

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, 1999 to June 30, 2000.

This Laboratory's scientific research is directed toward experimental and theoretical investigations in the areas of X-ray, gamma-ray, and cosmic-ray astrophysics. The range of interests of the scientists includes the Sun and the solar system, stellar objects, binary systems, neutron stars, black holes, the interstellar medium, normal and active galaxies, galaxy clusters, cosmic ray particles, gravitational wave astrophysics, and the extragalactic background radiation. Scientists and engineers in the Laboratory also serve the scientific community, including project support such as acting as project scientists and providing technical assistance 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 George Washington U., Stanford U., and the U. of Maryland.

1 PERSONNEL

Dr. Jonathan F. Ormes recently stepped down from being Chief of the Laboratory for High Energy Astrophysics. Dr. Nicholas White has been appointed as his successor. Dr. Neil Gehrels is Head of the Gamma Ray & Cosmic Ray Astrophysics Branch and Dr. Robert Petre is Head of the X-Ray Astrophysics Branch, succeeding Dr. White.

The civil service scientific staff includes: Drs. Louis Barber, Scott Barthelmy, David Bertsch, Elihu Boldt, Kevin Boyce, Thomas Cline, Keith Gendreau, Alice Harding, Robert Hartman, Stanley Hunter, Keith Jahoda, Frank Jones, Timothy Kallman, Demosthenes Kazanas, Richard Kelley, Frank Marshall, John Mitchell, Richard Mushotzky, Jay Norris, Jonathan Ormes, Ann Parsons, William Pence, F. Scott Porter, Reuven Ramaty, Donald Reames, Steven Ritz, Peter Serlemitsos, Caroline Stahle, Floyd Stecker, Robert Streitmatter, Tod Strohmayer, Jean Swank, Andrew Szymkowiak, Bonnard Teegarden, David Thompson, Jack Tueller, Tycho von Roseninge, Kim Weaver, and William Zhang.

The following scientists are National Research Council Associates: Drs. Zaven Arzoumanian, Bram Boroson, Andrew Chen, Taro Kotani, Jeffrey Lenters, Mark Lindeman, Gabriela Marani, Daniel Marks, David Marsden, Sandor Molnar, Igor Moskalenko, Sergei Nayakshin, Daniel Proga, Brigitte Ragot, Olaf Reimer, Samar Safi-Harb, Sean Scully, Yuichi Terashima, Raymond White, Rosa Williams, and Bing Zhang.

The following researchers are University Space Research Association Scientists: Drs. Lorella Angelini, Matthew Baring, Kevin Black (SAC), Jerry Bonnell, John Cannizzo, Kai-Wing Chan, Eric Christian, Robin Corbet, Michael Corcoran, Philip Deines-Jones, Seth Digel, Joseph Doodoo, Stephen Drake, Ken Ebisawa, Michael Harris, Ilana Harrus, Hans

Krimm, John Krizmanic, James Lochner, Natalie Mandzhavidze, Thomas McGlynn, Alex Moiseev, Koji Mukai, Kirpal Nandra, Scott Owens, David Palmer, Sangwook Park, Chris Shrader, Alan Smale, Steven Snowden, Yang Soong, Martin Still, Steve Sturmer, Toshiaki Takeshima, Ken Watanabe, and Georg Weidenspointner.

The following investigators are University of Maryland Scientists: Drs. Keith Arnaud, Manuel Bautista, Patty Boyd (UMBC), Fred Finkbeiner, Warren Focke, Ian George (UMBC), Una Hwang, Peter Kurczynski, Michael Loewenstein, Greg Madejski, Craig Markwardt, Chee Ng, Ian Richardson, David Smith, Jane Turner (UMBC), Azita Valinia, and Tahir Yaqoob (UMBC).

Visiting scientists from other institutions: Drs. Vadim Arefiev (IKI), Hilary Cane (U. Tasmania), Ernesto Esteban (U. P.R.), Ralph Fiorito (Catholic U.), Peter Gonthier (Hope College), Thomas Hams (U. Seigen), Donald Kniffen (Hampden-Sydney College), Ben Zion Kozlovsky (U. Tel Aviv), 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, Wayne Baumgartner, Frederick Berendse, Sven Geier, Donald Horner, Kip Kuntz, Barbara Mattson, Giridhar Nandikotkur, David Rupke, and Dusan Turcan; from George Washington U., Alaa Ibrahim; and from Stanford U., Enectali Figueroa-Feliciano.

2 RESEARCH PROGRAMS

2.1 Sun and Solar System

Dr. Ramaty, together with Drs. B. Kozlovsky and N. Mandzhavidze and in collaboration with Drs. V. Tatischeff (Orsay) and J.-P. Thibaud (Orsay), demonstrated that sufficient lithium-6 is produced in solar flares to account for the recently discovered solar wind deposited lithium-6 in lunar soil. They also identified the dominant lithium-6 producing reaction, accelerated helium-3 nuclei interacting with ambient helium-4. Helium-3 is abundantly accelerated in solar flares, as a result of gyroresonant interactions with plasma turbulence. This is the first instance that flare accelerated particles have been shown to have a role in nucleosynthesis.

Drs. Ramaty and Mandzhavidze edited the proceedings of the workshop High Energy Solar Physics - Anticipating HESSI, which took place in College Park in October 1999. The proceedings have appeared as volume 206 of the Astronomical Society of the Pacific Conference Series.

Drs. Reames, Ng and Tylka have utilized the high sensitivity and on-board processing power of the IMPACT instruments on the WIND spacecraft to study the temporal varia-

tion of the elemental composition of solar energetic particles during gradual events. Gradual events are events in which the observed energetic particles are accelerated by coronal shocks driven by fast Coronal Mass Ejections. This acceleration process can continue out even as far as the Earth's orbit and beyond. The elemental abundances vary substantially from event to event and within events. This has also been observed at higher energies by the Solar Isotope Spectrometer on the ACE spacecraft. Variability has been observed to some extent before, however the greatly improved sensitivity ($\sim \times 100$) and temporal resolution of the new instruments have presented a picture which was initially not understood. It had been expected that the variations would be organized in a simple way by particle rigidity (momentum per unit charge). Theoretical modeling of the acceleration process included the generation of waves by particles (predominantly protons) being scattered and accelerated by magnetic irregularities on either side of the shock. These waves in turn contribute to particle acceleration and to limiting the ease with which particles can escape from the shock region. One of the surprises of this modeling was that it predicted departures from simple rigidity ordering, and in fact was able to explain the observed temporal variations. This not only resolves an outstanding problem but establishes the importance of wave-particle interactions in shock acceleration.

2.2 Stars

Drs. Corcoran, Drake, Ishibashi, Swank, and Petre in collaboration with Drs. K. Davidson (U. Minnesota), A. Damineli (I. Astronomico e Geofisico da University de Sao Paulo), Ms. A. Fredericks (UMCP) and Mr. F. Chung (Eleanor Roosevelt HS) are continuing to monitor the X-ray variations from the extremely massive star Eta Carinae using RXTE and ASCA. Recent work suggests that, based on the X-ray lightcurve analysis, the mass loss rate from Eta Carinae must have increased by a large factor near periastron passage if all the X-ray absorption is from the wind of the star, and if the star is a binary.

Drs. Corcoran and Mushotzky in collaboration with Drs. A. Moffat (U. Montreal), I. Stevens (U. Birmingham), and Dr. A. Ptak (CMU) are working on an analysis of an X-ray image of the massive star forming region NGC 3603. Preliminary results suggest the detection of about 100 cluster members to an X-ray flux limit of 10^{-15} ergs cm^{-2} s^{-1} . Corcoran is also continuing as moderator of the XMEGA group, a collaboration of scientists interested in problems regarding the X-ray emission from massive stars.

Drs. Drake and White in collaboration with Drs. N. Brickhouse, R. Edgar, and A. Dupree (SAO), K.P. Singh (TIFR), and D. Liedahl (LLNL) studied the coronal structure and abundances of the well-known binary star Capella using simultaneous ASCA and EUVE observations. They find a good, albeit not perfect, degree of consistency between models derived from the two satellites, a coronal temperature structure with a strong peak at 6×10^6 K, and near solar abundances for most elements, except for neon which appears to be subsolar by a factor of 3 or 4. The new "VMEKAL-Mod" thermal plasma models used in this analysis include high-n lines for the ions Fe XVII - XIX, and

significantly improve the fit to the data in the 1.2 keV spectral range compared to the old VMEKAL models, improving the reduced chi-squared from 3.1 to 1.2.

Dr. Drake together with Drs. T. Simon (U. Hawaii) and D. Florkowski (USNO) continues to investigate the influence of binarity on coronal activity in late-type stars, asking the question are close binaries active merely as a result of their rapid rotation due to tidally-enforced orbital-spin coupling, or is there an additional boost due, for example, to environmental causes. They have compiled large samples of single and binary main-sequence and evolved late-type stars having X-ray and radio measurements, which can be used as proxies of their coronal efficiency. They find that, for main-sequence stars, there is no apparent difference between the single and binary stars, at least as evidenced by their overall emission levels, whereas, for evolved (subgiant and giant) stars, the binary stars are an order of magnitude more active.

Dr. Drake in collaboration with Drs. K.P. Singh (TIFR), S. Pandey and Padmekar (Pt. Ravishankar Shukla U.) have carried out a comprehensive multiwavelength study of the interesting K2 giant star HD 61396. Based on the measured 32 day photometric period (interpreted as being due to modulation by starspots covering up to 20% of the stellar surface), the variable H α emission feature, the large inferred X-ray and radio luminosities, and the hardness of the ROSAT (X-ray) spectrum, HD 61396 is most probably an active binary system of the Long-Period RS CVn class, and furthermore one of the half dozen most active such systems yet discovered.

2.3 Pulsars

Dr. Thompson, as part of a collaboration of radio, X-ray, and gamma-ray astronomers, helped with analysis showing possible evidence in the EGRET data for pulsed gamma-ray emission from PSR J0218+4232. If confirmed by future telescopes, this would be the first millisecond pulsar and the first binary pulsar seen in high-energy gamma rays.

2.4 Galactic Binaries

Drs. Mukai and Smale have analyzed a serendipitous ASCA observation of the X-ray binary in the globular cluster, NGC 6652. For the first time for this source, they have been able to study the spectral variation of an X-ray burst to show that it was a Type I event. Dr. Mukai with Dr. M. Ishida (ISAS) has studied the classical nova, V382 Vel, with ASCA and RXTE. The brightness of this nova (8th brightest of the century) and the availability of sensitive X-ray observatories have allowed them to study the evolution of early X-ray emission in unprecedented details. In the ASCA observation 20 days after the eruption, both the temperature (10 keV) and absorption (10^{23} cm^{-2}) were extremely high; they were seen to decrease gradually over the next 40 days. This is consistent with an origin of the X-rays due to a shock within the nova ejecta.

Dr. Smale in collaboration with Dr. E. Kuulkers (Amsterdam) conducted an in-depth RXTE study of the bright binary LMC X-2 which revealed that the system shows similar attributes to the Galactic Z-sources in their flaring branch, i.e.,

the shape of the X-ray color-color diagrams, the presence of prominent noise components in the power spectra, and an intrinsic luminosity near to or in excess of the Eddington limit. Confirmation would make LMC X-2 the first extragalactic Z-source.

Drs. Boyd and Smale in collaboration with Drs. J. Homan, P. Jonker, M. van der Klis, and E. Kuulkers (Amsterdam), conducted a series of RXTE observations during an extended low-state of the black hole candidate LMC X-3. The data show a hard X-ray spectrum, a 0.5-Hz QPO, and strong broad-band noise components, features quantitatively similar to those seen in the Galactic black hole candidates.

Dr. Smale in collaboration with Drs. S. Wachter (CTIO) and C. Bailyn (Yale) obtained the first new X-ray and optical data from the transient low-mass binary X1658-298 which recently resumed its strong and persistent X-ray emission after a 21-yr furlough. Their studies included the X-ray eclipses, an updated ephemeris, and the first optical light curve around its 7.1-hour orbital period. Combined together, the multiwavelength data imply an accretion disk structure characterized by enhanced optical emission coincident with the central X-ray-emitting region.

Dr. Smale in collaboration with Drs. M. Church and M. Balucinska-Church (Leicester) produced a timing analysis of RXTE data from the 21-hour dipping source X1624-490 which has resulted in the first accurate ephemeris for the system. Spectroscopy indicates that the X-ray emission can be described by a point-source blackbody combined with partial obscuration of an extended accretion disk corona.

Drs. Still, Borson, and Titarchuk in collaboration with Drs. K. O'Brien and K. Horne (U. St. Andrews) and S. Vrtilek (CfA) have detected X-ray reflection off the irradiated inner face of the companion star in the Hercules X-1 X-ray pulsar. The binary parameters and physical conditions within this eclipsing system are well known, and this provides a wonderful opportunity to test reflection astrophysics.

Dr. Still in collaboration with Drs. M. Hanson (Cincinnati) and R. Fender (Amsterdam) measured the mass of the companion star in the high mass X-ray binary Cygnus X-3, using infra-red emission line diagnostics. This confirms the mass is consistent with the Wolf-Rayet star inferred from the emission line spectrum.

Drs. Still and Borson in collaboration with Drs. O'Brien and Horne (U. St. Andrews), B. Oke (DAO), and R. Gomer (Rice) detected optical quasi-periodic oscillations from Hercules X-1 in fast spectroscopy from the Keck II telescope. The temperature and size of the oscillation region has been characterized.

Dr. Still in collaboration with Drs. H. Quaintrell (Open U.) and P. Roche (Leicester) have mapped the shadow of the accretion disk across the surface of the X-ray irradiated companion star of Hercules X-1, and found that the disk shape must be significantly different to the current theoretical calculations, or additional structure such as the impact between gas stream and accretion disk adds to the shadow.

Dr. Kazanas in collaboration with Dr. X.-M. Hua (Raytheon) have produced models of the light curves of accreting galactic black holes and neutron stars. Their model posits that most of the observed variability is due to the stochastic

nature of the Comptonization process (responsible also for the formation of their spectra); according to this model, the properties of the observed light curves can by and large be accounted by the random injection of soft photon bursts near the compact object and their reprocessing by an extended non-uniform corona. The timing properties of these light curves can then determine the properties (size and density profile) of the comptonizing corona, which can then lead to an understanding of the dynamics of accretion.

Drs. Shrader and Titarchuk are exploring self-consistent approaches towards modeling the spectral and temporal properties of accreting black holes. The now well known trend for high-frequency ($\sim 10^2$ Hz) QPOs to be associated with relatively hard (but high-state) broad-band X-ray spectra is explained naturally in the context of the bulk-motion Comptonization model, but is very difficult to explain for hot coronae models. Trends in the derived parameters, namely an apparent correlation between the appearance and strength of the QPOs and the illumination fraction of the bulk-inflow site have been identified, further strengthening this picture. Shrader and Titarchuk are now exploring observational tests of a new theory (developed by Titarchuk and Osheroovich) for the very low frequency QPOs (~ 0.1 Hz) in black-hole binaries that involve global-disk oscillations.

Dr. Shrader, with Dr. W. Cui (Purdue U.), and Drs. C. Haswell and R. Hynes (UK) have established UV-to-X-ray time lags in the X-ray nova XTE J1118+480. The lags are surprisingly large, consistent with a reprocessing site situated at about 10^4 schwarzschild radii from the central X-ray source. Variations in the high-excitation UV line profiles and their velocity components, as a function of X-ray intensity are evident in the data and are currently being studied. Additionally, quasi-periodic oscillations at a common frequency (~ 0.08 Hz) at optical, UV and X-ray energies.

2.5 Supernovae and Supernova Remnants

Drs. Hwang, S. Holt (Code 600), and Petre carried out an imaging study of the Galactic supernova remnant Cas A using new data from the Chandra Observatory. These results show the asymmetrical distribution of X-ray emitting ejecta of the elements Si, S, Ar, Ca, and Fe in this young Type II remnant. Together with their collaborators Drs. E. Gotthelf (Columbia), T. Jones, L. Rudnick, and Mr. B. Koraleskyat (U. Minnesota), they also used Chandra observations to identify the reverse and forward shocks in Cas A.

Drs. Hwang, Holt, and Petre in collaboration with Drs. D. Burrows, G. Garmire, and J. Nousek (PSU), R. Chevalier (U. Virginia), R. McCray and Mr. E. Michael (U. Colorado) imaged the X-ray remnant of SN1987a with Chandra.

Drs. Safi-Harb, Harrus, and Petre in collaboration with Drs. A. Koptsevich, D. Sanwal, and G. Pavlov (PSU) analyzed the X-ray emission from SNR G21.5-0.9 in order to better understand the X-ray emission from Composite-type supernova remnants (SNR) and search for their powering engines. Chandra observations of this remnant, long thought to be a Crab-like plerion, show evidence of an X-ray shell, giving the remnant a composite-type morphology in X-rays. The spectra of both the plerionic and shell-like components are best fitted with non-thermal models. They found no evi-

dence of line emission from the shell-like component, which is best fitted by a power law model with a photon index of 2.3. No pulsations were found from the central compact object. Using the Chandra HRC observations, they derived an upper limit of 20% on the pulsed fraction from the central engine.

2.6 Cosmic Rays

Dr. Streitmatter leads the High Energy Cosmic Ray HECR research group (Drs. Barbier, Christian, Geier, Krizmanic, Mitchell, Moiseev, and Ormes) in pursuing a broad-based investigative program seeking to unravel the processes of cosmic ray propagation and acceleration, characterizing the cosmic ray composition and sources themselves, and performing fundamental astroparticle physics measurements. The HECR group has been pursuing an active program using state-of-the-art balloon borne instruments (ISOMAX and NIGHTGLOW) developed at GSFC, as well as collaborating on experiments led by other institutions. The HECR group is a member of the WiZard/CAPRICE collaboration, which is headed by Dr. S. Stochaj at New Mexico State University and the BESS collaboration led by a group of Japanese investigators, Dr. S. Orito *et al.* Dr. Streitmatter also collaborates with Dr. A. Stevens of the Tata Institute of Fundamental Research in developing computational techniques used in cosmic ray transport calculations.

Dr. Ramaty, in collaboration with Dr. Scully and Prof. Kozlovsky and Dr. R. Lingenfelter (UCSD), developed a light element evolutionary code, the results of which have important implications on cosmic ray origin. Their results strongly suggest that the cosmic rays are accelerated out of fresh supernova ejecta in superbubbles generated by multiple supernova explosions of massive stars formed in giant OB associations.

2.7 Black Hole Astrophysics

Drs. Boldt and Loewenstein revisited the issue of whether the highest energy cosmic-ray particles ($> 10^{20}$ eV) could be produced by compact dynamos associated with dormant, spinning supermassive black holes in nearby elliptical galaxies. They showed that, for three well-studied systems, the ambient photon density is such that energy losses due to photo-pion production are insufficient to rule out the viability of such a mechanism. The emission from these systems may be dominated by TeV gamma-ray curvature radiation produced by interaction of these cosmic rays with the magnetic field threading the black hole. Preliminary Chandra results of Drs. Loewenstein, Mushotzky, Arnaud, and Angelini indicate that extremely low X-ray fluxes are the rule. This suggests, when considered in combination with results on local galaxy and black hole demographics, that such cosmic accelerators/TeV gamma-ray emitters may number in the dozens or more in the local (< 50 Mpc) universe.

2.8 Interstellar Matter and Molecular Clouds

Dr. Digel together with Dr. Hunter and Drs. I. Grenier (CE Saclay), T. Dame (Center for Astrophysics) and P. Thaddeus (Center for Astrophysics) studied the diffuse

gamma-ray emission observed by EGRET in Monoceros to evaluate the coupling of cosmic rays to interstellar gas in the outer Galaxy. The results suggest that cosmic rays are coupled to the Perseus arm, although the enhancement of cosmic-ray density in the arm, as inferred from the gamma-ray emissivity of the gas, is much less than expected from earlier work on the inner Milky Way. As in other studies with EGRET data, an apparent excess of gamma-ray emissivity above 1 GeV is found, although only for the gas within 1-2 kpc of the sun.

2.9 Our Galaxy

Mr. Kuntz and Dr. Snowden used all six energy bands of the ROSAT All-Sky Survey diffuse background data to finish a decomposition of the X-ray spectrum of the galactic halo. They showed that the galactic halo is composed of at least two components, a spatially smooth hotter component with $T \sim 10^{6.42}$ K and a more patchy, cooler component with $T \sim 10^{6.06}$ K. They are beginning a similar study of the halo of M101 using a 100 ks Chandra observation.

Drs. Park and Ken used an ASCA observation to study the Galactic diffuse X-ray background. This study was focused on the spectral analysis of the 0.5 - 2 keV Galactic X-ray background emission which is distributed < 3 kpc from the Sun in the Galactic plane. The 0.5 - 2 keV emission appears to originate from a ~ 1 keV plasma which is distributed within ~ 1 kpc. The 2-10 keV emission is likely associated with a 3-5 keV plasma which is distributed throughout the plane.

Dr. Park in collaboration with Drs. Y.-H. Chu and R. Gruendl (UIUC) used optical absorption line observations to support the study of an X-ray shadow detected at $l, b = 8^\circ, -8^\circ$. These observations help to measure the distance to the molecular cloud that casts the X-ray shadow.

2.10 Normal Galaxies

Drs. Loewenstein, Mushotzky, and Valinia analyzed the first RXTE observations of normal elliptical galaxies. A luminous, extended, hard X-ray emission component was measured in both galaxies studied – NGC 4472 and NGC 4649 – with spectral properties generally indicative of local Virgo Cluster emission. However, there is marginal evidence for an additional nonthermal component that may extend to very high energies for NGC 4472. The integrated X-ray binary spectra of these galaxies was also analyzed and found to differ, even though the galaxies have virtually identical stellar populations.

2.11 Starburst Galaxies

Dr. Weaver in collaboration with Drs. T. Heckman (JHU) and M. Dahlem (ESTEC) presented an in-depth analysis of ROSAT and ASCA X-ray data for the nearby edge-on starburst galaxies NGC253 and M82. Spectral fits indicate that multitemperature thermal plasma models with significant underlying soft X-ray absorption are more consistent with the imaging data than models with highly subsolar abundances, as claimed previously. These results suggest that with current

(i.e., pre-Chandra) data, the technique of measuring abundances in starburst galaxies via X-ray spectral modeling is highly uncertain.

2.12 Gamma Ray Bursts

Drs. Marani, Norris, and Bonnell in collaboration with Dr. J. Scargle (NASA ARC) utilized Bayesian analysis algorithms to characterize pulse distributions in gamma-ray burst (GRB) temporal profiles. Drs. Norris, Marani, and Bonnell studied spectral lags between high and low energy bands in the small sample of GRBs with associated redshifts, finding a nascent power-law relationship between luminosity and lag. A similar trend is evident between lag and peak flux in a larger set of bursts bursts with longer lags tend to have lower peak fluxes.

2.13 Active Galaxies

Drs. George, Mushotzky, Nandra, Turner, and Yaqoob in collaboration with Drs. H. Netzer (Tel Aviv U.), A. Laor (Technion), and T. Takahashi (ISAS) presented a sample of 27 ASCA observations of 26 radio-quiet quasars from the Palomar-Green Survey. A wide variety of X-ray spectra were observed across the sample, with photon indices between 1.5 and 3. Spectral complexity was evident, some sources showing evidence for flattening to high energies and some showing a steep spectral component at low energies. They confirm a previous finding, that the Fe $K\alpha$ line profile shows an evolution with nuclear luminosity.

Drs. Yaqoob, George, Nandra, Turner, Zobair and Serlemitsos presented the ASCA spectrum of the luminous radio-loud quasar, PKS 2149-306. An emission line was detected at 17 keV in the quasar rest-frame. Line emission at this energy has not been observed in any other active galaxy or quasar to date. The authors suggest that the emission is due to blueshifted Fe-K emission from material with bulk velocity of order $0.75c$. Curiously, if the emission-line feature recently discovered in another quasar (PKS 0637-752, $z=0.654$) at 1.6 keV in the quasar frame is due to blueshifted O VII emission, the Doppler blueshifting factor in both quasars is similar ($\sim 2.7-2.8$).

Drs. Nandra, George, Mushotzky, Turner, and Yaqoob presented an analysis of the relativistic Fe $K\alpha$ line in the Seyfert 1 galaxy NGC 3516 based on a continuous, 5 day ASCA observation. The continuum flux varied by $\sim 50\%$ during the observation and time-resolved analysis showed that the line also changed. The line core followed the continuum, but the blue wing was unrelated and the red wing was formally consistent with a constant but appeared to be correlated with the blue wing. There also appeared to be an absorption feature in the profile, consistent with resonance scattering in infalling material. This variable feature may be the signature of material being accreted by the central black hole.

Drs. Turner, George, and Nandra in collaboration with Mr. Turcan investigated the X-ray variability amplitude for 79 ASCA observations of 36 Seyfert 1 galaxies. They found that consideration of sources with the narrowest permitted lines in the optical band introduced scatter into the estab-

lished correlation between X-ray variability and nuclear luminosity. Consideration of the X-ray spectral index and variability properties together showed distinct groupings in parameter space for broad- and narrow-line Seyfert 1 galaxies, confirming previous studies. A strong correlation was found between hard X-ray variability and FWHM $H\beta$. A range of nuclear mass and accretion rate across the Seyfert population can explain the differences observed in X-ray and optical properties.

Drs. Turner and George in collaboration with Drs. C. Perola and G. Matt (U. degli Studi Roma), F. Fiore (SAX/SDC Nuova Telespazio), George, L. Piro (I. Tecnologie e Studio Radiazioni Extraterrestri), and L. Bassani (Istituto di Astrofisica Spaziale) collaborated on a BeppoSAX observation of NGC 7582. The new X-ray data revealed a previously unknown hard X-ray component in NGC 7582, peaking close to 20 keV. Rapid variability was observed with correlated changes in the 5-10 and 13-60 keV bands, indicating that a single-continuum component, produced by the active nucleus, provides the dominant flux across both bands.

Drs. Turner and George in collaboration with Dr. Netzer presented an ASCA observation of the narrow-line Seyfert 1 (NLSy1) galaxy Arakelian 564. A strong ($EW \sim 70$ eV) spectral feature was observed close to 1 keV. A similar feature has been observed in Ton S180, another member of the NLSy1 class of objects, but it has not been observed in broad-line Seyfert galaxies. The feature energy suggested a large contribution from Fe L-shell lines, but its intensity was difficult to explain in terms of emission and/or absorption from photoionized gas. The hard X-ray spectrum showed a broad and asymmetric Fe $K\alpha$ line of large equivalent width (~ 550 eV), suggestive of significant emission from the inner accretion disk.

Dr. Weaver in collaboration with Drs. R. Gilli, G. Risaliti (U. Firenze), R. Maiolino, A. Marconi (Osservatorio Astrofisico di Arcetri), M. Dadina (BeppoSAX), and E. Colbert (STScI) reported the transition to an active state of the nucleus in the Seyfert 1.9 galaxy NGC 2992. The 2-10 keV flux had declined by a factor of 20 from 1978 to 1994, but BeppoSAX observations in 1997 and 1998 caught the AGN rising to the same level of activity observed in 1978. Between the BeppoSAX observations, the iron $K\alpha$ line changed from being an unresolved feature at 6.62 keV (indicating highly ionized iron) to a broad feature consistent with neutral fluorescence. The spectral and flux changes are interpreted in terms of different phases of rebuilding an accretion disc.

Dr. Weaver in collaboration with Drs. A. Wilson (UMCP), C. Henkel (MPI für Radioastronomie), and J. Braatz (NRAO) presented ASCA results of the LINER/megamaser galaxy NGC 1052. Its 2-10 keV spectrum is unusually flat (photon index of 0.2) and is best described as intrinsically power-law shaped nuclear flux that is either attenuated by absorption that ranges from 3×10^{22} to 3×10^{23} cm^{-2} or reprocessed, with the nuclear source blocked and the X-rays Compton reflected by high column density ($> 10^{24}$ cm^{-2}) gas. The estimated range for the absorption-corrected 2-10 keV luminosity is 8×10^{41} to 2×10^{43} ergs s^{-1} .

Drs. Terashima, Mushotzky, Serlemitsos, and Yaqoob in

collaboration with Drs. L.C. Ho (Carnegie Obs.), A.F. Ptak (CMU), and H. Kunieda (Nagoya U.) used ASCA data of five LINER type galaxies without broad H α emission in their optical spectra. The X-ray fluxes of these objects turned out to be very low. This fact indicates that AGN in these LINERs are heavily obscured even at energies above 2 keV or that LINERs are powered by something other than an AGN.

Drs. Terashima in collaboration with Drs. Kunieda and K. Misaki (Nagoya U.) reported the results from ASCA observations of the low-luminosity Seyfert 1.5 galaxy NGC 5033. The source showed significant flux variability within one day and fluorescent iron emission line. These properties are rarely observed in low-luminosity AGN.

Drs. Terashima, Serlemitsos, and Yaqoob in collaboration with Drs. Ho (Carnegie Obs.), Ptak (CMU), Kunieda and Misaki (ISAS) found the variability of an iron emission line in low-luminosity AGN NGC 4579. The line center energy decreased from 6.7 keV to 6.4 keV in a 3.5 yr time interval. This variability shows that the origin of the iron line is not hot gas in the host galaxy but probably from an accretion disk in the AGN.

Dr. Nandra in collaboration with Dr. K. Iwasawa and Prof. A. Fabian (Institute of Astronomy, Cambridge) presented an X-ray spectra of the Seyfert 1 galaxy NGC 5548, which were obtained simultaneously with the ASCA and ROSAT satellites. They found that the continuum spectral index was significantly steeper in the ROSAT data, most likely due to a discrepancy in the response models for ASCA and ROSAT.

Dr. Nandra in collaboration with Drs. D. Maoz (Wise Observatory) and R. Edelson (UCLA) presented long-term monitoring data in the X-ray and optical for the Seyfert 1 galaxy NGC 3516. They found little correlation between the two wavebands at zero lag, but a possible delay of 100d in the sense that the slow X-ray variations lead those in the optical. Faster X-ray variations were not seen in the optical, requiring a separate production mechanism.

Dr. Nandra, in collaboration with Dr. Edelson and others presented the results of a variability campaign with HST, RXTE and ASCA observing NGC 3516 nearly continuously for 3 days. They found high amplitude variability in the X-ray band, but only very small and unrelated changes in the optical flux. The optical variability was simultaneous at all observed wavelengths. These observations are difficult to account for in either standard accretion disk models, or those in which the optical variations are due to reprocessed X-ray flux.

Dr. Kazanas along with U. Maryland summer students A. Berkley and J. Ozik computed the expected response of an optically thick accretion disk to the illumination of X-rays from an overlying source, the 'standard' model for the central engine of AGN. Using the observed X-ray light curve of NGC 7469 in a multiwavelength campaign, they produced model light curves for a number of wavelengths in the optical and UV part of the spectrum and compared them to those observed in the same monitoring campaign. Their calculations indicate that the 'standard' model cannot account for the observed variability in terms of X-ray reprocessing and it will have to be substantially modified.

Dr. Kazanas along with Drs. P. Becker (GMU) and P. Subramanian (NRL) produced a novel model for the accretion disks and acceleration of particles in AGN. Their model relies on the accretion disk shear as the driving engine for the acceleration of protons to relativistic energies. The distribution of these relativistic protons is then computed consistently within the model and it is argued that the escape of these relativistic protons can form the winds that power the relativistic jets of blazars.

Dr. Shrader, with Dr. J. Webb (Florida Int. U.) have, through a compilation of multi-wavelength observational data, presented evidence for a micro-lensing event in the blazar QSO PKS 0235+164. This source has a well known history of high-amplitude variability, however an event which occurred in 1997 was exceptional in terms of the multi-frequency light-curve morphologies. The radio, IR and optical light curves exhibited a coherent and symmetrical flaring, which seems to be inconsistent with a synchrotron event. The alternative interpretation presented in a forthcoming journal article suggests that the flare is a result of a micro-lensing event.

Drs. Hartman, Bertsch, and Thompson joined other EGRET scientists in a search for high-energy gamma rays from Mkn 501, now known to be a TeV source. An EGRET flare, uncorrelated with the X-ray emission, was found during 1996 May, with most of the emission above 500 MeV seen on May 6. The derived spectrum is very hard.

2.14 Clusters of Galaxies

Dr. Loewenstein constructed a theoretical framework for investigating the effect of heating on the structure of intra-cluster media. He concluded that the departures of cluster scaling relations from self-similarity could be explained for a universal heating of 1 keV per particle, provided that the heating were centrally concentrated and occurred during or after cluster formation. If the energy injection is supplied by the same supernovae responsible for the metal enrichment of the intracluster medium, the conversion into heat must be very efficient.

2.15 Sky Background Radiation and Cosmology

Mr. Kuntz and Dr. Snowden are continuing a study of the small-angular-scale variation in the $\frac{1}{4}$ keV and $\frac{3}{4}$ keV background. This study uses mosaics of deep ROSAT PSPC pointings to allow fluctuation analysis on scales of arc minutes to several degrees. The study hopes to place upper limits on diffuse extragalactic emission due to 1-10 million degree gas. As part of this study, they have calculated the contribution of unresolved stars to the diffuse soft X-ray background.

2.16 Extragalactic Background

Dr. Watanabe with Drs. Hartmann and Leising (Clemson U.) studied the cosmic chemical evolution parameters by using both their cosmic gamma-ray background (CGB) observation obtained from the solar maximum mission and their theoretical CGB model due to Type Ia supernovae. They also analyzed the gamma-ray bursts (GRBs) data from the Burst

And Transient Source Experiment (BATSE) on the Compton gamma-ray observatory (CGRO) to study how much GRBs contribute to CGB in the MeV regime.

Dr. Stecker has been working with Dr. M. Malkan (UCLA) to predict galaxy luminosity functions and source counts for various infrared wavelengths based on their model which has been highly successful in predicting the infrared background spectral energy distribution. They are in the process of writing up a paper presenting their results.

2.17 Catalogs

Drs. White, Angelini, and Park in collaboration with Dr. P. Giommi (ASI) have released the final version of WGCAT, a point source catalog generated using all the PSPC ROSAT observations in the HEASARC archive. Over the entire 4 year pointed phase, ROSAT has covered approximately 18% of the sky to varying degrees of sensitivity. While the sky coverage is not complete, each observation has an exposure typically a factor of 100 longer than that achieved during the six month ROSAT all sky survey. The first version of the WGCAT, released in 1994 November, contained an excess of 68,000 point sources. The final version, released in 2000 May, includes all the data taken with the ROSAT PSPC during the pointed phase and contains ~88000 sources. The catalog has been quality checked and for each source a number of useful parameters have been added. For each observation intensity, energy and timing images are available and for each source detected a spectrum and lightcurve. The catalog and the data products can be accessed via the HEASARC on-line.

3 OPERATING ORBITAL FLIGHT MISSIONS

3.1 Compton Gamma Ray Observatory (CGRO)

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

In its ninth year of operation, Compton 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. A new catalog of gamma-ray sources was published by the EGRET team. The Burst and Transient Source Ex-

periment (BATSE) has observed a total now of over 2700 gamma-ray bursts. They are isotropically distributed on the sky and have a deficit of weak bursts compared to a homogeneous distribution in space. The Compton Imaging Telescope (COMPTEL) team has published the first every catalog of sources at medium (1 - 30 MeV) gamma-ray energies.

3.2 Energetic Gamma Ray Experiment Telescope (EGRET)

Drs. Bertsch, Hartman, and Thompson worked with Dr. P. Wallace (a Summer Fellow at Goddard) and others in a systematic search for short-term variability of EGRET sources. Variability on scales of 1-2 days may indicate blazar activity, and 3EG J2006-2321 is shown to have properties like known EGRET blazars, although it is not a bright radio source. Most EGRET sources other than blazars do not show strong variability on these time scales.

After the publication of the third EGRET catalog, Drs. Thompson, Bertsch, and Hartman, along with scientists from COMPTEL and OSSE, discovered a new EGRET source, designated GRO J1400-3956, with a very steep spectrum. The absence of emission at energies below 10 MeV indicates that the spectral shape must change drastically in the 10-50 MeV range.

3.3 Solar Anomalous and Magnetospheric Explorer (SAMPEX)

Dr. von Roseninge 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. During the past year, studies of geomagnetic cut-offs and how they vary during large solar particle events have improved our understanding of the radiation hazards which the International Space Station will face.

3.4 Advanced Satellite for Cosmology and Astrophysics (ASCA)

The joint Japanese-U.S. ASCA mission is currently estimated to re-enter the Earth's atmosphere in early 2001. It is expected to be operational and produce high-quality data until a few months before re-entry, when precise attitude control becomes impossible. The focus of the GOF has shifted to the support of archival research, particularly in documenting and improving the spectral calibration of the instruments, in collaboration with the instrument team members. The GIS team, and Drs. Yaqoob and Ebisawa of the GOF, have made substantial progress in understanding the GIS response, although it has not yet reached the stage of releasing a new calibration; the SIS team with Dr. Mukai of the GOF, and the Astrophysics Data Facility led by Dr. E. Pier, are in the process of updating the calibration of the secular degradation of the instrument due to radiation damage.

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

The Transient Gamma Ray Spectrometer (TGRS) is a high-resolution gamma-ray astronomy experiment aboard the WIND spacecraft. The team, consisting of Drs. Teegarden, Cline, Gehrels, Ramaty, Harris, Kurczynski and Weidenpointer along with K. Hurley (Space Sciences Laboratory, UC Berkeley), has continued to analyze the data returned from TGRS. A high resolution spectrum of positron annihilation radiation from the Galactic center has been obtained using an on-board occulter. When the occulter is not used, the entire southern sky is observed by the detector, enabling useful survey work to be done. An extensive search for positron annihilation radiation from novae has therefore been undertaken, the first results from which are reported in Harris *et al.* (1999, ApJ, 522). Dr. Kurczynski has recently completed and successfully defended his PhD thesis on a thorough search for narrow gamma ray lines in the spectra of a large number of gamma rays. Drs. Harris and Weidenpointer in collaboration with scientists at the U. of Southhampton have recently undertaken a thorough modelling of the background production in TGRS. These results will be used to place limits on, or, hopefully detect, structure in the diffuse cosmic background radiation such as is expected from supernovae.

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

Dr. von Rosenvinge is the Principal Investigator for the Energetic Particles: Acceleration, Composition, and Transport (EPACT) experiment, developed in conjunction with Drs. Reames and Barbier for the Wind spacecraft and launched in November, 1994. Dr. G. Mason (UMCP) is also a coinvestigator. Sensitivity for low energy particles has been increased by two orders of magnitude, so that high sensitivity studies of the anomalous component, Corotating Interaction Regions and ^3He -rich events have been possible. Recent studies have utilized this high sensitivity to observed composition changes as a function of time during individual solar energetic particle events. This behavior is not simple but is in reasonable agreement with a theory developed by Drs. Reames, Ng, and Tylka. This theory attributes acceleration to a coronal/interplanetary shock and includes the effects of wave-particle interactions, with the waves being produced primarily by protons interacting with the shock.

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

Konus, a gamma-ray burst (GRB) monitor launched on the GGS-Wind spacecraft in November 1994, is the first Russian scientific experiment on a NASA mission. Dr. E. P. Mazets of the Ioffe Physico-Technical Institute in St. Petersburg, Russia is the PI and Dr. Cline is the co-PI. The Konus experiment, consisting of two sensors at opposite poles of the spacecraft (in its cislunar or interplanetary cruise, far outside the magnetosphere), has the two advantages over Earth-orbiting GRB monitors of uninterrupted coverage and

a steady background. With the demise of the Compton-GRO mission, Konus also provides a necessary near-Earth vertex in the interplanetary GRB network (IPN). The existing Ulysses/Konus/NEAR network has localized several GRBs with sufficient precision and with adequate rapidity to enable otherwise unobtainable counterpart studies (see IPN section). In addition to its GRB studies, Konus has contributed various recent advances in the studies of soft gamma repeaters (SGRs), their giant SGR flares, and other hard x-ray transients.

3.8 Rossi X-ray Timing Explorer (RXTE)

The Rossi X-ray Timing Explorer (RXTE) will have been in orbit 5 years at the end of 2000. It is fulfilling the hope for an extended lifetime; a few redundant elements have failed, but operations remain unusually flexible for an X-ray satellite and all instruments are obtaining high quality data. The spacecraft carries the collimated Proportional Counter Array (PCA) and High Energy X-ray Timing Experiment (HEXTE), that point at X-ray sources for 2-200 keV measurements on time-scales from microseconds to years, and the All Sky Monitor (ASM) that obtains long term light-curves of sources brighter than a few microJanskys, 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, or other space or ground based observatories. Of the non-TOO time another 25% is coordinated with other space or ground-based observations, including the Chandra and XMM Observatories. There is a large data base of public data obtained from TOO observations that were not part of accepted proposals, as well as from observations during the first four years. Information on the detectors, data access, data analysis tools, and results of the mission are available on the Web at http://xte.gsfc.nasa.gov/docs/xte/xte_1st.html.

With its combination of large area, flexible data modes, and high-rate telemetry, RXTE opened up the phase space of temporal measurements above 100 Hz. More than 20 accreting neutron stars in low-mass X-ray binaries have been found to exhibit two quasi-periodic oscillations (QPO) between 400 Hz and 1200 Hz. For each source they are separated by a nearly constant frequency characteristic of the source. While alternative models of these oscillations are still being developed, they all agree that the oscillations originate within a few kilometers of the neutron star surface, a location in which the effects of strong gravity are important. The saturation of frequency at a maximum for a given source appears to confirm the General Relativity prediction of the existence of an innermost stable orbit. The low frequency (10-50 Hz) oscillations that occur at the same time as the high frequencies are correlated with them. with the functional dependence of the Lense-Thirring effect, but too large a magnitude. Enough data has been obtained from a few sources that features can be detected in the power spectra which are only a few per cent of the strongest kilohertz QPO. In particular there is evidence for sidebands. Such features could break the degeneracy of the interpretations of the QPO.

Oscillations discovered in thermonuclear flash bursts from six sources continue to provide interesting new results. While oscillations during burst decays often start at a frequency about 1% below the asymptotic value, they have been shown to be coherent, consistent with being the rotation of the neutron star. This interpretation is strongly confirmed by the existence of the coherent 401 Hz pulsar in a transient burster, SAX J1808-369. Reappearance of this transient is a monitoring target, because to-date, the kilohertz oscillations in persistent flux have not been seen for it and the relation of the burst oscillation frequency to the difference frequency is crucial to the models. Evidence is accumulating that the bursts in which there is helium burning with some radius expansion have the oscillations.

RXTE has discovered 34 new transients, including types not previously known, and has carried out in depth studies of many outbursts. Five black hole candidates have now exhibited oscillations at frequencies from 67-300 Hz that are candidates to represent the predicted innermost stable orbits and together with the spectra would be sensitive to the angular momentum of the black hole. Ten new transients were found to produce radio emitting outflows near the start of the outbursts and four of these produced relativistic jets.

3.9 Interplanetary Gamma-Ray Burst Timing Network (IPN)

The interplanetary GRB network presently involves the Ulysses mission (Dr. K. Hurley, UC Berkeley, PI), the Konus experiment on the GGS-Wind mission (Dr. E. Mazets, St. Petersburg, PI and Dr. Cline, co-PI), and the Near-Earth Asteroid Rendezvous (NEAR) mission (Drs. R. Gold, APL and J. Trombka, Code 691). Other missions have also contributed, depending on circumstances, including the Rossi-XTE the BeppoSAX, and the Compton-GRO before its recent demise. The 3-spacecraft mutually long-baseline Ulysses/NEAR/Konus network now provides accurate and precise GRB localizations with a 1- to 1.5-day delay necessitated by the recovery of data from interplanetary missions. Its GRB alerts, using the Goddard GCN, even without BeppoSAX and/or Compton-GRO participation, have enabled follow-up optical and radio studies that, in turn, have contributed valuable additions to the list of GRB counterpart observations and redshift studies that the BeppoSAX initiated. This IPN should be able to continue to provide this service for several more years, hopefully in conjunction with data from the HETE-2 and the INTEGRAL missions, as well.

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

The ESA XMM-Newton X-ray observatory was successfully launched on 1999 December 10 into a highly elliptical, 48 hour orbit. Calibration and Performance Verification observations comprised the bulk of the observations through the first six months of operations and Guaranteed Time and Guest Observer (Science) observations commenced at the end of 2000 June. The checkout and calibration of the XMM-Newton science instruments went well with most instrumentation functioning nominally. Data should start flow-

ing to the observers by late summer/early fall 2000. XMM-Newton covers the 0.1 - 15 keV energy range with large effective area, moderate angular resolution (15"), and moderate (CCD) and high (grating) spectral resolution. XMM also includes an Optical Monitor for simultaneous coverage of the UV/optical band.

The NASA GSFC XMM-Newton Guest Observer Facility has continued to support US participation in the project. The GOF is currently supporting software development at Leicester U. (the Standard Analysis Software, SAS). GOF scientists Drs. Snowden, Still, and Harrus have interacted closely with both the instrument hardware teams and software development teams, both in the US and in Europe. A major effort was also spent on the NASA budget proposal process for US investigators.

3.11 Advanced Composition Explorer (ACE)

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

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, and the Russian Space Research Institute. 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 extra galactic 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 4π steradians (except for a $20^\circ \times 80^\circ$ patch around the Sun).

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° .

The MOXE flight instrument is complete, 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.

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

We regret to report the loss of the Astro-E observatory shortly after launch on 2000 February 10. Astro-E was to be the latest in a series of collaborative Japanese X-ray missions designed to provide powerful new instruments for X-ray astrophysics. Astro-E featured the high resolution X-ray Spectrometer (XRS) based on the microcalorimeter provided by GSFC, the University of Wisconsin and Japan, four CCD cameras for imaging X-ray spectroscopy (XIS) provided by MIT and Japan, and a hard X-ray detector system (HXD) developed at the University of Tokyo. These instruments were all coaligned to provide a simultaneous bandpass from 0.3-700 keV. The XRS and the four XIS cameras had separate focusing X-ray optics developed at GSFC based on conical-approximation foils with smooth replicated surfaces. Astro-E would have provided the first opportunity to use the comparatively new X-ray microcalorimeter in an observatory. This sensor is based on the thermal detection of individual X-ray photons and has very high energy resolution (~ 10 eV FWHM) over a large bandwidth with high intrinsic quantum efficiency.

The M-V launch vehicle carrying Astro-E developed problems soon after launch. It was immediately apparent that the trajectory was more vertical than required. The second and third stage engines fired properly and compensated for the lower azimuthal velocity, but these were not sufficient to overcome the first stage malfunction; the vehicle literally fell just short of establishing orbit. The problem was quickly traced to a faulty engine nozzle lining on the first stage of the M-V rocket, which led to damage of the attitude control system. It is not yet clear what might have caused the nozzle to fail. The launch failure is still under investigation.

The loss of Astro-E is a major set back for high energy astrophysics. Constellation-X would be the next mission to realize the full potential of high throughput, high resolution imaging X-ray spectroscopy. In the meantime, there are proposals in the US and Japan to try to recover as much of the Astro-E science as possible, especially while Chandra and XMM-Newton are still operational.

The Astro-E Guest Observer Facility played a major role in developing, integrating, and testing the data reduction software, in collaboration with the instrument teams and the Astrophysics Data Facility (ADF). In particular, the GOF and the FTOOLS group have developed a successful system of importing software developed by the instrument teams and converting them into multi-platform FTOOLS that can be distributed to the community. In a software end-to-end test performed jointly with Institute of Space and Astronautical Sciences (ISAS), the ADF processed ground test data taken through flight or flight-like electronics into telemetry

format and archived at ISAS, and produced standard-conforming FITS data files. GOF members and other testers successfully analyzed these data using multi-mission analysis tools, validating the data reduction pipeline in general. The GOF also supported the Cycle 1 US Guest Observer Program peer review and subsequent international merging.

4.3 Solar-TERrestrial Relations Observatory (STEREO)

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

4.4 International Gamma-Ray Astrophysics Laboratory (INTEGRAL)

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

4.5 Gamma-ray Large Area Space Telescope (GLAST)

Drs. Bonnell, Digel, Gehrels, Hartman, Hunter, Moiseev, Norris, Ormes, Ritz, and Thompson are GSFC members of a large consortium (Prof. P. Michelson of Stanford is the PI) that was selected to build the Large Area Telescope (LAT) main instrument for the Gamma-ray Large Area Space Telescope (GLAST), the next-generation high-energy gamma-ray mission. With a large field of view (2.4 sr), large peak effective area ($>10,000$ cm²), greatly improved point spread function ($<0.15^\circ$ for $E > 10$ GeV), and unattenuated acceptance to high energies, GLAST will measure the cosmic gamma-ray flux in the energy range 20 MeV to > 300 GeV with unprecedented precision and greater than a factor 50 higher sensitivity than the existing EGRET detector. The launch is planned for 2005. GLAST will open a new and important window on a wide variety of high energy phenomena, including black holes and active galactic nuclei;

gamma-ray bursts; supernova remnants; and searches for new phenomena such as supersymmetric dark matter annihilations and primordial black hole evaporation. The proposed instrument consists of a large effective area Si-strip precision tracker, an 8.5 radiation length CsI hodoscopic calorimeter, and a segmented plastic tile anticoincidence detector (ACD).

GSFC is the lead institution responsible for the ACD, including all hardware and readout electronics. Dr. Ormes, the ACD subsystem manager, and Drs. Moiseev, Thompson and Hartman are designing the flight unit. An engineering model for the ACD was constructed and used in a flight-scale GLAST tower beam test in 1999. A prototype custom Calorimeter front-end electronics chip was also designed (in collaboration with Dr. W.N. Johnson (NRL)) and tested by Goddard for the engineering model tower, demonstrating the analog capabilities needed for flight. This same tower will be used in a balloon flight in 2001, for which Dr. Thompson is a co-leader.

Drs. Bonnell, Digel, Norris, and Ritz are performing instrument simulations to optimize the design of the instrument. Under Stanford leadership, Drs. Digel and Norris are helping to coordinate the LAT team science software preparation. Drs. Gehrels, Ormes, Ritz and Thompson are members of the GLAST Senior Scientist Advisory Committee, which is chaired by Dr. Gehrels. Dr. Ritz is the LAT Instrument Scientist. Dr. Thompson is a LAT team member of the GLAST Science Working Group, and is also the LAT team multiwavelength coordinator. Drs. Baring, Harding, Hunter and Stecker are Associate Investigators on the LAT team, working on the preparation for science analysis. NRC Research Associates Drs. Kotani and Reimer work on ACD design and science analysis software, respectively. Goddard scientists also work with the GLAST project office, which is located at Goddard. Dr. Ormes is the GLAST project scientist and chair of the Science Working Group, and Drs. Gehrels and Ritz are deputy project scientists. During the AO competition, the project scientist was Dr. Bertsch.

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

Two of the most compelling issues facing astrophysics and cosmology are to understand the nature of the dark matter that pervades the universe, and to understand the apparent absence of cosmological antimatter. Both issues can be addressed by sensitive measurements of cosmic ray anti-protons and positrons, made with a space-based instrument capable of spanning a wide energy range. This is the goal of the polar orbiting PAMELA instrument, under development by an international collaboration among scientists from Italy, the US, Germany, Sweden, and Russia. The instrument will fly on a Russian Resurs-Arktika earth-observing satellite in mid 2003. PAMELA identifies particles from 50 MeV to over 100 GeV using a permanent magnet spectrometer with solid-state tracking, a time-of-flight system, a transition-radiation detector, and an imaging silicon/tungsten sampling calorimeter. PAMELA will also quantify the effects of solar modulation on the fluxes of galactic cosmic rays. This is critical to understanding the antiparticle signatures of exotic matter and is an important factor in understanding the dy-

namics of the Solar System. Dr. Mitchell is leading the HECR group work on PAMELA, focusing on the time-of-flight and trigger systems. Development of flight versions of these systems, as well as US scientific participation in PAMELA, was proposed by Goddard and New Mexico State University (NMSU) in February 2000 as a Mission of Opportunity under the SMEX AO. Dr. Mitchell is the PI of the proposed TEMPO (Timing Experiment Modules for PAMELA Observations) investigation and Drs. Barbier, Christian, Krizmanic, Moiseev, Ormes, Ramaty, and Streitmatter are Co-Investigators along with Drs. S. Stochaj and W. Webber of NMSU.

4.7 Constellation-X

The Constellation-X observatory is a revolutionary mission in X-ray spectroscopy providing a factor of nearly 100 increase in sensitivity at high spectral resolution ($E/\Delta E \sim 300-3000$). The mission was strongly endorsed in the recent National Academy of Sciences report "Decadal Survey on Astronomy" as the premier instrument for studying the formation of black holes. Substantial technical progress was achieved within the last year. These include demonstration of 2 eV spectral resolution at 1.5 keV with the calorimeter, construction of shell optics with a factor of 6 lower mass than with XMM technology, improved CdZnTe hard X-ray detector energy resolution, and demonstrated proof-of-concept for a resistive gate CCD.

4.8 Orbiting Wide-angle Light-collectors (OWL)

A collaboration led by Dr. Streitmatter is working on the design of an instrument for detecting the highest energy cosmic rays by observing from space the fluorescence light from giant air showers with energies greater than 10^{20} eV produced when these particles interact with the atmosphere. The Orbiting array of Wide-angle Light-collectors (OWL) collaboration includes the HECR group from GSFC, Marshall Space Flight Center (Drs. J. Adams, M. Christl), U. of Alabama (Drs. Y. Takahashi, J. Dimmock, T. Parnell), U. of Utah (Drs. P. Sokolsky, G. Loh, P. Sommers), and UCLA (Drs. D. Cline, K. Arisaka). OWL is in the NASA Strategic Plan.

4.9 Laser Interferometer Space Antenna (LISA)

Gravitational radiation has the potential of providing a powerful new window on the universe for observing the behavior of astronomical systems under conditions of strongly non-linear gravity and super-high velocities. Because of seismic and gravity gradient noise on Earth, searches for gravitational radiation at frequencies lower than 10 Hz must be done in space. The frequency range $10^{-4} \rightarrow 1$ Hz contains many of the most astrophysically interesting sources. In this band, predicted emission includes that associated with the formation or coalescence of massive black holes in galactic nuclei. Laser interferometry among an array of spacecraft in heliocentric orbit with separations on the order of a thousand Earth radii could reach the sensitivity to observe low-frequency gravitational radiation from likely sources out to cosmological distances, and would be an important comple-

ment to the ground-based experiments already being constructed. A specific concept for this space observatory known as Laser Interferometer Space Antenna (LISA) is under study as an advanced mission for the next decade. The LISA observatory for gravitational radiation is a cluster of three spacecraft that uses laser interferometry to precisely measure distance changes between widely separated freely falling test masses housed in vehicles situated at the corners of an equilateral triangle 5×10^6 km on a side. It is a NASA/ESA mission that is part of the NASA SEU roadmap for the latter half of the next decade. Drs. Boldt and Teegarden are members of the mission definition team, and are in the process of establishing an effort here in support of the LISA project. Dr. E. Waluschka of the Optics Branch has complete a year working in Boulder Colorado with Dr. P. Bender of JILA on the design and modeling of the LISA optics. Drs. Boldt and Teegarden attended the recent meeting of the LISA Mission Definition Team at Caltech. A post-doc to work on the LISA disturbance reduction system is likely to start at GSFC in the fall.

4.10 Advanced Cosmic-ray Composition Experiment for the Space Station (ACCESS)

Several cosmic ray instruments for the International Space Station (ISS) are currently being studied. The Advanced Cosmic-ray Composition Experiment for the Space Station (ACCESS) will study the fundamental questions of how galactic cosmic rays are accelerated and transported in the Galaxy. Elements up through iron will be measured to high energies ($\sim 10^{15}$ eV) to measure the composition approaching the "knee" region of the cosmic ray energy spectrum. The instrument will consist of two detecting parts: a calorimeter to measure hydrogen, helium, and other light elements, and a transition radiation detector (TRD) to measure heavier elements through iron. ACCESS is planned to replace AMS on Space Station in 2006. Goddard scientists involved are Drs. Streitmatter (Study Scientist), Barbier and Christian (Deputy Study Scientists), Ormes (calorimeter study team leader), Mitchell (accelerator test team leader), and Moiseev who is working on instrument simulations. Moiseev, Ormes and Mitchell have designed a cubic calorimeter that should increase the collecting power by a factor of at least 2 and perhaps more over the baseline and are forming a team to respond to the AO anticipated to be released in early 2001.

The ACCESS executive committee has led the development of a Study Report which will be published in the fall of 2000. This report outlines the science goals of ACCESS, the Space Station resources available, and outlines strawman instruments.

4.11 SWIFT

The Swift gamma-ray burst MIDEX proposal was selected by NASA October 14, 1999. It will fly in September 2003 for a nominal three year lifetime. Swift is an international payload consisting of wide and narrow field-of-view instruments with prompt response to gamma-ray bursts. A 1.4-steradian wide-field gamma-ray camera will detect and

image ~ 300 gamma-ray bursts per year with 1-4 arcmin positions. The Swift spacecraft then slews automatically in 20-70 seconds to point narrow-field X-ray and UV/optical telescopes at the position of each gamma-ray burst to determine arcsecond positions and performs detailed afterglow observations. The goal of the mission is to determine the origin of gamma-ray bursts and to use bursts to probe the early universe. The mission is managed at Goddard. Dr. Gehrels is the PI, Dr. White is the Science Working Group Chair and Dr. J. Nousek is the lead scientist at Penn State, the prime US university partner. Key hardware contributions are made by international collaborators in the UK and Italy.

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 the astrophysics community access to archival data from extreme-ultra-violet, X-ray, and gamma-ray missions. In order to provide the maximum scientific utilization of this archive, the HEASARC also makes available appropriate multi-mission analysis software and Web tools. In the summer of 1999, the Harvard-Smithsonian Center for Astrophysics (CFA) became a partner with LHEA in the HEASARC organization, and Dr. S. Murray of CFA was appointed Associate Director.

Highlights from the past 12 months of HEASARC operation include: a total volume of archival data reaching 2.0 Terabytes (TB); a record 1.7 TB of data downloaded by users via anonymous ftp and 0.83 TB of images, webpages, and data downloaded via the Web (http); a record 400,000 queries to the HEASARC's multi-mission database and catalog Web service, Browse, which now contains more than 250 tables; the acquisition from the German ROSAT group of the ROSAT All-Sky Survey (RASS) data, and the creation of a large number of RASS and ROSAT-related databases, including the ROSAT HRI Source Catalog and the final version of the WGACAT PSPC Source catalog; a record 500,000 images served to users of the Web-based SkyView facility (a tool which allows users to display images of portions of the sky in various projections and in a wide range of wavelengths based on a large number of existing large-area surveys which it incorporates); the unification of the HEASARC's FTOOLS and XANADU software suites into one package, HEASoft; the export of copies of the ASCA Data Archive to the U. Leicester (UK), the BeppoSax Data Center (SDC) in Italy, the European Space Agency XMM-Newton facility at ESTEC, and the Integral Data Center in Switzerland; the continuing ingest of BeppoSAX NFI data from the SDC and the export of a copy of these data to ISAS in Japan; the creation of packages within HEASoft to analyze the recently reformatted HEAO-1, OSO-8 and EXOSAT FITS data; the moving of the bulk of the HEASARC's data holdings from magneto-optical jukeboxes to a more fail-safe RAID (Redundant Array of Inexpensive Disks) system; a major revamping of the HEASARC website (<http://heasarc.gsfc.nasa.gov/>) to improve its functionality, structure

and appearance, including the creation of observatory Web pages for all the HEASARC's high-energy missions which describe the available data and software, and provide images and a mission bibliography; the unveiling of the "HEASARC Picture of the Week" on the HEASARC home page as a new way of providing imagery of the universe in X-rays and gamma-rays to the general public; the development of a Perl-based replacement of the HEASARC's obsolete captive account; and, finally, the commencement of development of a new Web package, Hera, which will provide all the capabilities of the current HEASoft package in a Web interface, thereby enabling users to seamlessly browse for data in the HEASARC archive, and then to immediately reduce and analyze the data using the same integrated Web interface.

5.2 High Resolution Detector Development

The X-ray astrophysics branch continues to be heavily involved in the development and application of X-ray microcalorimeters for high resolution X-ray spectroscopy. Members of the LHEA microcalorimeter team include Drs. Boyce, Finkbeiner, Gendreau, Kelley, Porter, Stahle, and Szymkowiak. Mark Lindeman recently joined our group as a NRC Research Associate from UC Davis/Lawrence Livermore National Laboratory. Dr. Lindeman did his Ph.D. thesis on "Microcalorimetry and the Transition-Edge Sensor." Enectali Figueroa-Feliciano (Stanford) and Barbara Mattson (U. Maryland) are graduate students in our group. In addition, we continue to collaborate with Dr. H. Moseley of the Infrared Astrophysics Branch at Goddard, and Prof. D. McCammon of the University of Wisconsin.

The specific areas of microcalorimeters we are developing include low noise, high sensitivity thermometers, schemes for fabricating large arrays with high filling factor, and X-ray absorbing thermalizers that can be directly incorporated into the device fabrication process.

During the past year, we have made considerable progress. In the area of microcalorimeters with semiconductor thermometers (ion-implanted silicon), we have developed a new process to produce thermometers with uniform concentration over a significantly larger volume. This should lower the intrinsic $1/f$ noise in the thermometer, which has been the limiting factor in determining the energy resolution of ion-implanted thermometers. Preliminary indications are that the new process produces significantly lower levels of $1/f$ noise. Devices that can be tested with X-rays for resolution measurements will be fabricated soon. The goal of this work is to produce devices with an energy resolution of ~ 6 eV or better at 6 keV for use on missions, including sub-orbital, prior to the Constellation-X program.

For Constellation-X, an energy resolution of 2 eV at 6 keV and below is required in an array capable of $5'' - 10''$ imaging over a field of view of at least $2.5'$. Toward this goal, we have fabricated and tested microcalorimeters with superconducting transition edge thermometers. Using a device with a Mo/Au bilayer (transition temperature of ~ 100 mK) on silicon nitride, we obtained a resolution of 2.9 eV (FWHM) at Al $K\alpha$ (1.5 keV). This device had a relatively low saturation energy because we had not yet optimized the

magnitude of the device heat capacity with respect to the sharpness of the superconducting transition. The device did not have an X-ray absorber, which led to some artifacts in the monochromatic response that were, nonetheless, easy to separate from the primary response because of the high spectral resolution. Future work will concentrate on fully characterizing and optimizing these devices, developing arrays, and then integrating the X-ray absorbers with the thermometers.

For the absorbers, we have fabricated arrays of bismuth squares engineered to have a stem and an overhanging portion around the circumference. This is designed to cover the calorimeter support beams and interconnecting leads. Arrays of 1024 pixels (32×32) have been fabricated with individual pixel dimensions of 300–500 μm .

In the area of applications, we have assembled a microcalorimeter spectrometer based on Astro-E/XRS and XQC engineering model and spare components. This will be used for laboratory spectroscopy work with an electron beam ion trap (EBIT) at the Lawrence Livermore National Laboratory in collaboration with S. Kahn and P. Beiersdorfer. The goal of this work is to measure the atomic transition properties of highly ionized elements and use the results to derive cross sections for plasma codes.

5.3 Future Hard X-ray Detector Development

The research and development of new detector and optics technologies for future hard X-ray astrophysics instrumentation has long been an important endeavor in the LHEA. Drs. Parsons, Barbier, Barthelmy, Gehrels, Palmer, Teegarden and Tueller of the Low Energy Gamma-Ray Group (LEGR) have continued their highly successful technology development program to produce new cadmium zinc telluride (CdZnTe) and cadmium telluride (CdTe) detector arrays and focal plane sensors for balloon and spacecraft applications. Improvements in the availability of high quality room temperature semiconductors such as CdZnTe and CdTe have made it possible to produce large, convenient, light-weight detector arrays for hard X-ray imaging and spectroscopy. The advantages of CdZnTe and CdTe detectors include good energy resolution in the 5–300 keV energy range without the complexity of cooling and high-Z for greater stopping power with a thinner, more compact instrument. Working with Dr. C. Stahle and P. Shu in the GSFC Detector Systems Branch (Code 553), the LEGR group has developed the capability to design, process and package CdZnTe and CdTe detectors and readout electronics for a variety of space applications. Detector systems fabricated in the past include double-sided CdZnTe strip detectors with 100 micron pitch that would allow fine (arcsecond) imaging of hard X-ray sources and gamma-ray bursts. A 6×6 array of such strip detectors has been assembled at GSFC with over 500,000 separate resolution elements. The LEGR group has also flown CdZnTe detectors at balloon altitudes to investigate the CdZnTe detector background dependence on the active shielding configuration. The baseline detector systems for many future missions described elsewhere in this report depend on detector technologies that were developed through this program such as the proposed Swift Gamma-Ray Burst Explorer;

InFOC μ S, a balloon-borne hard x-ray focusing telescope; and the Hard X-ray Telescope for the Constellation-X program.

Future thrusts in the development of these technologies will be to improve spectroscopic performance throughout a more extended energy range (1–600 keV) with the use of both thicker CdZnTe detectors and stacked Si and CdZnTe detector arrays. As the angular resolution of hard X-ray optics improves, the trend in the development of future hard X-ray focal plane sensors will also be toward finer pitch detector arrays with an increasingly large number of pixels that must be read out within a physically small space. Small Application Specific Integrated Circuits (ASICs) provide each pixel with its own readout electronic circuit. One of the challenges of ASIC design is to fit the readout circuits with the required functionality into a space less than 400 microns square. While GSFC strip and pixel detectors have been read out using a variety of commercially available ASICs, GSFC engineers are currently developing an in-house low noise, lower power readout ASIC practical for future large area arrays.

5.4 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, deuterium, and helium isotopes fluxes in the energy range from a few hundred MeV/nucleon to three GeV/nucleon. Analysis of the measurements of the proton and helium primary spectra from a few hundred MeV/nucleon to a few hundred GeV/nucleon has also been completed. Dr. Krizmanic has completed and presented the results of an analysis of the data from the IMAX experiment which measured the atmospheric muon flux as a function of atmospheric depth. Measurements of the atmospheric muon flux by balloon-borne magnetic spectrometers provide an experimental measure of atmospheric neutrino production as the production of muons and neutrinos are kinematically related. The unique capabilities of the IMAX instrument enabled measurements which were uncontaminated by backgrounds, especially pions, in the momentum range $0.2 \rightarrow 0.45$ GeV/c. The uncertainties in the absolute neutrino flux remain a dominant source of systematic error in experiments such as Super-Kamiokande which measure atmospheric neutrino interactions. As these experimental measurements have given strong evidence that neutrino oscillations are responsible for the atmospheric neutrino anomaly, the uncertainties in the absolute neutrino flux lead to a large range of possible neutrino mass and mixing parameters. The IMAX results, when compared to that of the Bartol Atmospheric Monte Carlo Predictions, which used the IMAX primary, cosmic ray spectra measurements as input, indicate good agreement at the lowest and highest atmospheric depths. However, the results at mid-atmospheric depths demonstrate an over-prediction of the flux by the simulation. The source of this disagreement has been attributed to effects not included in the original Bartol simulation and work is in progress to compare the IMAX measurements to the predictions of new simulations which model these effects. The IMAX experiment is a collaboration among

GSFC, Caltech Drs. A. Davis, A. Labrador, R. Mewaldt, S. Schindler, New Mexico State U. Drs. S. Stochaj, W. Weber, and U. of Siegen Drs. M. Simon, M. Hof, W. Menn, O. Reimer.

5.5 International Focusing Optics Collaboration for μ Crab Sensitivity (InFOC μ S)

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

5.6 Gas Micro-Structure Detector SR&T

Drs. Black, Deines-Jones, and Hunter have continued their development of large area, high spatial resolution, two-dimensional micro-well detectors (MWDs), a new type of gas proportional counter. These charge-sensitive detectors are being developed for astrophysical instrument applications requiring large area, low-power, two-dimensional position sensing. MWDs are similar in operation to micro-strip detectors. Unlike micro-strip detectors, however, the cathode of a MWD is raised above the anode, separated by a thin dielectric. This allows for two-dimensional readout if the anodes and cathodes are segmented into orthogonal strips. The MWD geometry also relies on a long avalanche region for gas multiplication rather than a small, wire-like anode. This aspect of the MWD geometry allows very robust, spark-tolerant construction.

The MWD electrodes are commercially fabricated at very low cost as a flexible printed circuit board, using copper clad polymer substrates. The wells are then drilled at GSFC's UV laser micro-machining facility. The ablation process takes advantage of the fact that polymers are ablated by intense UV light, but the copper anode acts as a stop layer. Recently,

it has been demonstrated that the cathode can be made by using the laser to pattern a thin, sputtered metal layer.

Further segmentation of the anode into pads allows for true pixel MWDs. The readout of a pixelized MWD requires an array of FET switches. The FET array for these detectors is being developed using thin film transistor technology at Pennsylvania State University.

We have demonstrated 1) fabrication of 5 cm×5 cm detectors with 400 um pitch, 2) stable proportional operation at a gas gain >30,000 in Ar- and Xe-based gases, 3) ability to sustain repeated breakdown with no performance degradation, 4) nominal proportional operation and good electron collection efficiency with FWHM energy resolution of 20% with 6 keV X-rays, and 10% resolution with 20 keV, and 5) <160 um X-ray spatial resolution.

5.7 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. ISOMAX is a collaboration of GSFC Drs. Streitmatter, Barbier, Christian, Geier, Krizmanic, Mitchell, Moiseev and Ormes, with Caltech Drs. R. Mewaldt, S. Schindler and G. DeNolfo and the U. of Siegen Dr. M. Simon with students H. Goebel, T. Hams, and D. Vasilas. ISOMAX had its maiden flight in August 1998 and Dr. Geier received his Ph.D. with a dissertation based on an analysis of the ^{10}Be measurements. A second flight of ISOMAX extending the Be measurements to higher energies is planned for the summer of 2000.

5.8 Extremely Heavy Cosmic-ray Composition Observatory (ECCO)

Dr. Barbier was the NASA Study Scientist for the Extremely Heavy Cosmic-ray Composition Observatory, ECCO, an International Space Station mission. ECCO (Dr. Andrew Westphal, LBL, PI), is an extension of the TREK/MIR experiment that found that Pb is under abundant in the cosmic-rays. Since Pb is easily ionized, this contradicts standard models of the cosmic ray source as being a solar-like, ionized medium. ECCO will measure the rare actinides, Th, U, Np, Pu, Cm, with high accuracy for the first time, which will help our understanding of the true cosmic ray source.

ECCO was redesigned last year as a free-flyer mission (combined with the ENTICE instrument from Washington U.) and proposed to NASA as a MIDEX Mission. The collaboration was expanded to include the U. of Michigan. Selections are expected from NASA in the fall of 2000.

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, S. Schindler, 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.

The TIGER program had a successful engineering flight in 1997 and is preparing for the TIGER 2002 Ultra-Long Duration Balloon (ULDB) flight. This flight will take place from either Antarctica or New Zealand in January 2002. Next year (Jan. 2001) a test flight of the ULDB package will take place from Alice Springs, Australia and preparations are underway for this now. TIGER was mentioned in the November 1999 Scientific American magazine article on ULDB. The TIGER Co/Ni ratio from the 1997 flight results of 0.093 ± 0.037 are in clear conflict with ACE data below 0.5 GeV/nucleon. The ACE results suggested negligible ^{59}Ni at the cosmic-ray source, the TIGER results imply more Ni.

5.10 Nightglow

A new balloon instrument called NIGHTGLOW (Dr. L. Barbier, PI) has been constructed to monitor the UV light produced in the atmosphere and which constitutes a background source for ultra-high energy cosmic ray particles which produce air showers. This is being done in collaboration with the University of Utah (Drs. G. Loh and P. Sokolsky).

Nightglow had a successful engineering flight of 8 hours duration from Palestine, Texas. Data analysis from that flight is ongoing and a NIM paper on the instrument is being written. Planning is now underway for a science flight from Alice Springs, Australia in January-February 2001.

5.11 Gamma Ray Burst Coordinates Network (GCN)

The interplanetary GRB network presently involves the Ulysses mission (Dr. K. Hurley, UC Berkeley, PI), the Konus experiment on the GGS-Wind mission (Dr. E. Mazets, St. Petersburg, PI and Dr. Cline, Co-PI), and the Near-Earth Asteroid Rendezvous (NEAR) mission (Drs. R. Gold, APL and J. Trombka, Code 691). Other missions have also contributed, depending on circumstances, including the Rossi-XTE, the BeppoSAX, and the Compton-GRO before its recent demise. The 3-spacecraft mutually long-baseline Ulysses/NEAR/Konus network now provides frequent accurate and precise GRB localizations with a 1- to 1.5-day delay, necessitated by the recovery of data from interplanetary missions. Its GRB alerts, using the Goddard GCN, even without BeppoSAX and/or Compton-GRO participation, have enabled follow-up optical and radio studies that, in turn, have contributed additional statistics in the list of GRB counterpart observations and redshift studies that the BeppoSAX initiated. This IPN should be able to continue to provide this service for several more years, hopefully in conjunction with data from the HETE-2 and the European INTEGRAL missions, as well.

5.12 Foil Mirrors for X-Ray Telescopes

The primary involvement of the Mirror Lab is in fabricating the reflectors for the InFOCUS balloon-borne mission in

collaboration with our colleagues at Nagoya U., Japan. The deposition of Pt/C multilayers on our foil reflectors extends their energy response beyond 40 keV, suitable for a balloon instrument. An important breakthrough in this program has been our ability to replicate reflector surfaces directly off multilayer coatings deposited on glass mandrels.

An equally important involvement is our continuing effort to fully understand spatial errors of our foil mirrors in order to improve their imaging capability. The relevance of this effort is supported by the distinct possibility of our group being involved, once again, in the fabrication of mirrors for a second Astro-E payload to replace the one lost earlier this year. The need to remain competitive in the 2004-2005 period with the two major observatories, Chandra and Newton, launched some 5 years earlier, makes it important that we seek enhancements in the performance of an Astro-E II. In addition, we continue to be aware of the excellent suitability of light weight foil mirrors for future observatories, such as Constellation-X or smaller Explorer type missions, provided we are able to significantly improve their spatial resolution as required by these future instruments.

We have been using slumped thin glass sheets as mirror substrates. We have achieved a typical single-pair angular resolution of 40 to 50 seconds of arc. We are in the process of isolating different contributing sources to the above angular resolution: overall figure errors resulting in forming the substrate, distortion caused during the replication process, misalignment between the primary and secondary mirrors, temperature excursions during the process, and the figure error of the replication mandrel.

Finally, a smaller effort is devoted into two projects, supported by the Director's Discretionary Fund, in which we attempt to extend the utility of the replication techniques we have developed and of multilayers into other areas of research such as light weight optical mirrors and medical diagnostic instruments.

5.13 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.

The LHEA outreach group released the 4th edition of the Imagine the Universe! CD-ROM. In addition to the Imagine web site, this year's CD also contains StarChild, and the Astronomy Picture of the Day for 1999. Dr. Lochner, Mr. M. Arida, S. Fantasia, B. Hewitt, Ms. M. Masetti, J.A. Hajian, K. Smale, and S. Humphrey prepared and released the CD-ROM. As before, the CD is compatible with both Macintosh and PC platforms, and cgi activities were converted to javascript so all the interactive features were available in this format. The CD-ROM is distributed free upon request and distributed at teacher conferences.

The LHEA outreach group also continued its series of posters and information/activity books. We published a new set on gamma ray bursts, and started development of the next set on galaxies, the hidden mass problem, and X-ray observations of galaxies.

The Imagine the Universe! web site was evaluated by Cornerstone Evaluation Associates (Pittsburgh, PA) for both functionality and usability. The evaluation confirmed the overall usefulness of the site. But as a result of analysis by web experts and a teacher focus group, the site was given a more up-to-date look.

The LHEA outreach group represented the Structure and Evolution of the Universe Theme at many national and regional meetings, including the National Science Teacher's Association annual meeting, the Science Teachers of New York State meeting, and two American Astronomical Society meetings. We presented workshops on gamma-ray bursts, and on using data from the RXTE All Sky Monitor in the classroom.

5.14 Workshops

Drs. Bautista and Kallman organized the workshop "Atomic Data Needs for X-ray Astronomy" (1999 December 16-17) at NASA GSFC. Over 150 scientists from all over the world participated in the event to discuss outstanding issues on atomic data needs for the study of X-ray spectra of astronomical sources. The discussions included observations, theoretical atomic calculations, experimental data, spectra modeling, databases, and funding. The proceedings of the event became available online at <http://heasarc.gsfc.nasa.gov/docs/heasarc/atomic/>.

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