kuntz developed a new mosaicking technique for ROSAT data that allows such a study to be made using serendipitously overlapping ROSAT PSPC pointings to obtain several-degree-size fields with deeper exposures than the ROSAT All-Sky Survey. This technique produces mosaics with significantly smaller region-to-region variation than previous methods.

Dr. Snowden with Drs. R. Egger, M. Freyberg (MPE), Plucinsky (CfA), and Mr. D. Finkbeiner (UC Berkeley) used ROSAT all-sky survey data to study the distribution of emission responsible for the 1/4 keV soft X-ray diffuse background. They found that 75% of the observed flux originates in the Local Hot Bubble with most of the rest originating in the halo of the Milky Way. The halo emission provides up to 50% of the observed flux in some directions.

Drs. Valinia and Marshall examined the spatial extent and spectral nature of the diffuse X-ray emission from the Galactic ridge using RXTE in order to determine the origin of the emission. The emission was found to have two spatial components: a thin disk of full width less than 0.5 degrees, and a broad component with FWHM of about 4 degrees. In the 3-35 keV energy band, the spectrum of the diffuse emission was modeled with a power law component with photon index of about 1.8 (dominating above 10 keV) and a thermal component of temperature 2-3 keV, less than the previously reported values of 5-15 keV. They have explained the origin of the emission in terms of thermal and nonthermal processes in the Galaxy.

Drs. Digel and Snowden with Mr. M. Almy (U. Wisconsin), Prof. L. Bronfman (U. Chile), and Mr. J. May (U. Chile) have undertaken a study of the shadowing of the diffuse soft X-ray background by the interstellar cloud G337+4 using ROSAT PSPC observations and ground-based data for the CO 2.6 mm and HI 21 cm lines. G337+4 is well-placed in both direction and distance to allow the component of the soft X-ray background that is associated with the halo of the Milky Way to be distinguished from the emission of the Local Hot Bubble.

2.9 Gamma Ray Bursts

Drs. Chen and Shrader with Drs. R. Hynes, C. Haswell, R.P. Fender (U. Sussex), K. Horne, E. Harlaftis, K. O'Brien (U. Andrews), and C. Hellier (U. Amsterdam) detailed the 1996 May outburst of GRO J1655-40. The data were obtained through the successful simultaneous multiwavelength campaign which involved XTE, HST and several ground-based telescopes. The X-ray and optical light curves show a peculiar anti-correlation on time scales of a few months, while the short term light curves on time scales of a few to a few hundred seconds clearly show a close correlation in which the optical variations lag behind the X-rays by about 20 seconds, indicating that the optical comes from the reprocessed X-rays.

Drs. Norris and Bonnell continued a collaboration with Dr. J. Scargle (NASA/ARC) on Bayesian analysis algorithms designed to fit gamma-ray burst (GRB) temporal profiles. Drs. Bonnell and Norris, with Dr. R. Nemiroff (Mich. Tech U.) and Dr. G. Marani (GMU), studied the brightness distribution of GRBs, and described the potential of spike-like GRBs to gravitational lens stars and place limits on cosmological parameters.

Graduate student Jennifer Catelli with Drs. B. Dingus (U. of Utah) and E. Schneid (Northrop-Grumman) continue to analyze spectra from the EGRET NaI(Tl) detector for 1-100 MeV emission from gamma-ray bursts. At least 30 bursts have now been found with high-energy emission.

2.10 Physics in Strong Magnetic Fields

Drs. Baring and Harding in conjunction with Dr. P. Gonthier (Hope College) have investigated the behaviour of the resonant Compton scattering cross-section in supercritical magnetic fields. They have obtained numerical results and approximate analytic forms in the case where incoming photons propagate almost along the magnetic field, and found that Klein-Nishina suppression of the cross-section yields significantly different polarization properties from the ''Thomson'' regime of subcritical fields. Such computations will be extremely useful for models of strongly-magnetized pulsars and soft gamma repeaters.

Dr. Baring, together with Dr. J. Weise and Prof. D. Melrose (U. Sydney), have been researching the physics of the process of magnetic photon splitting. They have re-derived analytic expressions for the S-matrix rates and have obtained further significant simplification of the formulation. In special cases, these rates reduce to certain well-known simple forms that were obtained by another technique, the proper-time formalism, and agree with proper-time rates computed by a code developed by Drs. Baring and Harding. These rates are useful for astrophysical models of pulsars and soft gamma repeaters.

2.11 Normal Galaxies

Dr. Loewenstein with Dr. R. E. White III (U. Alabama) investigated the dark matter properties of elliptical galaxies using temperatures measured with the ROSAT PSPC in an optically complete sample. They conclude that dark matter halos are ubiquitous in bright elliptical galaxies, and that the average visual mass-to-light ratio inside six half-light radii is about 20 (in solar units), independent of optical luminosity. The latter implies that less luminous galaxies are more dark matter dominated–a conclusion consistent with weak lensing observations, but contrary to the predictions of Cold Dark Matter models for halo formation if all ellipticals have the same baryon fraction.

Drs. Mushotzky and Loewenstein have measured H- and He-like Si line strengths in ASCA spectra of the X-ray brightest elliptical galaxies. They found excellent agreement between these line ratios and those predicted by the temperature obtained from global spectral fitting, thus supporting the standard characterization of the hot ISM as an approximately single-phase gas with sub-solar abundances. They also found consistency between optical and X-ray Fe abundances; however, the relative overabundance of alpha-elements seen in the optical Mg/Fe ratio is not reflected in the hot gas where the Si/Fe ratio is generally solar.

Drs. Colbert and Mushotzky investigated the origin of nuclear X-ray sources in normal galaxies. They found compact X-ray sources in 21 (54%) of 39 nearby face-on spiral and elliptical galaxies with available ROSAT HRI data. Six of the galaxies show a hard component with a relatively steep ($\gamma \sim 2.5$) spectral slope. Blackbody model fits to the spiral-galaxy data suggest that the X-ray object in these galaxies may be similar to a Black Hole Candidate in its soft (high) state. The steeper spectral slopes and relatively low absorbing columns compared to normal type 1 AGNs indicate that these objects are somehow geometrically and/or physically different from AGNs in normal active galaxies.

2.12 Active Galaxies

Drs. George, Turner, Nandra, Mushotzky, and Yaqoob with Dr. H. Netzer (Wise Observatory) have presented the third in a series of papers describing the X-ray spectra of Seyfert 1 galaxies. Absorption by ionized gas was found to be extremely common, and probably multi-zone. Many sources also exhibit the emission signature of this warm absorber.

Drs. George, Nandra, Turner, and Mushotzky with Drs. A. Laor (Technion, Haifa), F. Fiore (Osservatorio de Roma), and Netzer presented an ASCA spectrum of PG 1114+445, which showed the signatures of ionized gas: a rare find in quasars.

Drs. George and Mushotzky with Dr. K. Leighly (Columbia U.) and others have presented X-ray observations of the broad-line radio galaxy 3C390.3, which showed dramatic variability in the soft X-ray band.

Drs. George and Shrader with Dr. K.P. Singh (Tata I.) have presented the first high-quality X-ray spectrum of the high-polarization quasar PKS 1510-089.

Drs. Mushotzky and Nandra, with Dr. Leighly and Mr. K. Forster (Columbia U.) have presented evidence for relativistic outflows in three narrow-line Seyfert 1 galaxies, based on the detection of blueshifted absorption features–attributed to oxygen–in their ASCA spectra.

Drs. Nandra, Mushotzky, George, Turner and Yaqoob have demonstrated an inverse correlation between the strength of iron K-alpha line of AGN and their luminosity. This ''X-ray Baldwin Effect'' is accompanied by changes in profile, perhaps due to changes in ionization state of the accretion disk in which the line is produced.

Drs. Turner, George, Nandra and Mushotzky have presented a series of three papers describing the X-ray spectra of Seyfert 2 galaxies observed by ASCA. A highlight of this work is the discovery of widespread broadening and redshift of the iron K-alpha lines. The profiles were found to be similar to Seyfert 1 galaxies, in apparent conflict with orientation-dependent unification schemes.

Dr. Andrew Ptak (U. Maryland, Dr. Serlemitsos advisor) successfully defended his Ph.D. dissertation dealing with nuclear emission in the X-ray band from nearby spiral galaxies. Using imaging and spectral data from ASCA and ROSAT, he derived constraints on accretion and starburst processes in these galaxies.

Dr. Turner with Dr. Netzer has presented detailed photoionization modeling of the soft X-ray lines observed in the Seyfert 2 galaxy NGC 1068.

Dr. Ghosh with Dr. M. Abramowicz (U. Goteborg) critically reassessed the strengths of magnetic fields threading the horizons of disk-accreting black holes in radio galaxies and active galactic nuclei, showing that these strengths are considerably lower than previously imagined. Hence the strength of the Blandford-Znajek (BZ) process for extracting the black hole's rotational energy is correspondingly lower, and cannot account for the luminosities of the strongest double radio sources. However, the BZ process still accounts for the bulk of the radio-source population, and the BZ luminosity dominates that due to accretion.

Dr. Ghosh analyzed the structure of stationary, axisymmetric, Schwarzchild black-hole magnetospheres in the ''3 +1'' formalism, discovering a set of solutions which has a term-by-term analogy with the familiar multipole solutions of flat-space electrodynamics. These solutions will serve as building blocks in future modeling of black-hole magnetospheres in interesting astrophysical situations.

Dr. Madejski with Mr. P. Wozniak (Princeton) and Drs. A. Zdzarski (Copernicus Ctr.), D. Smith (U. Leicester), and N. Johnson (NRL) assembled the available X-ray and gamma-ray data for radio-loud Seyfert galaxies. Unlike the radio-quiet Seyferts, spectra of these objects in general are devoid of Compton reflection component, but show a Fe K line that is comparable in strength to that observed in radio-quiet Seyferts.

Dr. Madejski with Dr. A. Wehrle (IPAC) and others published the results of multi-band monitoring campaign to observe the prototypical EGRET gamma-ray blazar 3C279, which revealed correlated X-ray and GeV gamma-ray variability.

Dr. Madejski with Dr. M. Sikora, Mr. R. Moderski (Copernicus Ctr.), and J. Poutanen (Stockholm Obs.) investigated general constraints on the structure of jets in blazars, giving the limits of applicability of synchrotron self-Compton models to blazars with emission lines.

Dr. Madejski with Drs. H. Kubo (Tokyo U.), T. Takahashi (ISAS), and others analyzed the X-ray emission from blazars observed by the ASCA satellite. These data, together with the EGRET observations, imply that the blazars associated with quasars showing strong emission lines have high energy emission consisting of multiple spectral components, most likely Synchrotron Self-Compton for the X-ray band, and External Radiation Compton for the GeV gamma-ray band.

Stimulated by a high optical state of BL Lacertae, a Compton Observatory Target of Opportunity observed this AGN in July, 1997. During this period, BL Lac was seen by EGRET at its highest state in the 10 times it had been observed. The correlation with the optical high state reemphasizes the need for simultaneous multiwavelength observations in blazar studies. The EGRET and corelated optical analysis effort was led by Dr. Bloom.

Dr. Sreekumar along with members of the EGRET team reported the clearest evidence yet for the detection of the nearest active galactic nuclei, Centaurus A. This is based on refined positional analysis and good broad-band spectral agreement (from 30 keV to 1 GeV) with OSSE and COMPTEL results. The refined EGRET position for the first time eliminates other viable radio counterparts, a source of concern with both the COMPTEL and OSSE analysis. Unlike the blazar-class of AGN seen by EGRET, Cen A is characterized by a large inclination jet, and shows for the first time the presence of significant high-energy gamma-ray emission in another class of AGN.

2.13 Clusters of Galaxies

Drs. Arnaud and Mushotzky used BBXRT observations of the Perseus cluster to argue that the excess absorption seen in cooling flows is due to dust.

Drs. Hwang, Mushotzky, and White with Dr. J. Burns (New Mexico State U.) are continuing to use ASCA and ROSAT data to carry out spectral measurements of galaxy groups and to calculate their gas and binding masses. Their X-ray bright groups have properties at the low end of the range for richer clusters.

Drs. Valinia, Loewenstein, Mushotzky, and Madejski, with Drs. M. Henriksen (U. North Dakota) and Kurt Roettiger (U. Missouri), observed Abell 754, a cluster undergoing merging, with RXTE in order to find evidence of inverse Compton scattering from the intracluster medium (ICM). Only an upper limit for the nonthermal emission was found. From this, they derived a lower limit for the magnetic field strength in the ICM.

2.14 Extragalactic Background

Dr. Gendreau with Drs. A. Fabian (IoA, Cambridge) and X. Barcons (I. de Fisica de Cantabria) conducted a fluctuation analysis of deep, 2-10 keV ASCA SIS images in order to probe hard X-ray source counts downs to a limiting flux of 2×10^{-14} ergs cm^{-2} s^{-1}. Down to this limit, the source-count function follows a Euclidean form which extrapolates well to previous results at higher fluxes. The integrated contribution of these source counts amounts to 35 +/- 13% of the extragalactic 2-10 keV X-ray background.

Dr. Gendreau with Drs. H. Tsunemi and K. Yoshita (Osaka U.) have conducted an analysis of the subpixel structure of ASCA SIS CCDs. They are exploring ways to extend this work toward making an X-ray polarimeter.

Drs. Jahoda, Boldt, and Scharf with Drs. M. Treyer (Potsdam), O. Lahav (IoA, Cambridge), and T. Piran (Racah I., Jerusalem) used harmonic analysis of large scale surface brightness fluctuations of the cosmic X-ray background to establish constraints on the structure of the Universe on scales of hundreds of Mpcs.

Drs. Jahoda and Scharf with Drs. M. Birkinshaw (Bristol), S. Boughn (Haverford), and Mr. S. Molnar (Bristol) began a search for inter-cluster X-ray emission from the Shapely Super Cluster.

2.15 Catalogs

Drs. Hwang, Petre, and Snowden launched a program to create an image archive of ROSAT observations of supernova remnants. Processing of the HRI data is nearly completed, and that of PSPC data has begun.

Dr. Hartman and the EGRET team are completing work on a third EGRET catalog of high-energy gamma ray sources. With this catalog, the number of high-energy gamma-ray sources will increase to more than 270.

3. OPERATING ORBITAL FLIGHT MISSIONS

3.1 Roentgen Satellite (ROSAT)

This joint German-US-British satellite-borne X-ray observatory is in its 9th year of extremely successful operation. Most of the remainder of the PSPC gas was utilized in early 1998 for a small number of pointings designed to fill in the few remaining gaps of the ROSAT All-Sky Survey and a few Target of Opportunity Observations. The PSPC sky coverage is now nearly 100% complete. Normal Guest Observations continued with the HRI until late April, 1998, when the remaining spacecraft star tracker failed. Efforts are continuing to replace the lost star tracker information with data from the tracker attached to the Wide Field Camera. The LHEA houses the Guest Observer Facility for the U.S. ROSAT Science Data Center. Dr. Petre is U.S. ROSAT Project Scientist. Dr. Corcoran serves as HEASARC liaison and archive scientist. Scientific support is provided by Drs. Snowden and Turner. The technical support staff is led by Mr. Arida. Significant milestones in 1998 were the completion of both the comprehensive reprocessing of all ROSAT observations and the first release of an HRI source catalog as part of the ROSAT Results Archive. Efforts to understand PSPC and HRI calibration issues continued.

3.2 Compton Gamma Ray Observatory (CGRO)

The Compton Gamma Ray Observatory (CGRO) has been in orbit since April 1991. The spacecraft and instruments are performing well, and the science return is large. The four instruments onboard cover an unprecedented six orders of magnitude in energy, 30 keV to 30 GeV, with an order of magnitude improvement in sensitivity over previous missions. The scientific theme of CGRO is the study of physical processes taking place in the most dynamic sites in the Universe, including supernovae, novae, pulsars, black holes, active galaxies, gamma-ray bursters, and solar flares. The first 15 months of the mission (Phase 1) were dedicated to a full-sky survey. A Guest Investigator program has been implemented and a Science Support Center established at the Goddard Space Flight Center to support the Guest Investigators. Dr. Gehrels is Project Scientist and Drs. Bertsch and Norris are Deputy Project Scientists.

In its sixth year of operation, CGRO has made many exciting discoveries. The Energetic Gamma-Ray Experiment Telescope (EGRET) instrument has continued to find that many blazars, at extremely large distances, emit more energy in gamma rays than all other types of emission put together, and seem to brighten and fade even during a 2-week observation. EGRET has also detected high-energy gamma-ray emission from gamma-ray bursts up to 90 minutes after the burst. The Burst and Transient Source Experiment (BATSE) has observed a total now of over 2000 gamma-ray bursts. They are isotropically distributed on the sky and have a deficit of weak bursts compared to a homogenous distribution in space. A new accurate-location capability has been implemented by the BATSE team for rapid release of $\sim$ 1 degree positions for bright bursts. The Compton Imaging Telescope (COMPTEL) has a new all-sky map of the 1809 keV line emission from ^{26}Al which traces the sites of nucleosynthesis in the Galaxy over the past million years.

3.3 Energetic Gamma Ray Experiment Telescope (EGRET)

The EGRET instrument, which covers the energy range from 30 MeV to over 30 GeV, continues to function fairly well after over seven years in orbit on board the Compton Gamma Ray Observatory. Highlights of the observations include: (1) the finding of a new class of objects – high energy gamma-ray emitting blazars, (2) the emission of high energy gamma-rays from a burst for over an hour, with some gamma-rays having energies over a GeV and two having energies of over 10 GeV, (3) the observation of seven high-energy gamma-ray pulsars, (4) the determination with high certainty that cosmic rays are galactic, (5) the detailed mapping of the Galactic diffuse radiation and the measurement of the pion bump in the high-energy spectrum, (6) the absence of microsecond bursts and its implication for certain physics unification theories, (7) the long time of over eight hours for observing energetic solar particles following a flare, and (8) a measurement of the extragalactic diffuse radiation and its consistency with that expected from AGN emission. The data processing effort is proceeding well. The specified preliminary results and the final data products are being supplied to the GRO Science Support Center on schedule. There continues to be a fruitful interaction with many Guest Investigators.

3.4 Solar Anomalous and Magnetospheric Explorer (SAMPEX)

Dr. von Rosenvinge is Project Scientist for and a Co-Investigator on the SAMPEX small explorer mission launched in 1992. SAMPEX is in an extended mission phase to study both trapped and interplanetary anomalous cosmic rays, the charge states of solar energetic particles, and the acceleration of magnetospheric particles and their effects on the upper atmosphere. SAMPEX has also documented the build-up of energetic particles in the magnetosphere which frequently accompany satellite failures.

3.5 Advanced Satellite for Cosmology and Astrophysics (ASCA)

The joint Japanese-U.S. ASCA mission continues to work well and produce excellent data. The Guest Observer Facility (GOF) successfully supported the AO-6 proposal review cycle, and has continued its routine support of guest observers. The ASCA archive at HEASARC now contains over 1800 sequences, and it continues to grow as new sequences go public; all sequences have been processed using the Rev2 script. Drs. Gotthelf and White have produced the ASCA SIS source catalog, which currently contains over 400 individual detections. In addition, the GOF has taken a proactive role in the ASCA team's effort to update and improve the calibration. Dr. Gotthelf (in collaboration with Dr. Ueda) have recalibrated the attitude solution, which has resulted in a reduction in the point source position uncertainties by a factor of two. Dr. Yaqoob, in collaboration with Drs. Gendreau, Ebisawa, and the GIS team, has gained additional insight into the small discrepancies in the current XRT+GIS calibration. Dr. Mukai, in collaboration with Drs. Pier and Huang (ASCA Data Facility, NASA GSFC) and the SIS team, has identified a previously unknown factor which contributes to the low energy calibration uncertainties of SIS. The GOF is collaborating with the respective hardware teams to produce improved versions of the response matrices.

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

The Transient Gamma-Ray Spectrometer (TGRS) aboard the GGS/WIND spacecraft (launched November 1, 1994) is primarily designed to perform high resolution spectroscopy of transient gamma-ray events, such as cosmic gamma-ray bursts (GRBs) and solar flares. Measurements can be performed over the energy range 15 keV to 8.2 MeV with a spectroscopic resolution of $\sim$ 3 keV at 500 keV. The detector itself consists of a large high purity Ge crystal kept at cryogenic temperatures by a passive radiative cooler. In addition to the transient event measurements, the instrument observes transient X-ray pulsars, diffuse gamma-ray background, and monitors changes in the intensity of continuum and annihilation radiation from the Galactic Center. TGRS also contributes to the next interplanetary gamma-ray burst network. The scientists involved from this Laboratory are Drs. Teegarden (PI), Harris, Gehrels, Cline, Palmer and Ramaty and P. Kurczynski. Dr. Palmer has been working on the analysis of GRB spectra with an emphasis the events with detected afterglows. P. Kurczynski is working on a PhD thesis involving the search for fine structure in the spectra of GRBs. Dr. Harris is conducting a search for gamma-ray line emission from galactic novae.

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

Dr. von Rosenvinge is the Principal Investigator for the Energetic Particles: Acceleration, Composition, and Transport (EPACT) experiment, developed in conjunction with Drs. Reames and Barbier for the Wind spacecraft and launched in November, 1994. The experiment consists of the ELITE instrument which studies $1 \leqslant Z \leqslant 28$ high energy particles up to 250 MeV/nuc, and the Low Energy Matrix Telescope instrument, designed to study lower-energy and higher-Z particles. ELITE includes two telescopes provided by Dr. G. Mason (U. Maryland). Sensitivity for low energy particles has been increased by two orders of magnitude, so that high sensitivity studies of the anomalous component, Corotating Interaction Regions and ^{3}He-rich events have been possible. Recent studies have been focusing on the solar events which are accompanying the current rise of solar activity.

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

The first astrophysics experiment from Russia flown on a NASA mission was Konus, launched on the GGS-Wind mission in November, 1994 (Dr. E.P. Mazets, St. Petersburg, PI). Consisting of two gamma-ray burst spectrometers, it monitors events at about half the rate of detection of the large area detectors on CGRO-BATSE. At its several-light-second distance from Earth, its coverage is continuous, not limited by Earth occultation or magnetospheric effects, so that about half of all the GRB events missed by the CGRO are observed. Studies are underway to evaluate the presence or upper limits to the presence of spectral features in GRBs. Also, Dr. Cline, the Co-PI, and Drs. P. Butterworth (GSFC/RSTX) and Barthelmy, have made provisions to automatically include the Konus data into the GCN reporting system for the interplanetary network. This will make possible a higher rate of GRB rapid response notices with the GCN system when the NEAR data are included (see the IPN section).

3.9 Rossi X-ray Timing Explorer (RXTE)

The Rossi X-ray Timing Explorer (RXTE), in its third year of operation, continues to meet all of its operational requirements. Continued operation for up to 5 years has been recommended and is being planned. The spacecraft carries the collimated Proportional Counter Array (PCA) and High Energy X-ray Timing Experiment (HEXTE), that produce 2-200 keV measurements on time-scales from microseconds to years, and the All Sky Monitor (ASM) that obtains long term lightcurves of sources brighter than a few microJanskys, and detects new sources as well as changes in known sources. As much as 25% of the pointed detectors observing time is for targets of opportunity (TOOs), that is, made in response to discoveries of either the ASM, the CGRO's BATSE, or public data obtained from TOO observations that were not part of accepted proposals. Information on the detectors, data access, data analysis tools, and results of the mission are available on the Web at http://heasarc.gsfc.nasa.gov/docs/xte/XTESOC.html.

RXTE opened up, with its combination of large area, flexible data modes, and high-rate telemetry, the phase space of temporal measurements above 100 Hz and especially above 500 Hz. Highlights from last year include the discovery of the first millisecond accreting X-ray pulsar. The 2.5 ms period discovered for SAX J1808-369 conclusively demonstrates the link between low mass X-ray binaries (LMXBs) and millisecond radio pulsars. The similarity of the period to the periods of the oscillations seen during bursts from LMXBs further suggests that these burst oscillations are the results of neutron star spins. These burst oscillations are being used to determine parameters of the spinning neutron star and thereby constrain the equation-of-state of material in extreme conditions. RXTE has carried out extensive investigations of ''microquasars'' in our galaxy. These sources are thought to be small-scale version of extragalactic quasars whose proximity facilitates detailed studies. GRS 1915+105 exhibits bipolar superluminal ejection events whose triggers are coincident with dips in the X-ray intensity. The X-ray spectral changes indicate that these dips are times when the inner accretion disk disappears. These detailed studies of the formation of relativistic jets are unique. RXTE has also discovered 7.5 second pulsations from the soft gamma-ray repeater SGR 1806-20. The observed spindown rate indicates a magnetic field of 2×10^{14} G—one of the largest values ever seen.

A breakthrough in the modeling of the internal background for the PCA means that the spectra and variability of weak sources such as active galactic nuclei can now be determined with confidence. The data from many AGN monitoring campaigns can now be interpreted. For example, a 30-day observation of NGC 7469 produced the startling result that changes in the X-ray flux lag changes in the UV flux by about 4 days.

The RXTE Learning Center released its ''Tour the ASM Sky'' feature allowing the public to access live ASM data via a user-friendly CGI interface. This feature encourages teachers to use this data in the classroom by supplying teacher-written lesson plans. The Learning Center also keeps the public updated on RXTE's science with its ''RXTE Discoveries'' feature. For example, past ''Discovery'' articles have been written about the millisecond pulsar SAX J1808.4-3658, the magnetar SGR 1806-20, and the pulsars discovered near SMC X-3. A print booklet on X-ray Astronomy and RXTE entitled ''Shedding a New Light on the Universe'' is in development. It will feature an easily-assembled full-color paper model of RXTE. Since the RXTE Learning Center's layout was redone in October of 1997, the number of times it is accessed a month has consistently climbed, recently culminating in over 26,000 accesses for a single month.

3.10 Interplanetary Gamma-Ray Burst Timing Network (IPN)

The Interplanetary Network now incorporates gamma-ray burst information from the Ulysses mission (Dr. K. Hurley of UC Berkeley, PI), Compton-GRO, (Dr. G. Fishman, MSFC, BATSE PI), GGS/Wind, (Dr. Teegarden, GSFC, TGRS PI, and Dr. E. P. Mazets, St. Petersburg, and Dr. Cline, GSFC, Konus Co-PIs), and the Near Earth Asteroid Rendezvous (Dr. R. Gold, APL, PI). An intended contributory mission, the Mars-96 spacecraft, suffered a launch failure. Software modifications made to enable a burst response on the NEAR mission have been tested successfully with bursts that were observed when NEAR was close to the Earth in December, 1997. In the autumn and winter of 1998, NEAR will be sending data again, when it is more than 1 AU from the Earth. This will complete a long baseline network with Ulysses at several AU. GRB events will be automatically included in the GCN system, making possible the first reporting system using a high-precision GRB network. It is hoped that this development will enable a much higher rate of searches for delayed GRB-associated phenomena such as optical and radio transients.

3.11 Advanced Composition Explorer (ACE)

The Advanced Composition Explorer (ACE) was successfully launched on August 25, 1997. LHEA scientists involved include Drs. Christian and von Rosenvinge (Project Scientist). ACE includes two instruments which were developed jointly by Caltech, GSFC, and Washington University in St. Louis. The Cosmic Ray Isotope Spectrometer has made unprecedented new measurements of heavy cosmic ray isotopes. These measurements include observations of the isotopes ^{59}Ni and ^{59}Co which suggest that there is a delay of $\sim 10^5$ years or more between the synthesis of ^{59}Ni by supernovae and its acceleration to cosmic ray energies. The Solar Isotope Spectrometer has measured isotopes in the Anomalous Cosmic Rays (ACRs) and in solar energetic particle events. It has been demonstrated that the $^{22}Ne/^{20}Ne$ ratio in the ACRs, which are a sample of the local interstellar medium, is similar to this ratio in the solar system and unlike this ratio in cosmic-ray sources. This implies that the cosmic rays are not simply accelerated out of the interstellar medium, as has been commonly supposed.

4. FUTURE FLIGHT MISSIONS

4.1 The Monitoring X-ray Experiment (MOXE)

The Monitoring X-ray Experiment (MOXE) is an all-sky monitor being developed as one of the core instruments for the Spectrum-X-Gamma mission. MOXE is a collaboration between LHEA (Drs. Black and Kelley), the Los Alamos National Laboratory (Drs. W. Priedhorsky and E. Fenimore), and the Russian Space Research Institute (Drs. Borozdin, Kaniovsky, and Arefiev). It will monitor several hundred X-ray sources on a daily basis, and will be the first instrument to continuously monitor most of the X-ray sky, thus providing long-term light curves of many galactic as well as some extragalactic sources. MOXE will also alert users of more sensitive instruments on Spectrum-X-Gamma to transient activity.

MOXE distinguishes itself with respect to other all-sky monitors in its high duty cycle, thus having unprecedented sensitivity to transient phenomena with time scales between minutes and hours. This duty cycle is a result of both the instrument design and Spectrum-X-Gamma's four day orbit. The instrument consists of a set of 6 X-ray pinhole cameras based on imaging proportional counters. Together, they view 4 π steradians. With a 24 hour exposure, MOXE will have a sensitivity of about 2 mCrab and be able to locate a 10 mCrab source to better than 0.5 degrees.

The MOXE flight instrument is complete and has passed a flight acceptance test at Goddard and is ready for delivery. The MOXE engineering model has been delivered to the Russian Space Research Institute and undergone complex tests there with other engineering model instruments on Spectrum-X-Gamma. Delivery of the flight instrument to Russia is planned for late 1998.

4.2 X-ray Multi-Mirror (XMM)

A Guest Observer Facility has been organized to support US participation in the European XMM project. XMM, which will be launched 2 August 1999, will cover the 0.1 - 15 keV energy range with large effective area, moderate angular resolution ($15''$), and moderate (CCD) and high (grating) spectral resolution. XMM will include an Optical Monitor for simultaneously cover the UV/optical band. The GOF is currently supporting software development at Leicester U. and gearing up to support the proposal process (starting 15 September 1998).

4.3 X-Ray Spectrometer (XRS/Astro-E)

Astro-E is Japan's fifth X-ray Astronomy mission and is scheduled to be launched in early 2000. It is being developed at Institute of Space and Astronautical Science (ISAS) in collaboration with US (NASA GSFC, MIT) and Japanese institutions. Astro-E will cover the energy range 0.4 - 700 keV by the three instruments, X-ray micro-calorimeter (X-ray Spectrometer; XRS), X-ray CCDs (X-ray Imaging Spectrometer; XIS), and the hard X-ray detectors (HXD). Astro-E will have four foil X-ray telescopes (XRT, see Section V) in front of four XIS and one XRT in front of XRS. The US contributions to this mission involve Goddard Space Flight Center to build the X-ray telescopes and micro-calorimeters, and MIT to build the four X-ray imaging spectrometers.

The XRS instrument consists of an array of cryogenically cooled X-ray microcalorimeters capable of an energy resolution of $\sim$ 12 eV over the range 0.3 - 12 keV. Such detectors are thermal sensors and determine the energies of individual X-ray photons by sensing the temperature increase they generate when absorbed in a small detector element. In order to measure the small change in temperature with high signal-to-noise the detector must be operated below 0.1 K. A detector assembly, adiabatic demagnetization refrigerator (ADR), superfluid helium cryostat, and associated analog and digital electronics are being developed at Goddard and will be installed in a solid neon dewar being developed in Japan. The X-ray optics for the XRS (and four CCD cameras) will be conical foil mirrors developed by Dr. Serlemitsos *et al.* The overall development of the instrument, including testing and preparation of the microcalorimeter array, anticoincidence detector, fabrication of the detector assembly and calibration are being carried out by Drs. Kelley (PI), Boyce, Gendreau, Porter, Stahle, Szymkowiak, Moseley (GSFC LASP), and Dr. D. McCammon (U. Wisconsin). Dr. S. Holt (Director of Space Sciences GSFC) is the Project Scientist for the NASA involvement in Astro-E. The high resolution of the calorimeters coupled with their high throughput with the conical mirrors (up to 400 cm^2 at FeK) will allow high resolution spectral measurements with unprecedented sensitivity from a wide range of astrophysical sources. During the past year the instrument was essentially completed. This included the He cryostat, adiabatic demagnetization refrigerator, detector assembly, blocking filters and instrument electronics. The detector array consists of 32 pixel elements in a 6x6 arrangement (minus the four corners). The pixels are about 625 microns on a side and the full array is about 3.9 mm across. In the focal plane of the X-ray mirror this corresponds to 30 arcsec pixels and a 3 arcmin total field of view. Assembly and testing of the flight array and several flight spares was successfully completed along with several anticoincidence detectors. A full performance test and calibration were conducted during a 6 week period in February-March 1998. The essential goal of 12 eV resolution at 6 keV across the entire array was achieved. The calibration of the detector system, including the five aluminum/polyimide filters, was carried out using several devices. Drs. Gendreau and Audley brought two X-ray monochromators on line. One is based on a double crystal scheme and the other is a reflection grating monochromator developed by Dr. M. Hettrick (Hettrick Scientific). A continuum X-ray source was also used for gain and efficiency measurements. Extensive data on the spectral redistribution and detector gain have been obtained. The digital electronics, including the software for pulse detection and processing were completed and tested by Drs. Boyce and Szymkowiak. The instrument successfully passed an electromagnetic compatibility test. A vibration test of the fully integrated system will take place in September and the instrument will be shipped to Japan in October 1998.

Guest Observer Facility/Software: The main activities of the ASTRO-E GOF at this point in the mission are the archiving and documentation of ground calibration data, the specification of the data file format, and the preparation of the data analysis software. A series of discussions have been conducted with the hardware teams and a broad agreement has been reached on the data format and the framework for software development. Initial tests have been performed to produce FITS format event files from ground calibration data. In addition, a team led by Mr. Antunes (RSTX) is developing new mission scheduling software and web-based mission planning aids for guest observers.

4.4 International Gamma-Ray Astrophysics Laboratory (INTEGRAL)

INTEGRAL is a joint ESA-NASA gamma-ray astronomy mission that will be the successor to the CGRO and GRANAT missions. It was selected by ESA in 1993 as its next Medium Class scientific mission (M2). The launch is scheduled for 2001. It will be an observatory class mission that will perform high-resolution spectroscopy and imaging in the 20 keV to 10 MeV region. There are two main instruments, a spectrometer (SPI) and an imager (IBIS). By taking advantage of new technology, the INTEGRAL will have greatly improved performance over prior comparable missions, e.g., 40 times better energy resolution and 10 times better angular resolution than the CGRO. GSFC is participating in the development of scientific data analysis software for the spectrometer. The Goddard scientists involved are Drs. Gehrels (Mission Scientist), Teegarden (NASA Project Scientist), Naya, Shrader, and Sturne.

4.5 Gamma-ray Large Area Space Telescope (GLAST)

Drs. Bertsch, Bonnell (USRA), Seth Digel (RSTX), Gehrels, Hartman, Hunter, Krizmanic, Peter Leonard (RSTX), Moiseev (USRA), Norris, Ormes, Streitmatter, and Thompson are GSFC members of a large consortium contributing to the development of the Gamma-ray Large Area Space Telescope (GLAST), a next-generation high-energy gamma-ray telescope. The proposed instrument consists of an 8000 cm^2 effective area Si-strip tracker, a 10 radiation length CsI hodoscopic calorimeter, and a segmented plastic tile anticoincidence detector (ACD). GLAST extends the energy coverage of its predecessor EGRET a decade higher, to 300 GeV, while realizing much improved angular resolution and effective area over a wide ($\sim \pi$ steradian) field of view. Drs. Bonnell, Moiseev, and Norris are performing simulations to optimize design of the calorimeter and ACD. Dr. Digel is studying the capabilities of GLAST for astronomical source detection. Dr. Leonard is coordinating outreach activities for GLAST at GSFC. Drs. Moiseev, Ormes, and Thompson are implementing a prototype for the ACD. Drs. Krizmanic and Norris are collaborating with Dr. W. Neil Johnson (NRL) on the development a very large dynamic range, low-power ASIC readout for the calorimeter. Dr. Gehrels is the co-chair of the GLAST Facility Science Team and Dr. Ormes is the GLAST study scientist for NASA.

4.6 Constellation-X

The Constellation-X mission (formerly known as HTXS) is a future X-ray observatory being prepared for launch in about 10 years time with very large collecting area and high resolution spectrometers an X-ray equivalent of the Keck Telescope. The basic mission configuration is to fly six identical spacecraft to provide the large collecting area at minimum cost and risk. Funding for technology development began in earnest and the LHEA was awarded via a competitive opportunity funding for the development of X-ray calorimeters. The mission study continues to make substantial progress both in house at GSFC and at SAO with the first cooperative agreement notices being awarded to industry (TRW and Ball) in June. The Facility Science Team met for the first time in March 1998 at SAO and has begun work on simulating an observing program for the observatory to ensure its capabilities are well tuned to the science goals.

4.7 Orbiting Wide-angle Light-collectors (OWL)

A collaboration led by Dr. Ormes is carrying out a study of the possibility of detecting the highest energy cosmic rays by observing from space the fluorescence light from giant air showers produced when these particles interact with the atmosphere. The Orbiting array of Wide-angle Light-collectors (OWL) project includes the GSFC HECR group, Marshall Space Flight Center (Dr. T. Parnell), U. Alabama (Dr. Y. Takahashi) and the U. Utah (Drs. G. Loh, P. Sokolsky, and P. Sommers). Dr. Krizmanic is leading efforts to simulate OWL instrument performance, and Dr. Mitchell is leading efforts to develop a focal plane detector system for OWL.

Dr. Barbier is the PI on the NIGHTGLOW instrument, a proposed UV monitoring balloon instrument capable of measuring the nighttime ultraviolet background for the OWL spacecraft. NIGHTGLOW is a collaboration between the Goddard HECR group and the U. of Utah, which also runs the Fly's Eye experiment. OWL is a space-based version of Fly's Eye; it measures ultra-high energy ($> 10^{19}$ eV) cosmic ray air showers by measuring the nitrogen fluorescence in the atmosphere. NIGHTGLOW will make critical measurements of the background UV levels for OWL. If funded, NIGHTGLOW will be built in 1999 and flown in 2000.

4.8 Positron Electron Magnet Spectrometer (POEMS); PAMELA

In 1997 Dr. Barbier led the preparation of a SMEX proposal for the Positron Electron Magnet Spectrometer (POEMS) instrument. The POEMS instrument is a small permanent magnet spectrometer instrumented with GSFC developed silicon strip detectors to measure low energy electrons and positrons (10 MeV - 2000 MeV) from a polar orbiting spacecraft. Special low power, ASIC chips were developed for reading out the silicon strip detectors. This proposal was one of two SMEX proposals ranked Category I in space sciences, however it was not selected for flight.

Dr. Barbier has led efforts in submitting a proposal for HECR group participation in the PAMELA experiment, a multinational collaboration designing an orbiting permanent magnet spectrometer which will make measurements of antiprotons, positrons and electrons over a large energy range. Members include six physics departments of Istituto Nazionale Fisica Nucleare (Italy, INFN, Dr. P. Spillantini *et al.*), Moscow Engineering Physics Institute (Dr. A. Galper *et al.*), New Mexico State U. (Dr. S. Stochaj), U. of Siegen (Germany, Drs. M. Simon, W. Menn and M. Hof), and Royal Institute of Technology (Sweden, Dr. P. Carlson *et al.*).

4.9 Laser Interferometric Space Antenna (LISA)

Gravitational radiation is the most important remaining unproven prediction of Einstein's general theory of relativity. Several major ground-based interferometric observatories for such radiation are now under construction around the world, with initial operation expected in 2-3 years. Because of seismic disturbances and baseline limitations on the earth, searches for gravitational waves at frequencies much below $\sim$ 1 Hz must be done in space. This lower frequency regime (down to $\sim 10^{-4}$ Hz) is of particular scientific interest because it is the appropriate one for the radiation expected from supermassive compact systems (e.g., black hole binaries). The LISA (Laser Interferometer Space Antenna) observatory for gravitational radiation is a cluster of three spacecraft that uses laser interferometry to precisely measure distance changes between test masses located on each of the spacecraft. It is an ESA/NASA mission that is part of the NASA SEU roadmap for the latter half of the next decade. Dr. Boldt, a member of the mission definition team, and Dr. Teegarden are in the process of establishing an effort here in support of the LISA project. Dr. Eugene Waluschka of the Optics Branch will be spending a year in Boulder working with Dr. Peter Bender of JILA on the design and modeling of the LISA optical bench. Drs. Boldt, Teegarden and E. Waluschka (Optics Branch) participated in the Second International LISA Symposium at Caltech; Dr. Boldt reported there on evidence for a substantial population of supermassive black hole quasar remnants in the local universe.

4.10 Space Station

The Advanced Cosmic ray Composition Experiment for the Space Station (ACCESS) is being studied as a mission to address many of interesting questions of cosmic ray origin and their lifetime in our galaxy. It will measure elemental composition over the entire range of the periodic table. The more abundant nuclei, lighter than iron, will be measured to high energies ($\sim 10^{15} eV$) to directly explore the ''knee'' region of the cosmic ray energy spectrum. ACCESS is also designed to detect fluxes of ultra-heavy nuclei with high charge resolution. This will allow some definitive measurements on the nucleosynthesis origins of elements for $Z < 83$. The instrument will consist of three main detecting parts: Ultra Heavy nuclei detector (UH), Transition Radiation detector (TRD), and Calorimeter with total mass of about 5 tons. ACCESS is planned to replace AMS on Space Station in 2005. The NASA GSFC scientists involved are Drs. Streitmatter (Study Scientist), Ormes (calorimeter study team leader), Mitchell (accelerator test team leader), Barbier and Christian (Deputy Study Scientists), and Moiseev who is working on instrument simulations.

The Extremely heavy Cosmic-ray Composition Observatory (ECCO) is a huge ($\sim$ 30 m^2) passive track detector which will be placed on the International Space Station for a $\sim$ 3 year mission. At the end of its mission it will be returned to earth for analysis. The goal is to study the extremely rare r and s process material in the cosmic-rays. Dr. Barbier was appointed Study Scientist for ECCO.

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

5.1 High Energy Astrophysics Science Archive Research Center (HEASARC)

The High Energy Astrophysics Science Archive Research Center (HEASARC) provides access to and expertise in the analysis of data from current (ROSAT, ASCA, RXTE, CGRO, and BeppoSAX) and past X- and Gamma-ray missions. The usage of these data has continued to soar over the past year with $\sim$ 40 Gbyte per month being downloaded from the $\sim$ 700 Gbyte online archive. Over the past year the RXTE and BeppoSAX archives opened for the first time. Newly restored data from the HEAO-1, OSO-8 and EXOSAT were made available, and the EUVE archive was also included. The HEASARC has continued to promote archive and software standards across astrophysics. The release of the ''fv'' graphical interface to display and edit FITS files and the AstroBrowse tool to access multiple archives around the world are notable examples of this.

5.2 High Resolution Detector Development

The X-ray Astrophysics Branch, together with the Goddard Solid State Device Development Branch, is continuing to develop high-resolution, high-quantum-efficiency X-ray spectrometers by improving microcalorimeters with semiconductor thermometers and investigating alternative detector technologies.

The major activity this year has been the completion of a flight microcalorimeter array and spares for the Astro-E XRS. Dr. Stahle has completed 32-element arrays with both a bilinear (2x16) and a square (6x6 minus corners) geometry, with equivalent resolution. These are silicon thermistors with HgTe X-ray absorbers affixed to each detector element. These arrays typically yield a resolution of 9-10 eV at 3 keV and 11-12 eV at 6 keV, uniformly across the pixels, as has been born out in both laboratory testing and a 6-week XRS calibration run.

There continues to be steady improvement in the capability to develop and test microcalorimeters with superconducting transition edge sensors. The higher sensitivity, compared with the semiconductor devices, is traded against heat capacity in order to overcome thermalization problems in the X-ray absorber. This will permit higher count rates and higher energy resolution. Drs. Finkbeiner and Stahle have been investigating this type of sensor. Several test thermometers have been fabricated by Dr. Finkbeiner in cooperation with the Solid State Device Development Branch. The effort has been concentrated on issues of fabrication and optimization of materials, which will switch soon to producing a functional X-ray device. In connection with Constellation-X technology development, there is now a fortunate active collaboration with Drs. Mark Irwin and John Martinis at NIST (Boulder) who pioneered this work and who have made recent significant advances.

5.3 Future Hard X-Ray Detector Development

Drs. Barbier, Barthelmy, Gehrels, Krizmanic, Palmer, Parsons, Teegarden, and Tueller are working with P. Shu and Dr. Carl Stahle in the GSFC Solid State Device Development Group to develop new technology for future hard X-ray astrophysics instrumentation. Recent improvements in room temperature semiconductors such as cadmium zinc telluride (CdZnTe) have made it possible to produce convenient, large, light-weight detector arrays for hard X-ray imaging and spectroscopy. Advantages of CdZnTe detectors include good energy resolution (5-300 keV) without the complexity of cooling and high-Z for greater stopping power with a thinner, more compact instrument. Goddard is developing the capability to process and package CdZnTe detectors and electronics to produce complete CdZnTe instruments for future balloon and spacecraft applications.

Many different prototype segmented CdZnTe detector arrays have been built and tested for use in future hard X-ray instruments. Examples include a prototype 6 x 6 array of 15 mm square double-sided, 100 micron pitch strip detectors with 500,000 separate resolution elements built as a demonstration of the BASIS concept; the 1′′ square CdZnTe pixel detectors used in the focal plane of the InFOCμS balloon instrument; and ae large area CdZnTe array proposed as part of the Swift gamma-ray burst explorer mission.

Since the trend in this detector technology is toward segmented semiconductor sensors with a large number of resolution elements, the LHEA is working to support the development of large scale integrated electronics to read out signals from these very large detector arrays. Whether for a physically large array (many 1000s cm^2) with millimeter size segments or a small 1 inch square focal plane with 100 micron segments, we need a convenient way to handle 10^4 electronics channels in a low-power, compact package suitable for balloon and spaceflight applications. LHEA and GSFC are investing in building a capability for developing Application Specific Integrated Circuits (ASICs) in-house to support large segmented semiconductor instruments like GLAST and Swift, in addition to packaging externally produced ASICs for the InFOCμS and Constellation-X programs.

One of the main limitations in the CdZnTe semiconductor applications is the uniformity of quality in the CdZnTe material itself. Drs. Barthelmy, Gehrels, Parsons and Tueller are working with Bradford Parker of the GSFC Materials Engineering Branch to characterize the performance of CdZnTe semiconductor wafers so that uniformly high quality detectors can be identified for use in the focal planes of hard X-ray focusing telescopes such as InFOCμS and the future Constellation-X Hard X-ray Telescope.

5.4 Novel Detector and Electronics Development

Drs. Barbier and Krizmanic of the High Energy Cosmic Ray group are involved along with other LHEA and Goddard groups in the research and development of novel detectors and related electronics for astrophysics applications. The detector technologies include silicon microstrip and cadmium zinc telluride microstrip detectors which are fabricated at Goddard by the Solid State Detector Development Branch of the Engineering Directorate. This research effort has also led to the design at LHEA of a variety of application specific integrated circuits (ASICs). The applications include performing the readout of microstrip detectors and forming the readout circuitry for electromagnetic calorimetry.

5.5 Lobster-Eye All-Sky X-ray Monitor

Drs. Zhang, Peele, and Petre have continued their pursuit in implementing the lobster eye optics for an X-ray all sky monitor. They have assembled together 50 pieces of flat reflectors and demonstrated in X-ray tests that they indeed focus X-rays. They will proceed to construct a more elaborate unit for a complete characterization both in terms of X-ray focusing properties and mechanical and thermal properties.

5.6 Isotope Matter Antimatter eXperiment (IMAX)

The HECR group has continued working on data analysis from the IMAX (Isotope Matter Antimatter Experiment) that made measurements of antiproton, proton, deuterium, and helium isotopes fluxes in the energy range from a few hundred MeV/nucleon to three GeV/nucleon. Dr. Krizmanic has been performing an analysis of the data to determine the muon flux as a function of atmospheric depth and its implications to the atmospheric neutrino anomaly. The IMAX experiment is a collaboration among GSFC, Caltech (Drs. A. Davis, A. Labrador, R. Mewaldt and S. Schindler), New Mexico State U. (Drs. S. Stochaj and W. Webber), and U. of Siegen (Drs. M. Simon, M. Hof, W. Menn, and O. Reimer).

5.7 International Focusing Optics Collaboration for μCrab Sensitivity (InFOCμS)

InFOCμS is a balloon-borne instrument incorporating recent breakthroughs in hard X-ray focusing optics and detectors to achieve order of magnitude improvements in both sensitivity ($\sim$ 100 μCrabs in 12 hours, 20 μCrabs for LDB) and imaging resolution ($\sim$ 1 arcmin), with high-resolution spectroscopy ($<$ 2 keV FWHM). Very low backgrounds achievable with this configuration will produce systematics-free results for very long, high sensitivity observations. Most traditional sources are so bright that background subtraction would be unnecessary. Exciting new results are expected, such as direct imaging of cosmic ray acceleration and nucleosynthesis (44Ti lines) in the Cas A supernova remnant and the first measurement of intergalactic magnetic field strengths by measuring the upscattering of the cosmic blackbody radiation by electrons in the radio lobes of AGN. This international collaboration (Drs. Tueller, Barthelmy, Gehrels, Naya, Palmer, Parsons, Petre, Serlemitsos, Stahle, Teegarden, White and Mr. P. Shu at GSFC; Drs. H. Kunieda, Ogasaka, Y. Tawara, K.Yamashita at Nagoya U.; B. Barber, E. Dereniak, D. Marks, E. Young at U. of Arizona; W. Baumgartner, F. Berense, and M. Leventhal at U. of Maryland) includes world leaders in the development of foil mirrors, multicoated optics, segmented CdZnTe detectors, and balloon payloads with the experience and resources necessary to successfully exploit these promising new technologies for the future HTXS mission.

The InFOCμS team made the first image using focusing optics at energies well above 10 keV (20 - 40 keV band). This test was performed in an ASTRO E housing with 20 foil mirror elements made at LHEA and with multilayers applied at Nagoya University. A full mirror contains 2000 foils. Images of an X-ray calibration source were made with a CdZnTe strip detector developed in LHEA. This is a major breakthrough in technology for hard X-ray astronomy and the team is pushing ahead towards a first flight for this technology in 1999. Dr. Tueller is also the head of a team funded by GSFC to develop stable contacts for germanium detectors that will allow fine segmentation for greatly improved position resolution. This technology could be used as a focal plane for an InFOCμS-type instrument, or in coded aperture and Compton telescope instruments for mapping diffuse nuclear lines from our Galaxy.

5.8 Isotope Magnet Experiment (ISOMAX)

Some of the most significant questions in the field of particle astrophysics can be addressed by measurements of the isotopic composition of the cosmic radiation. In particular, measurements of the radioactive clock isotope ^{10}Be, which has a half-life of 1.6 million years, will allow strong constraints to be placed on models of cosmic ray transport in the galaxy. To make such measurements, the HECR group has developed a new magnetic rigidity spectrometer for balloon-borne flight, the Isotope Magnet Experiment (ISOMAX). A successful first flight of the ISOMAX instrument was made in August, 1998 from Manitoba, Canada. ISOMAX is a collaboration of GSFC (Drs. Streitmatter, Barbier, Christian, Krizmanic, Mitchell, and Ormes and graduate student Sven Geier) with Caltech (Drs. R. Mewaldt, S. Schindler and G. deNolfo) and the U. of Siegen (Dr. M. Simon and graduate students T. Hams and H. Goebel).

5.9 Trans-Iron Galactic Element Recorder (TIGER)

Dr. Christian has led the HECR group’s efforts in a collaboration with Washington U. in St. Louis (Drs. R. Binns and P. Hink), U. of Minnesota (Dr. J. Waddington), and Caltech (Drs. R. Mewaldt and M. Wiedenbeck) on the Trans-Iron Galactic Element Recorder (TIGER), a balloon-borne instrument which will measure the elemental composition of the heavy component of the cosmic radiation for comparison with solar system abundances. An UltraLong Duration Balloon (ULDB) flight is planned in 2001 as a demonstration flight.

5.10 Gamma Ray Burst Coordinates Network (GCN)

Dr. Barthelmy continues the development of the GCN system (used to be called BACODINE). There are three parts to the GRB Coordinates Network: (1) the real-time distribution of GRBs detected by CGRO-BATSE (the original BACODINE system), (2) the near-realtime distribution of GRB locations detected by other spacecraft, and (3) the distribution of follow-up observation reports submitted by the GRB community (GCN Circulars).

The original BACODINE portion of the system is continuing to successfully send gamma-ray burst source coordinates to the community in real time. The BATSE portion of the telemetry from CGRO is monitored for the onset of a GRB, and its source coordinates are calculated in RA and Dec and are sent (as the burst may still be taking place) to sites that can make multi-band follow-up observations. The worst-case time delay is little over 5 seconds. The accuracy of the location depends on the intensity of the GRB and varies in radius over several degrees, depending on the burst brightness.

The GRB Coordinates Network (GCN) has generalized BACODINE by adding inputs from other GRB instruments/spacecraft, including the interplanetary network (IPN) and GRO-COMPTEL, RXTE-PCA/-ASM, BeppoSAX-WFC/-NFI, and extreme UV-transients from ALEXIS. These burst locations plus the BATSE-derived locations provide a wide range of time delays (seconds to hours) and range of error box sizes (arminutes to degrees). The global GCN client list includes over 70 optical, radio, x-ray, gamma-ray, and air-shower telescopes and instruments. The coordinates for all these sources are distributed via direct Internet socket connections, or by electronic mail, alpha-numeric pagers, cell-phones, and/or dedicated phone lines.

The GCN Circulars close the loop on the study of GRBs by allowing the follow-up observer to report his/her results to the scientific community in a rapid fashion. People are added to a distribution list which allows them to submit short reports (a few paragraphs) about their follow-up observations and these reports are automatically distributed to everyone on the list (within a minute).

5.11 Foil Mirrors for X-Ray Telescopes

The LHEA X-ray Mirror Laboratory has been the leading institute for the production of state-of-the-art thin-foil X-ray reflecting mirrors with surface smoothness at 3-5 Angstroms below millimeter spatial wavelengths. This is the essential element of high throughput, light weight, low cost, X-ray astronomy telescopes. Following this line of development, we supplied the X-ray telescopes for three space/upper atmospheric flight missions: a rocket flight in 1987, BBXRT (a shuttle-borne Broad Band X-Ray Telescope) in 1990, and ASCA (Advanced Satellite for Cosmology and Astrophysics) in 1993. Results from these successful missions led to reductions in the errors from various elements of the telescopes such as alignment, curvature of the reflectors, and smoothness of the surface. Due to these improvements, the half power diameter of the image has been reduced from $3.5'$ before 1993 to the current value of nearly $1'$. These improvements are being incorporated into the fabrication of the mirrors for Astro-E, a US-Japanese mission, with delivery of the telescopes in late 1998 for a launch in February 2000. Astro-E will carry four identical telescopes of 4.75 m focal length with CCD cameras, and a slightly different mirror of 4.5 m focal length with the first-in-flight quantum calorimeter with an unprecedented $\sim$ 10 eV energy resolution.

An important development in terms of broadening the energy response of the telescope is being pursued. Multilayering of different materials on top of a smooth substrate can produce constructive interference in an extended energy range. This phenomena has been successfully demonstrated above 10 keV by various groups in the field, including LHEA at Goddard, DSRI in Denmark, and Nagoya U. in Japan. A more significant demonstration, the imaging of a point source at $\sim$ 30 keV, was done here at Goddard for the first time through the joint efforts of Goddard and Nagoya U. There is currently a collaborative effort between Goddard and Nagoya U. to fly a balloon which will carry a broad band telescope to do imaging above 20 keV.

In the next 2-3 years the Constellation-X mission will further push the limits of our technology. The goal is to improve the angular resolution to $0.2'$ or better in half power diameter and to increase the area to $10^4 cm^2$.

5.12 Public and Education Outreach

The Laboratory for High Energy Astrophysics continues its outstanding educational and public outreach program, with the release of new products and strong representation at national and regional meetings.

In response to feedback from users, the High-Energy Astrophysics Learning Center was converted to the new Imagine the Universe! web site. The site was given a new, user-friendly look and easier navigation tools. The site's focus on high-energy phenomena is being expanded as well; the site will soon include all wavelengths of light and means of probing the structure and evolution of the Universe. M. Bene (RSTX) provided web support to completely switch on the order of a thousand pages of the web site to the new format (http://imagine.gsfc.nasa.gov/) as well as programming support for StarChild activities. The sites have received much attention and won many content-based awards in the past year. Most noteworthy, the StarChild site won the 1997 Webby award in the Education category. Accesses continue to explode, and now exceed 500,000 hits a month (StarChild) and 200,000 (Imagine!).

The LHEA outreach group released, for the second year in a row, a CD-ROM capturing its educational web sites. This year's CD contains six sites, including Imagine the Universe!, StarChild, the RXTE Learning Center, the Solar and Heliospheric Learning Center, the CGRO Learning Center, and AstroCappella (a package of astrophysically correct songs by a professional a capella group, the Chromatics). M. Bene, M. Masetti, A. Cliffe, S. Fantasia (RSTX) and Dr. Whitlock prepared and released Volume 2 of the CD-ROM. The CD-ROM, which is given out free to educators and the public, is one of the LHEA outreach group's most popular items. It is both Mac and PC compatible and comes with all the necessary software. The LHEA outreach continues to expand our programs beyond the web site, with the development of a second set of posters and activity books.

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