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# Final Technical Report for NASA Grant NAG5-1176
# Cooperative Research in High Energy Astrophysics

This grant covered the period July 1989 through April 1994. The research covered a variety of topics including

1. Detectionof cosmic rays and studies of the solar modulation of galactic comic rays
2. Support work for several X-Ray satellites
3. High resolution gamma-ray spectroscopy
4. Theoretical Astrophysics
5. Study of Active Galaxies

Details of the research are appended

1989-1990

## 2. Proposed Joint Effort of the University of Maryland and the NASA Goddard Space Flight Center Laboratory for High Energy Astrophysics

This grant supports activities conducted by University personnel both on campus and at the Goddard Space Flight Center. Work will be concentrated in the following areas:

1) Detection of cosmic rays and studies of the solar modulation of galactic cosmic rays
2) Support work for several past and upcoming X-ray satellites
3) High resolution gamma-ray spectroscopy of celestial sources
4) Theoretical astrophysics
5) Active galaxies

This section describes the work accomplished to date and the proposed joint effort for the next grant period for each of these areas within the overall research program. During the upcoming year, we propose to continue our joint efforts in the areas listed above.

### 2.1 High Energy Cosmic Rays

Cosmic rays are the only samples of matter which reach earth from outside the solar system. As such, they carry information on their origin, acceleration, and subsequent propagation.

#### 2.1.1 Cosmic Ray Detections

Past measurements of the flux of antiprotons at low energies is in disagreement with expectations from the best current theory. In an effort to check these measurements, the Low Energy Antiproton experiment (LEAP) was performed as a collaboration between GSFC, University of New Mexico and University of Arizona. The LEAP instrument is a magnetic spectrometer which measures the particle momentum, mass and charge through the use of multiwire proportional counters (MWPC), a time of flight (TOF) detector and a Cherenkov radiation detector.

The LEAP instrument was launched from Prince Albert, Canada, on August 7, 1987. The LEAP instrument had a successful, 22 1/2 hr, flight during which over 10 million events were recorded. University of Maryland graduate student, Mr. Steven Stochaj, played a major role in the development of the TOF detector and is presently involved with the data analysis. Mr. Stochaj is a co-author of a paper presenting LEAP results Adv. Space Res. (1989) Vol. 9, p. 1265, as well a final paper in preparation.

Between the present low energy antiproton measurements, which extend up to about 1 GeV/n and the higher energy measurements of Golden (around 5 GeV/n) there are no antiproton measurements except those of Bogomolov, which have error bars extending over an order of magnitude. We are planning an experiment (the Isotope Matter-Antimatter Experiment) which will measure the antiproton fluxes from 100 Mev to about 4 GeV. The experiment will utilize the NASA Balloon Borne Magnet Spectrometer (BBMF), three Cherenkov detectors, and a TOF system. The experiment is a collaboration with CalTech and New Mexico State University. University of Maryland graduate student Shantanu Bhattacharya, who worked with this group in the summer of 1989, will join the IMAX experiement when he passes his qualifying exam in August 1990. Mr. Bhattacharya will be working with this group on preparatory laboratory work for IMAX this coming summer, 1990 as well.

Another experiment in which this group is involved is the MASS (Matter-Antimatter Spectrometer) experiment scheduled flight in the spring of 1991. This experiment using the BBMF will measure antiprotons in the 5 - 10 GeV range, as well as making low energy positron measurements. Mr. Glen Allen, a Maryland graduate student, will be working with this group this summer, and is potentially a graduate student on MASS.

### 2.1.2 Low Energy Cosmic Ray

The directional distribution (anisotropy) of energetic charged particles in interplanetary space can provide information on their origin and propagation, and on the structure of the interplanetary magnetic field. The NASA/Goddard Space Flight Center Medium Energy Cosmic Ray Experiment on the ISEE-3/ICE spacecraft has measured the distribution of > 1 MeV/n and > 5 MeV/n ions since launch in August 1978. However, this data set has been little exploited in the past since it could not be conveniently accessed. Ian Richardson has now transferred the complete data base at 15 minutes resolution onto optical disk where it can be accessed via a PC. Software has been written allowing the data to be rapidly reviewed and interpreted. Data from the Goddard instruments on IMP-8 and Helios will also be made available in the future. Changes in particle distributions associated with particle acceleration at interplanetary shocks are being investigated using the ISEE-3/ICE data and a preliminary study was presented at the International Cosmic Ray Conference, Adelaide in January 1990. Studies of the structure of the interplanetary magnetic field include the rapid propagation of solar particles from events on the eastern solar hemisphere in pre-existing magnetic "bottles" extending from the sun, and investigation of the structure of coronal mass ejections using data taken during 1989 when the spacecraft was off the west limb of the sun. The properties of energetic ions at quiet times are also being studied. Minor activities have included collaboration with Imperial College, London on investigations of ISEE-3/ICE energetic particle observations in the geomagnetic tail and at comet Giacobini-Zinner. Papers were also contributed to the International Cosmical Ray Conference on the acceleration of ions at comet Giacobini-Zinner and the spectra of > 35 keV ions in corotating ion enhancements.

Hilary Cane's research since early 1989 has been mainly directed towards investigating the composition of solar energetic particles. A paper on this topic was presented at the International Cosmic Ray Conference. Work has also continued on attempting to determine the origins of interplanetary disturbances that cause geomagnetic storms. An invited paper on this topic was given at the December 1989 AGU meeting, in collaboration with E. Cliver of AFGL. Future work will combine these efforts as there may be compositional variations in interplanetary events with different solar origins.

## 2.2 X-Ray Astronomy

James Lochner completed his thesis ("Chaos and Random Processes in the X-ray variability of Cygnus X-1"), was awarded his Ph.D., and left to take up a postdoctoral position with the X-ray group at the Los Alamos National Laboratory. Personnel now supported by the University of Maryland at the Goddard X-ray group consistent of Dr. Keith Arnaud, as an Assistant Research Scientist, and three graduate students: Damian Christian, Kim Weaver, and Warren Focke.

Dr. Keith Arnaud has been instrumental in the establishment of the High Energy Astrophysics Archival Research Center (HEASARC), a collaboration at Goddard between the LHEA and the National Space Science Data Center (NSSDC). The aim of the HEASARC is to make available to US astronomers raw data and products from previous and forthcoming high energy astrophysics missions along with the software tools to enable this data to be analyzed. The HEASARC subsumes the ROSAT guest observer facility (to be sited at the LHEA) along with the archiving efforts associated with the BBXRT and Astro-D missions. Already the HEASARC is making available, by electronic means, data from the Einstein Observatory and the ESA EXOSAT satellites. The addition of the HEAO-1 A2 dataset is underway. Arnaud has continued his research on X-ray observations of clusters of galaxies and active galaxies. With collaborators in England and Hawaii he has submitted papers (to MNRAS and ApJ, respectively) on X-ray cluster luminosity and temperature functions. The temperature function is particularly interesting because it can be converted into a mass function and this constrains the primordial perturbation spectrum, from which structure in the Universe is assumed to grow. The current results show a slope and normalization for the perturbation spectrum that is inconsistent with the popular cold dark matter model. On the active galaxy front he is involved in several projects to characterize the X-ray spectrum in the energy range of 0.1 - 20 keV using Einstein Observatory data.

Damian Christian is studying the spectral and temporal behavior of Low Mass X-ray Binaries (LMXB) under the direction of Dr. Jean Swank. LMXB are among the most luminous X-ray sources known. Their large luminosity is attributed to accretion onto a neutron star from a companion less massive than the sun. An attempt is being made to find the best spectral models that can be applied to a physically reasonable picture for these sources from the analysis of several archive data sets, OSO-8, HEAO-1, and HEAO-2 (Einstein) and the upcoming BBXRT mission. Currently he is involved in the analysis of Solid State Spectrometer (SSS) and Monitor Proportional Counter (MPC) data from the HEAO-2 Observatory. He has completed an extensive recalibration of the SSS. These improvements, along with fitting spectra with the combination of the SSS plus MPC (0.5 - 20 keV) will determine continuum spectra for nearly 50 LMXB. In addition to interpreting the physical meaning of continuum models, he is calculating a self consistent accretion disk corona. This calculation, if successful, will help constrain current X-ray observations and will give testable predictions for the upcoming BBXRT mission. He has organized the observation of a dozen LMXB with BBXRT to look for Fe Line emission, which can be used to further constrain the physics behind these sources.

Kim Weaver has worked on several projects to analyze X-ray spectra of active galactic nuclei. With Drs. Jane Turner, Richard Mushotzky, Steve Holt, and Greg Madejski she has used to Einstein Observatory SSS and MPC spectra to investigate a sample of Seyfert galaxies. Many objects in the sample have spectra that are not consistent with a simple absorbed power-law but require some sort of excess at energies $< 1$ keV. This excess may be from an accretion disk surrounding the black hole that is hypothesized to lie at the center of active nucleus. This work was presented at the AAS meeting in January 1990 and will shortly be submitted to ApJ. Weaver has also worked with Madejski, Mushotzky and Arnaud on the Einstein Observatory SSS and MPC spectra of Bl Lac objects. This work has confirmed the presence in PKS2155 of a sharp absorption feature at $\approx 0.6$ keV as seen by the Einstein Observatory Objective Grating Spectrometer. In addition the same feature has now been found in three other Bl Lacs. This is the only sharp spectral feature observed in Bl Lacs at any wavelength. One interpretation is that this is absorption from warm gas a jet pointing towards us. This work was also presented at the January AAS and is being written up for publication.

Warren Focke has been working with Swank on detector developement for the X-ray Timing Explorer (XTE), a collaborative project between Goddard, MIT, and UCSD, due for launch in 1995. He has contributed to the design and construction of the SAA detector and is currently assisting in the calibration and testing of the Proportional Counter Array (PCA), being built by the Goddard X-ray group. The latest results show excellent spectral response (17% at 22 keV) for a xenon-filled counter but some potential background problems. Focke is also working on a project to find out whether HEAO-1 A2 data can be used to investigate the K$\alpha$ iron line seen from the diffuse Galactic emission by the Japanese Ginga satellite.

## 2.3 Low Energy Gamma-Ray Astronomy

The main focus of this research is high resolution gamma-ray spectroscopy of celestial sources in the 20 keV to 10 MeV energy range. The principal experimental objective of this program is to search for and study narrow lines in the low-energy gamma-ray spectrum. Such lines can be produced by 1) cosmic ray induced emission from nuclear excited states, 2) remnant

radioactivity from nucleosynthesis, 3) positron annihilation, and 4) cyclotron line emission from the strong magnetic field regions near the poles of a neutron star. Observational evidence exists at present for processes 2), 3), and 4). The technique of nuclear spectroscopy applied to astrophysics promises to be a powerful new diagnostic tool for probing high-energy astrophysical processes such as are known to exist in the vicinity of neutron stars and black holes. This is a young field, but already results are in hand that conclusively demonstrate the potency of the method.

The principle experimental activity within this program is the development and operation of balloon- and satellite-borne instrumentation that perform high-resolution gamma-ray spectroscopy using Germanium detectors. In addition, ground based optical instrumentation is being developed to support the balloon and satellite observations.

The individual programs are described briefly as follows:

### 2.3.1 Gamma-Ray Imaging Spectrometer (GRIS)

GRIS is a very sophisticated and powerful gamma-ray telescope that is nearing its final stages of development. It will be carried above the earth's atmosphere on high altitude balloons. The basic experiment consists of an array of seven large high-purity Germanium detectors to make precise measurements ($E/\Delta E \sim 500$) of gamma-ray energies in the 20 keV to 10 MeV range. The detector array is surrounded by a thick massive anti-coincidence shield to suppress the strong atmospheric and instrumental gamma-ray background flux. In addition there is an active NaI coded-aperture mask that will produce gamma-ray images over a 9° x 15° field of view. GRIS measures gamma-ray fluxes that are five to ten times weaker than could be detected by the best previous instruments. GRIS was first flown successfully in 1988 from Alice Springs, Australia. Exciting new results were obtained on the Galactic Center arc SN 1987. It will be flown 1 - 2 times yearly over the next 5 - 6 years.

### 2.3.2 Transient Gamma-Ray Spectrometer (TGRS)

The TGRS is a satellite-borne gamma-ray spectrometer intended to perform high resolution studies of the spectra of gamma-ray bursts. It is planned for flight on the WIND spacecraft that is part of the Global Geospace System (GGS), a new multiple-spacecraft mission to be launched. Its primary purpose is to make the first precise detailed studies of the lines that are known to exist in the spectra of gamma-ray bursts. Two kinds of lines have been observed. First, lines in the vicinity of 50 keV occur in many bursts. They are believed to result from electron cyclotron emission in the enormous magnetic fields ($10^{12}$) gauss that are typically present at the poles of neutron stars. Second, lines in the vicinity of 400 keV have been observed in 10% of the bursts. These are believed to be due to electron-positron annihilation (511 keV) radiation produced near the surface of a neutron star. This radiation is subsequently redshifted as it escapes the strong neutron star gravitational field. If this is true then it represents the first direct measurement of the gravitational potential of a neutron star. The basic instrument consists of a single Germanium crystal radiatively cooled to a temperature of 95K. The detector is unshielded and nearly omnidirectional as the gamma-ray burst may come from any random direction in the sky. It will make spectral measurements with typically 40 times better energy resolution than the best previous instrument.

2.3.3 Rapidly Moving Telescope (RMT)

RMT is a ground based optical telescope capable of slewing to any target on the sky in less than one second, tracking the target with sub-arcsecond stability, and imaging it with one arcsecond resolution. It can see objects as faint as 15-th magnitude with one second exposures. Its purpose is to locate and identify the optical counterpart flash to Gamma Ray Burst events. It will operate in conjunction with the MIT Explosive Transient Camera. The RMT instrument is able to move so quickly, because unlike a traditional telescope, only the mirror assembly moves (an azimuth-elevation mechanism); thereby picking out a patch of the night sky and reflecting it into a fixed telescope. Imaging is done with a CCD camera. The instrument is designed to operate totally automated. The observing program and data analysis is all computer controlled. Currently the instrument is undergoing integration and shakedown operation at the Goddard Optical Test Site. After this initial trial operation, it is expected to be installed at its permanent location at Kitt Peak, AZ around May 1989.

## 2.4 Theoretical Astrophysics

Theoretical studies are essential in order to determine the most important directions to pursue in future measurements, the interpretation of existing observations within a self-consistent framework, and in the development of new experimental techniques. Theoretical research is pursued in x-, gamma- and cosmic ray astrophysics, as well as in extragalactic astronomy, cosmology compact object astrophysics, and solar physics.

Research relevant to x- and gamma-ray astrophysics is carried out by Drs. Harding, Kazanas, Kallman, and Ramaty. Drs. Jones and Perko are pursuing a program in cosmic ray astrophysics with particular emphasis on acceleration and solar modulation problems. Particular emphasis is given to the physics and radiation mechanisms in compact sources both on stellar and galactic scales, such as pulsars and active galactic nuclei. A significant fraction of this research is the study of gamma ray spectroscopy associated with $e^+e^-$ annihilation lines, both in active galactic nuclei (including the galactic center) and in gamma ray bursts (Drs. Ramaty, Kazanas, and Harding). Research in high energy radiation from pulsars, with particular emphasis on processes in superstrong magnetic fields, is conducted by Dr. Harding, and R. Preece, a graduate student.

Dr. Kazanas is modeling the emission of similar radiation from active galactic nuclei with P. Giovanoni, a graduate student, with particular emphasis on the observational effects of relativistic neutrons on the spectrum of these objects. It has in fact been shown that the latter particles could indeed have unique signatures, which are apparently present in the spectra of "radio loud" active galaxies.

Dr. Kallman is examining in detail the physics of broad emission line clouds of the latter objects and also the UV and optical line radiation associated with compact galactic x-ray sources. Also in collaboration with K Ko, a graduate student, they are studying the effects of X-ray irradiation on the structure and the dynamics of accretion disks in galactic X-ray sources.

Dr. Harding, in collaboration with Drs. Gaisser and Stanev of the Bartol Research Foundation, is examining the possible gamma-ray signatures due to particles accelerated by the pulsar (compact remnant) of SN 1987A upon their interaction with the supernova ejecta. Research pertaining to cosmology and the interplay between the latter discipline and particle physics is performed by Dr. Stecker in collaboration with Dr. Shafi of the Bartol Research Foundation. This research emphasizes the impact that our knowledge of high energy physics has on understanding the largest scale features of the universe, such as the formation of the large scale structure, the nature of the unseen (dark) matter in galaxies and clusters of galaxies, the fluctuations of the microwave background, and the production of matter-antimatter asymmetry in the universe.

Solar flare research is carried out by Drs. Kozlovsky, Ramaty, and J. Miller, a graduate student, emphasizing particle acceleration and transport of the gamma-ray line and neutron production in these events as well as interpretation of data from the Solar Maximum Mission.

## 2.5 Active Galaxies

Zlatan Tsvetanov has studied the ionizing radiation field in Seyfert galaxies by means of observing spatially resolved phenomena. Two observational techniques explored -- narrow band emission-line imaging and long-slit spectroscopy. Images centered on redshifted positions of [OIII]$\lambda$5007, $H_\alpha$ and adjacent continua are used to obtain "pure" emission-line maps as well as ionization and/or reddening maps. There permit the study of both general morphology and angular distribution of the ionizing flux. Long-slit spectroscopy, on the other hand, provides important information for the ionizing mechanism (line-ratio diagrams) and for the study of the velocity field. In addition to the observational approach a powerful photoionizing code is used to model the line ratios as a function of position.

### Observations

Two observing runs were completed successfully in this period. Four nights were awarded in January 1990 at the 2.5 m INT telescope at La Palma Observatory for detailed long-slit spectroscopy. This project is in collaboration with I. Perez-Fournon and J. M. Rodriguez-Espinosa (IAC) and A. Wilson (UMD). The objects were selected so that emission-line maps could be used to guide the slit positions to cover effectively extended emission region. Weather conditions were relatively good and permitted the fully complete observation of two objects. Entire extended narrow-line regions (ENLR) of both NGC 3516 and Mkn 3 were covered by a grid of high resolution spectra (to study the kinematics of the emitting gas) and a number of medium resolution spectra (for the line-ratios). This is a very good data base for studying both kinematics and ionization structure of the circumnuclear region as well as interactions of the ionizing flux with the ISM of the host galaxy. Several other objects were observed at one or two slit positions. Data reduction is in progress.

A program of narrow-band imaging of southern Seyfert galaxies was started with four nights in March 1990 at 3.5 m ESO New Technology Telescope (NTT) located at La Silla Observatory, Chili. This project is in collaboration with B. Fosbury (ESO) and C. Tadhunter (RGO). Objects were selected to form as complete as possible volume limited sample of nearby Seyferts. The aims of the project are: (1) to make emission-line and ionization maps of different types of AGNs in order to relate the systematics (e.g., extent, morphology, total luminosity, ionization shape) of the extended narrow-line region to other parameters such as Seyfert type, X-ray and radio properties and the overall morphology of the host galaxy; (2) to use this information to study the role of beaming in determining the emission line properties and the relationships between different types of active galaxies; (3) to use the ionization maps in a follow-up study to guide the long-slit observations to study velocity fields, ionization mechanisms, etc. About 1/3 of the objects (~20) were observed this March in subarcsecond seeing conditions. Observational material is in early stage of reduction and preliminary results are expected this fall.

A VLA 6 cm and 20 cm continuum maps of NGC 5252 were taken in late April. Both maps are important for better understanding relationships between optical and radio emission beaming in this excellent example of the "cone" hypothesis.

Photoionization Code

Emission-line ratios and intensities observed in the extended emission regions are best explained in terms of photoionization of a gas illuminated by the hard radiation from the nculeus. In many cases this is the only way to get an estimate of unobservable values such as ionizing flux density. One of the state-of-the-art codes is MAPPINGS, written by L. Binette (CITA). This is a complex program able to run both photoionzation and shock wave models as well as hydrodinamical ones. The code was kindly provided by the author.

Currently MAPPING is used extensively for modelling the line ratios of Mkn 573 and NGC 5252 as a function of position.

Individual Objects

As stated above, complex observational data has been collected for several individual objects to be studied in detail. Some early results on Mkn 573 and NGC 5252 based on only small part of the observations have already been published. Meanwhile new observations have been added and most of the existing data have been reduced. Current status of the individual projects is as follows:

Mkn 573. Preliminary results were published in the Proceedings of the ESO Workshop "Extranuclear activity in galaxies" (1989). Those were based purely on observational data with not much of an interpretation. Following the initial discussion an attempt has been made to reproduce the observational features. The basic idea of the model is that of anisotropic ionizing radiation illuminating the ISM of the host galaxy. Velocity field modelling (in collaboration with J. Walsh, ST-ECF) shows the observed picture is best matched if illuminated gas is involved not only in normal galaxy rotation but also has a substantial radial velocity component. A bi-cone of opening angle of 80° is tilted by 80° to the rotation axis of the galaxy which has a rotation curve with a maximum value of 300 km $s^{-1}$. In addition there is radial expansion of 200 km $s^{-1}$ at the center declining sharply outwards. Recently a few high resolution spectra have been added for better understanding the velocity picture. Also, the photoionizing code MAPPINGS is used to model the line ratios and thus to determine radial and angular dependence of model depending parameters such as ionizing parameter U. A detailed paper is near completion and will be submitted soon.

NGC 5252 (project in collaboration with C. Tadhunter) offers, perhaps, the most spectacular evidence for an anisotropic ionizing field yet observed in Seyfert galaxies. A paper based on narrow band images was published in Nature (341, 422, 1989). Emission-line images ([OIII]$\lambda$5007 and $H_\alpha$) are dominated by a sharply defined bi-conical structure with an opening angle of ~ 75° extending in a series of shells out to a maximum radius of ~ 50 arcsec to the north and ~ 45 arcsec to the south of the nucleus. In continuum light, however, we see a typical SO galaxy with major axis misaligned by ~ 30° with respect to the major axis of the bi-conical structure. This picture is consistent with what one would expect to see if the ISM of the host galaxy is illuminated by an anisotropic radiation field from the nucleus. Several long slit spectra have been added to the narrow band imaging data. Those include positions parallel to the cone axis as well as at different position angles with respect to it. Positions parallel to the axis have been reduced and the other are under reduction. All these spectra wil be used to measure line ratios sensitive to ionization spectrum to study both radial and angular dependence of the ionizing flux thus putting constaints on possible beaming mechanisms.

**NGC 3516 and Mkn 3.** Extensive observational data have been collected for both objects. Those consist of a number of medium resolution long-slit positions with a wider wavelength coverage to study the line ratios and a grid of high resolution spectra for the velocity field. Data reductions of the high resolution spectra are in progress. First results are expected later this summer.

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for the Period July 1, 1990 to June 30, 1991

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This grant supports activities conducted by University personnel both on campus and at the Goddard Space Flight Center. Work will be concentrated in the following areas:

1) Detection of cosmic rays and studies of the solar modulation of galactic cosmic rays
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This section describes the work accomplished to date and the proposed joint effort for the next grant period for each of these areas within the overall research program. During the upcoming year, we propose to continue our joint efforts in the areas listed above.

### Cosmic Rays

Cosmic rays are the only samples of matter which reach earth from outside the solar system. As such, they carry information on their origin, acceleration, and subsequent propagation.

### Cosmic Ray Detections

Measurements of antiproton fluxes above a few GeV are in disagreement with current theories of cosmic ray propagation, there being "too many" measured antiprotons. The Low Energy Antiproton Experiment (LEAP) previously examined the flux of antiprotons at low energies (few hundred MeV) and found no discrepancy between measurement and theory. This experiment of the High

Energy Cosmic Ray Group was the thesis project of University of Maryland student Steve Stochaj, who received his Ph.D. in July 1990.

Low Energy Cosmic Rays

Ian Richardson has continued to exploit the charged particle anisotropy data base from the NASA/Goddard Space Flight Center Medium Energy Cosmic Ray Experiment on the ISEE-3/ICE spacecraft. This data base, accessible from optical disk using a PC, now extends from launch in 1978 to 1991 with a resolution of 15 minutes. Similar data bases for the Goddard Helios-1 and -2 instruments have also been created, allowing simultaneous particle anisotropies at widely separated spacecraft to be readily compared. A data base of near-Earth solar wind parameters has also been compiled for comparison with the energetic particle data. The software used to review and interpret the data has been further developed.

Intervals of bidirectional field-aligned ion streaming, associated with particles trapped within closed solar wind magnetic field regions, have been identified in the ISEE-3/ICE data. Ion abundances are being investigated to infer the origin of the trapped ions. Solar flare particle injections observed within these regions indicate that they may have a "magnetic bottle" field configuration, extending down to the sun. The Helios-1 and 2 data bases have also been similarly scanned, allowing multi-spacecraft observations to be used to investigate the topology of bidirectional ion regions. A report will be presented at the International Cosmic Ray Conf. in Dublin (Aug. 1991). Magnetic bottles may guide particles from eastern solar events as has been discussed in a paper in J. Geophys. Res. (May 1991).

The spectra, abundances and anisotropies of energetic ions at 35 keV to 20 MeV during solar maximum and solar minimum "quiet times" have been investigated (in conjunction with D.V. Reames and the Space Science Dept. of

ESA) and reported in Astrophys. J. (Lett.).

Ion enhancements associated with high-speed solar wind streams which corotate with the sun are also being studied. These are seen at all stages of the solar cycle but are most prominent around solar minimum. The abundances and anisotropies are consistent with acceleration at corotating interaction regions in the outer heliosphere. A presentation on this topic has been made at the American Geophysical Union Spring meeting (May 1991).

The spectrum of 35 keV–20 MeV ions from impulsive solar events is being studied in collaboration with D.V. Reames and the Space Science Dept. of ESA. A presentation will be made at the Dublin ICRC.

Minor activities have included collaboration with Imperial College, London and the Laboratory of Extraterrestrial Physics, GSFC, on investigations of ISEE–3/ICE low energy ion observations at comet Giacobini–Zinner and in the lobes of the Geomagnetic tail, with results published in Ad. Space Res., Planetary and Space Sci., and AGU Chapman Conf. Proceedings.

X-Ray Astronomy

Scientists associated with the University of Maryland currently conducting research in X-ray astronomy at NASA/Goddard Space Flight Center consist of Dr. Keith Arnaud, as an Assistant Research Scientist, and six graduate students: Damian Audley, Damian Christian, Warren Focke, Chris Lanczycki, Takamitsu Miyaji and Kim Weaver.

Dr. Keith Arnaud was night-time science analyst during the Broad Band X-Ray Telescope (BBXRT) mission in December 1990. With his colleagues he was able to analyze data in near realtime and hence provide useful input for mission planning. Since the return of STS–35 he has been involved in understanding the instrument calibration (i.e., trying to fit the Crab nebula) and analyzing the observations of the Perseus cluster. The first results from this were presented at the 28th Yamada Conference in Nagoya, Japan, in April 1991. Dr. Arnaud has continued his work in preparing for the support of ROSAT guest observers. This has become more urgent since ROSAT was successfully launched in May 1990.

This is the year in which the HEASARC came into existence and Dr. Arnaud has been involved in training and providing support for the newly-hired staff members.

The XSPEC spectral fitting program has continued its conquest of the X-ray astronomy community. The last year saw the release of version 7 complete with a revised user's manual. This was distributed to sites as diverse as STScI and the Univ. of Wollongong, New South Wales.

Dr. Arnaud has also worked on a number of projects with graduate students and these are described in the appropriate sections. Among other projects of particular note is the completion of the work with Drs. Birkinshaw and Hughes (CfA) on the measurement of the Hubble constant using the Sunyaev-Zel'dovich effect of Abell 665. The resultant value is consistent with 50 but inconsistent with 100 (or indeed 80). In the last year Dr. Arnaud has also submitted papers with a variety of colleagues around the world on the X-ray spectra of Bl Lacs, quasars, and cooling flows.

Kim Weaver is finishing her fourth year as an Astronomy graduate student and was accepted as a Ph.D. canadidate on March 1, 1991. Kim was recently awarded a NASA Graduate Research Fellowship for her thesis research entitled, "A Study of Soft X-Ray Excesses in Seyfert Galaxies". This research, under the guidance of Drs. Wilson (UMD) and Mushotsky (GSFC), began in December 1990 with the launch of Goddard's Broad Band X-Ray Telescope. Weaver is presently analyzing BBXRT data on the Seyfert galaxy NGC4151, and preliminary results will be presented at the AAS meeting in May 1991. She is also working on energy calibration and generating off-axis response matrices for the BBXRT detectors. Weaver has recently completed data analysis for a paper entitled, "Einstein Observatory SSS and MPC Observations of the Complex X-ray Spectra of Seyfert Galaxies" by Turner, Weaver, Mushotzky, Holt, and Madejski which has been accepted for publication in The Astrophysical Journal. In addition, she has been applying modified Fourier Analysis techniques to the Einstein SSS data on Seyfert galaxies, and plans to extend this analysis to include BBXRT data. She is also presently writing a paper entitled, "Constraints on AGN Iron Line Parameters and Reflection Models using HEAO-1 A2 Data", which completes a project she began in the summer of 1990.

Takamitsu Miyaji has worked on some projects investigating the spatial distribution of nearby AGNs detected with the HEAO-1 A2 experiment. He has extracted 56 nearby AGNs ($z<0.06$) from the HEAO-1 A2 database. The dipole moment of the X-ray flux from these AGNs around the Local Group was investigated to compare with the peculiar velocity of the Local Group. The dipole is found to be well aligned with the peculiar velocity of the local group for the AGNs with $z \leq 0.015$ as also indicated by the IRAS and optical galaxies. This suggests that the X-ray emitting AGNs (as well as IRAS and optical galaxies) are indicators of the underlying mass distribution. This work was presented at the workshop 'After the First Three Minutes' held in October, 1990 at UMCP. In relation to the above project, he is also involved in an investigation of a cross-correlation function between these AGNs and optical galaxies with Drs. Lahav (IoA, Cambridge, U.K.), Jahoda and Boldt. Miyaji is also active in analyzing data from BBXRT on a cluster of galaxies Abell 2256 (with Dr. Mushotzky) and on a distant QSO HS1700+6416 ($z=2.72$) (with Dr. Boldt). With a possible, but suspicious, BBXRT detection of HS1700+6416, Boldt and Miyaji have submitted a ROSAT proposal to observe this

QSO and the surrounding field primarily to investigate the X-ray behavior of a high redshift object with a big uv bump, which could have a Compton reflected flat spectral component in X-rays with a potential importance on the origin of the X-ray background.

Damian Audley has been working with Dr. Kelley on the use of kinetic inductance thermometers in X-ray microcalorimeters. Present day microcalorimeters use ion-implanted thermistors to measure the temperature rise associated with the absorption of an X-ray photon. Kinetic inductors promise a substantial improvement in resolution because of the elimination of Johnson noise. Devices operating at 1.5 K have already been fabricated here. Audley has assisted Dr. Rawley in the development of tunnel diode oscillators to read them out. He has also constructed and tested a temperature controller which will facilitate their evalution.

Damian Christian is completing his thesis on the spectral and temporal behavior of Low Mass X-ray Binaries (LMXB), under the direction of Dr. Swank. Warren Focke has been working with Dr. Swank on detector development for the forthcoming X-ray Timing Explorer (XTE) and, under her guidance, is also analyzing stellar X-ray data obtained from BBXRT. Chris Lanczycki has started looking into the question of surface brightness fluctuations in the X-ray background and what can be inferred about the spectra of unresolved sources; this is being done with Drs. Arnaud and Mushotzky.

Low Energy Gamma-Ray Astronomy

The main focus of this research is high resolution gamma-ray spectroscopy of celestial sources in the 20 keV to 10 MeV energy range. The principal experimental objective of this program is to search for and study narrow lines in the low-energy gamma-ray spectrum. Such lines can be produced by 1) cosmic ray induced emission from nuclear excited states, 2) remnant

radioactivity from nucleosynthesis, 3) positron annihilation, and 4) cyclotron line emission from the strong magnetic field regions near the poles of a neutron star. Observational evidence exists at present for processes 2), 3), and 4). The technique of nuclear spectroscopy applied to astrophysics promises to be a powerful new diagnostic tool for probing high-energy astrophysical processes such as are known to exist in the vicinity of neutron stars and black holes. This is a young field, but already results are in hand that conclusively demonstrate the potency of the method.

The principle experimental activity within this program is the development and operation of balloon- and satellite-borne instrumentation that perform high-resolution gamma-ray spectroscopy using Germanium detectors. In addition, ground based optical instrumentation is being developed to support the balloon and satellite observations.

The individual programs are described briefly as follows:

<u>Gamma-Ray Imaging Spectrometer (GRIS)</u>

GRIS is a very sophisticated and powerful gamma-ray telescope that is nearing its final stages of development. It is carried above the earth's atmosphere on high altitude balloons. The basic experiment consists of an array of seven large high-purity Germanium detectors to make precise measurements ($E/\Delta E \sim 500$) of gamma-ray energies in the 20 keV to 10 MeV range. The detector array is surrounded by a thick massive anti-coincidence shield to suppress the strong atmospheric and instrumental gamma-ray background flux. In addition there is an active NaI coded-aperture mask that will produce gamma-ray images over a 9° x 15° field of view. GRIS measures gamma-ray fluxes that are five to ten times weaker than could be detected by the best previous instruments. GRIS was first flown successfully in 1988 from Alice Springs, Australia. Exciting new results were obtained on the Galactic Center arc SN 1987. It will be flown 1 – 2 times yearly over the next 5 – 6 years.

Transient Gamma-Ray Spectrometer (TGRS)

The TGRS is a satellite-borne gamma-ray spectrometer intended to perform high resolution studies of the spectra of gamma-ray bursts. It is planned for flight on the WIND spacecraft that is part of the Global Geospace System (GGS), a new multiple-spacecraft mission to be launched. Its primary purpose is to make the first precise detailed studies of the lines that are known to exist in the spectra of gamma-ray bursts. Two kinds of lines have been observed. First, lines in the vicinity of 50 keV occur in many bursts. They are believed to result from electron cyclotron emission in the enormous magnetic fields ($10^{12}$) gauss that are typically present at the poles of neutron stars. Second, lines in the vicinity of 400 keV have been observed in 10% of the bursts. These are believed to be due to electron-positron annihilation (511 keV) radiation produced near the surface of a neutron star. This radiation is subsequently redshifted as it escapes the strong neutron star gravitational field. If this is true then it represents the first direct measurement of the gravitational potential of a neutron star. The basic instrument consists of a single Germanium crystal radiatively cooled to a temperature of 95K. The detector is unshielded and nearly omnidirectional as the gamma-ray burst may come from any random direction in the sky. It will make spectral measurements with typically 40 times better energy resolution than the best previous instrument.

Rapidly Moving Telescope (RMT)

RMT is a ground based optical telescope capable of slewing to any target on the sky in less than one second, tracking the target with sub-arcsecond stability, and imaging it with one arcsecond resolution. It can see objects as faint as 15-th magnitude with one second exposures. Its purpose is to locate and identify the optical counterpart flash to Gamma Ray Burst events. It will operate in conjunction with the MIT Explosive Transient Camera. The RMT instrument is able to move so quickly, because unlike a traditional telescope, only the mirror assembly moves (an azimuth-elevation mechanism); thereby picking out a patch of the night sky and reflecting it into a fixed telescope. Imaging is done with a CCD camera. The instrument is designed to operate totally automated. The observing program and data analysis is all computer controlled. Currently the instrument is undergoing integration and shakedown operation at Kitt Peak. First sky observations will occur in 1991.

Gamma-Ray Astronomy

The EGRET instrument on the Gamma Ray Observatory will make significant advances in gamma ray astronomy. To continue these advances a new with increased sensitivity and angular resolution will be required. Large area, 2m x 2m drift chambers are being developed for the imaging detector for this instrument. In addition to the large area imaging detector, large area anti-coincidence, coincidence and energy measuring systems will be required to complete the design of this instrument. Previously, various scintillating materials, viewed with photomultiplier tubes, have been used for these systems. To build large versions of these systems an alternative approach to the large number of photomultipliers is needed. Modern photodiodes, including PIN diodes and avalanche photodiodes, may be a possible replacement for phototubes. In order for photodiodes to be viable alternative, solutions to several problems will need to found. High gain amplifiers are required to amplify and sum the small output singnals from the several photodiodes viewing each piece of scintillator. This must, however, be done with a minimum of power to be usable on a satellite instrument.

Theoretical Astrophysics

Theoretical studies are essential in order to determine the most important directions to pursue in future measurements, the interpretation of existing observations within a self-consistent framework, and in the development of new experimental techniques. Theoretical research is pursued in x-, gamma- and cosmic ray astrophysics, as well as in extragalactic astronomy, cosmology compact object astrophysics, and solar physics.

Research relevant to x- and gamma-ray astrophysics is carried out by Drs. Harding, Kazanas, Kallman, and Ramaty. Dr. Jones is pursuing a program in cosmic ray astrophysics with particular emphasis on acceleration and solar modulation problems. Particular emphasis is given to the physics and radiation mechanisms in compact sources both on stellar and galactic scales, such as pulsars and active galactic nuclei. A significant fraction of this research is the study of gamma ray spectroscopy associated with $e^+e^-$ annihilation lines, both in active galactic nuclei (including the galactic center) and in gamma ray bursts (Drs. Ramaty, Kazanas, and Harding). Research in high energy radiation from pulsars and gamma-ray bursts, with particular emphasis on processes in superstrong magnetic fields, is conducted by Dr. Harding, [and R. Sina, a graduate student].

Dr. Kazanas is modeling the emission of similar radiation from active galactic nuclei with P. Giovanoni, a graduate student, with particular emphasis on the observational effects of relativistic neutrons on the spectrum of these objects. It has in fact been shown that the latter particles could indeed have unique signatures, which are apparently present in the spectra of "radio loud" active galaxies.

Dr. Kallman is examining in detail the physics of broad emission line clouds of the latter objects and also the UV and optical line radiation associated with compact galactic x-ray sources. Also in collaboration with K. Ko, a graduate student, they are studying the effects of X-ray irradiation on the structure and the dynamics of accretion disks in galactic X-ray sources.

Dr. Harding, in collaboration with Dr. Protheroe of the University of Addaide, Australia, is examining the possible gamma-ray signatures due to particles accelerated by the pulsar (compact remnant) of SN 1987A upon their interaction with the supernova ejecta. Research pertaining to cosmology and the interplay between the latter discipline and particle physics is performed by Dr. Stecker in collaboration with Dr. Shafi of the Bartol Research Foundation. This research emphasizes the impact that our knowledge of high energy physics has on understanding the largest scale features of the universe, such as the formation of the large scale structure, the nature of the unseen (dark) matter in galaxies and clusters of galaxies, the fluctuations of the microwave background, and the production of matter-antimatter asymmetry in the universe.

Solar flare research is carried out by Drs. Kozlovsky, Ramaty, and J. Miller, a graduate student, emphasizing particle acceleration and transport of the gamma-ray line and neutron production in these events as well as interpretation of data from the Solar Maximum Mission.

Active Galaxies

Zlatan Tsvetanov studied the ionizing radiation field in Seyfert galaxies by means of observing spatially resolved phenomena. Two observational techniques were explored—narrow band imaging and long-slit spectroscopy. Images centered on redshifted positions of bright emission lines and on adjacent continua used to study the morphology of the high excitation gas. Extended emission-line regions in selected objects are mapped spectroscopically by a grid of slit positions, which provides both kinematical (velocity map) and ionization mechanism information (line-ratio diagrams) for studying the impact of the nuclear radiation on the ISM in the host galaxy. Observed line ratios are compared with a photoionizing code to estimate model dependent parameters, such as the ionization parameter U, and to put constraints on the angular distribution of the ionizing flux.

Observations

Observing runs completed in this period included: (1) Three nights in December 1990 at the 2.5m Nordic Optical Telescope (NOT) on La Palma, were used for narrow-band imaging of early type Seyfert galaxies. Most of this time was wiped out by bad weather, but some useful images were taken. This project is in collaboration with A. Wilson (UMD), M. Valtonen (Turku Observatory, Finland) and I. Perez-Fournon (IAC, Spain). (2) Four more nights were given at NOT for the same project in April 1991. Half of this time was clear and several more objects were imaged through [OIII]$\lambda$5007 filters. (3) Four nights at the 4.2-m William Herschel Telescope at La Palma were given for detailed long-slit spectroscopy of nearby Seyfert galaxies. This project is in collaboration with A. Wilson and I. Perez-Fournon. We use emission-line maps, obtained by somebody of us, to guide the slit position and to cover the entire extended emission region effectively. Unfortunately, a serious technical problem on the mountain almost wiped out the first two nights in April, 1991. Nevertheless, one object was partially covered in the 3.5 hours left. Data reduction is in progress.

Photoionization Code

A state-of-the-art photoionization code—MAPPINGS, written by L. Binette (CITA)—is used to model the observed emission line ratios in order to get an estimate of some of the model dependent parameters, such as the ionizing parameter U. Currently MAPPING is used extensively for comparison of the line ratios in several of our objects as function of position with respect to the nucleus.

Individual Objects

Complex observational data has been collected for several individual objects to be studied in detail. Current status of the individual projects is as follows:

Mkn 573. The observations of this Seyfert 2 radio galaxy were collected at La Silla, Chile. These include narrow-band images in [OIII]$\lambda$5007, H$\alpha$ and [SII]$\lambda\lambda$6716 + 31 and a grid of slit positions excitation peak is offset by ~4 arcsec in the same direction to the southeast. A simple geometric model (in collaboration with J.R. Walsh, ST-ECF), is used to study effects of various parameters on the observed picture. The best fit is achieved when a bi-conical radiation field illuminates the ISM of the host galaxy that takes part in a normal galaxy rotation and has some radial motion component close to the nucleus. Line diagnostic diagrams are modeled using the photoionization code MAPPINGS. It is shown that the ionizing spectrum of a thin accretion disk or hot black body produces a better fit to the line ratio diagrams than a simple power-law spectrum does. On the other hand, the general trend of the line ratios requires that the ionizing parameter U decreases with radial distance up to approximately 2 arcsec and then increases further outwards. The density measured from the sulphur ratio is used in conjunction with U from the models to estimate the angular dependence of the ionizing flux. It is shown that the number of ionizing photons is higher along the axis than in perpendicular direction. A paper is submitted to Ap.J., and a poster is presented at the Heidelberg conference on Physics of AGN (June 3-7).

**High Resolution Imaging of a Volume Limited Sample of Seyfert Galaxies.** Project in collaboration with R. Fosbury (ST-ECF) and C. Tadhunter (RGO). This is a program for high resolution emission-line imaging of a distance limited sample ($cz \leq 3600$ km/s) of southern Seyfert galaxies. The main scientific aim of the project is to study the morphology of the ENLR and how it relates to Seyfert type and other properties, such as host type, X-ray emission, radio emission, etc. We also plan to use the data to look for systematics in the excitation maps as a function of angle from the cone axis and to search for signatures of an obscuring torus. About 20 objects were observed in March 1990 with the ESO 3.5-m NTT telescope and data has been reduced. Several objects known to have extended emission were observed in subarcsecond seeing and some new ENLRs were detected. More than 1/3 of the objects show clear signatures that the circumnuclear gas is ionized by the hard nuclear radiation, while another 1/3 of the galaxies are rich of HII regions, suggesting that gas properties are dominated by young stars rather than the active nucleus. Four more nights have been allocated for this project at the ESO 3.6-m telescope at La Silla. Preliminary results were presented at the AAS meeting in January, 1991 in Philadelphia.

**Two Dimensional Spectroscopy of the ENLR in Nearby Seyfert Galaxies.** Project in collaboration with A.S. Wilson (U. of Maryland) and L. Perez-Fournon (IAC, Spain). They have used emission-line images and excitation maps to guide long-slit observations. The ENLR is covered by a grid of slit positions. This allows measuring both line intensities and velocities at various positions with respect to the nucleus. Line ratios are then compared with photoionization models. The main goals are to study the kinematics of the high excitation gas and to put constraints on the angular dependence of the ionizing spectrum on the angle from the cone axis. Complete data sets on NGC

3516 and Mkn 3 and to lesser extent, on NGC5506 were collected using telescopes at La Palma and Kitt Peak. Our hihg dispersion spectra reveal several kinematically distinct components to the extended emission line gas in NGC 3516 (in collaboration with J. Mulchaey, graduate student, UMD). The analysis of the data favours an explanation by a bipolar outflow, which is essentially in the plane of the sky close to the nucleus and it is gravitationally bended further away. There are clear indications that the ionizing flux is higher along the axis. Preliminary results were presented at the AAS meeting in January in Philadelphia. Work on NGC 3516 is in advanced stage and a paper is expected to be submitted later this summer.

**Narrow Band Imaging of a Sample of Early Type Galaxies.** Project in collaboration with A. S. Wilson, M. Valtonen (U of Turku, Finland) and I. Perez-Fournon (IAC). This is a program for emission-line imaging of a complete sample of Seyferts in early type galaxies. The project was stimulated by the fact that all best examples of the cone geometry of the ionizing field are found in Seyferts residing in SO/Sa galaxies. We have been given six nights at the 2.5 Nordic Optical Telescope at La Palma.

1441-76

## 2. Proposed Joint Effort of the University of Maryland and the NASA Goddard Space Flight Center Laboratory for High Energy Astrophysics

This grant supports activities conducted by University personnel both on campus and at the Goddard Space Flight Center. Work will be concentrated in the following areas:

1) Detection of cosmic rays and studies of the solar modulation of galactic cosmic rays
2) Support work for several past and upcoming X-ray satellites
3) High resolution gamma-ray spectroscopy of celestial sources
4) Theoretical astrophysics
5) Active galaxies

This section describes the work accomplished to date and the proposed joint effort for the next grant period for each of these areas within the overall research program. During the upcoming year, we propose to continue our joint efforts in the areas listed above.

### 2.1 Cosmic Rays

Cosmic rays are the only samples of matter which reach earth from outside the solar system. As such, they carry information on their origin, acceleration, and subsequent propagation.

**2.1.1 Cosmic Ray Detection** Measurements of antiproton fluxes above a few GeV are in disagreement with current theories of cosmic ray propagation, there being "too many" measured antiprotons. The Low Energy Antiproton Experiment (LEAP) previously examined the flux of antiprotons at low energies (few hundred MeV) and found no discrepancy between measurement and theory. This experiment of the High Energy Cosmic Ray Group was the thesis project of University of Maryland student Steve Stochaj, who received his Ph.D. in July 1990.

**2.1.2 Low Energy Cosmic Rays** Ian Richardson has continued to exploit the charged particle anisotropy data base on optical disk from the NASA/Goddard Space Flight Center experiments on ISEE-3/ICE, Helio-1 and Helios-2, and to further develop the associated software to present the data in various formats. An IMP-8 data base at 2 hour resolution, currently extending from 1973 to 1989, has also been added. This together with the ISEE-3/ICE data provides a comprehensive set of near-Earth ~ MeV/amu ion anisotropy observations extending over nearly two solar cycles. The long-term data base will allow the solar cycle dependence of various phenomena to be investigated and a large number of events to be examined.

A search for intervals of bidirectional field-aligned ion streaming has been made using the IMP-8, ISEE-3/ICE and Helios 1/2 data, and initial results presented at the International Cosmic Ray Conference, Dublin, in August 1991. A paper is about to be submitted to Astrophys. J. Supplement giving details of bidirectional ion intervals observed by IMP-8 and ISEE-3/ICE between 1973 and 1991. Around 1000 intervals are listed, increasing the number of such intervals identified in the literature by at least a factor of 5. Such ion flows may be associated with closed loop or magnetic bottle-like fields in the solar wind associated with coronal mass ejections (CMEs) into the solar wind. The frequency with which bidirectional flows are observed at 1 AU, and the solar cycle dependence, with more intervals of bidirectional flow at solar maximum, are found to be consistent with the rate at which CMEs are observed to leave the Sun, supporting this interpretation. A similar listing of the Helios 1 and 2 intervals is planned.

A separate study of IMP-8 energetic ion observations associated with the magnetic cloud (a CME with a clear magnetic field rotation) of 14–15 January, 1988 has been made in conjunction with C.J. Farrugia and L.F. Burlaga (GSFC/Laboratory for Extraterrestrial Physics) and presented at the Dublin ICRC. A paper has been submitted to J. Geophys. Res. by the co-authors. The energetic ion observations suggest that a prompt solar particle event was observed by IMP-8 within the cloud, indicating that magnetic field-lines within the cloud were not closed but were still rooted at the Sun when the cloud passed by the spacecraft.

A study of 64 corotating high-speed solar wind streams and the associated energetic ion enhancements have been made (in conjunction with D.V. Reames and L.M. Barbier (GSFC) and submitted to J. Geophysical Research. A preliminary report was presented at the Dublin ICRA, and the ion abundances discussed in a paper in Astrophysical Journal (Lett), Nov. 1991. The observations consistent with ion acceleration at corotating shocks in the outer heliosphere. The multi-spacecraft observations show the positive radial ion intensity gradient and corotation with the Sun for several events. The ion spectra at < 1 MeV/amu to ~ 20 MeV/amu are ordered by energy/amu for ions from protons to Fe. At > 1 MeV/amu, the spectra may be represented at an exponential in momentum. $dJ/dP \sim \exp(-P/P_0)$, $P_0 = 11\text{–}16$ MeV/c/amu, or by a distribution function $f \sim \exp(v/v_0)$, $v_0 = 0.18\text{–}0.25$ $(\text{MeV/amu})^{1/2}$, with little solar cycle dependence. Previous authors have drawn a distinction between solar energetic particle (SEP) and corotating event abundances. Rather, there appears to be a continuous range of abundances in corotating events from EP-like in < 500 km/s high-speed streams to previously reported "corotating event" abundances in the fastest streams. The individual ion abundances are correlated (or anti-correlated) with the solar wind speed and are ordered relative to photospheric abundances by the first ionization potential (FIP). Low FIP (< 11 ev) ions are overabundant relative to higher FIP ions, indicating that neutral-ion fractionation in the chromospheric transition region is the predominant process determining the ion abundances. The corotating ions may reflect the composition of the high-speed solar wind plasma from which they are accelerated. In this case, the composition variations suggest that the temperature of the fractionation region may be higher, and the ion-neutral separation weaker, below coronal holes from which higher speed solar wind is emitted. The typical abundances of SEP events may arise since these are more likely to be accelerated by shocks travelling through slower solar wind than through high-speed stream plasma. The different compositions of ions accelerated at corotating forward and reverse shocks in the outer heliosphere may also result from acceleration out of slow and high-speed stream plasma. It is proposed to compare the composition at 1 AU with in-situ composition data from the GSFC/CalTech instrument on the Voyager spacecraft in the outer heliosphere.

The energy spectra of impulsive solar flare events at 35 keV to 20 MeV have been investigated in conjunction with D.V. Reames (GSFC) and K.-P. Wenzel (ERA/ESTEC), the results presented at the Dublin ICRC and in Astrophysical J. (March 1992).

The ion anisotropy observations have contributed to a paper (J. Geophys. Res., Nov. 1991) with H.V. Cane (GSFC/U. of Tasmania) and K. Harvey (Solar Phys. Res. Corp.) discussing the filament disappearances and associated shocks of May 1979.

Collaboration with L.C. Tan and G.M. Mason (U. of Md/Dept. of Physics) on analysis of combined data from the ULECA and EPAS instruments during the ISEE-3/ICE comet Giacobini-Sinner encounter is being carried out and a paper estimating diffusion coefficients in the vicinity of the comet is nearing completion. A contribution has also been made to a paper on the theory and observation of the geotail plasma sheet in conjunction with C.J. Owen (GSFC/LEP) and S.W.H. Cowley (Imperial College, London) to appear in the proceedings of AGU Chapman Conf. on Magnetospheric Substorms.

### 2.2 X-ray Astronomy

Scientists associated with the University of Maryland currently conducting research in X-ray astronomy at NASA/Goddard Space Flight Center consist of Dr. Keith Arnaud, as an Assistant Research Scientist, and six graduate students: Damian Audley, Damian Christian, Warren Focke, Chris Lanczycki, Takamitsu Miyaji and Kim Weaver.

The main concerns of Dr. Keith Arnaud over the last year have been the BBXRT and Astro-D missions. He has been heavily involved with the BBXRT data; helping with the calibration, writing software, and analyzing the X-ray spectra of clusters of galaxies. The Perseus cluster is particularly interesting, the spectra are able to constrain temperature and abundances in the core of the cluster with a spatial resolution of about five arc minutes. There is also unambiguous evidence for absorption above the expected from the column density of neutral hydrogen along the line-of-sight. This exciting result was discovered using the Einstein Observatory Solid State Spectrometer but the BBXRT detection is both much more significant and can constrain the ionization state of the absorbing matter. Dr. Arnaud presented the BBXRT results on clusters of galaxies at the "Ginga to Astro-D" conference at ISAS, Tokyo in Feb. 1992. A paper on the Perseus iron line results is in draft.

Dr. Arnaud has been co-chair of the Astro-D software task team, which was charged with the design of the ground software system for the Japanese-US collaboration on the Astro-D satellite. The design is now largely decided and implementation is under way. To foster better international relations Dr. Arnaud spent six months working with his Japanese colleagues at ISAS in Tokyo. This has resulted in a liking for raw fish.

Support of the XSPEC spectral fitting program has continued to occupy a significant fraction of Dr. Arnaud's time. The beta test for version 8 is now available and is being used by a number of brave volunteers. This new version contains a number of features developed during the analysis of BBXRT data and with an eye towards future work on Astro-D.

Damian Christian completed his analyses of the Einstein Observatory Solid State Spectrometer (SSS) and simultaneous Monitor Proportional Counter (MPC) data base on the Low Mass X-ray Binaries (LMXRB). Using the extended energy range of the SSS and MPC, he compared the spectral characteristics of classes of sources among the LMXRB with respect to a set of models of the X-ray continuum and determined the implied physical parameters of the emission regions. The results included a set of column densities of cold absorbing material which provide evidence for absorption associated with the binary systems. Damian's work on these bright targets required him to tune the response matrices of both the SSS and MPC on the basis of in-orbit data. He submitted the response matrices to HEASARC. With coauthors Swank, Szymkowiak, and White, he submitted an article describing them for publication in the HEASARC newsletter Legacy. The SSS spectra of a few sources confirmed reports of line emission (K lines from O and Si, and L lines from Fe). Line emission in spectra of the source X0614+09 was especially bright and also variable. These spectra suggested an absorption edge due to $O_{VIII}$ in addition to emission, evidence for warm material which could be associated with the outer part of the accretion disk. The X0614+09 line results will be submitted for publication shortly. The short BBXRT observations of 3 LMXRTB (M15, X0614+09, and Cyg X-2) could not by themselves confirm low energy line features and soft excesses, despite better energy resolution and greater area. Damian could put limits on the K emission line contributions and including these in his thesis. Preparation of his thesis is almost complete.

Kim Weaver is finishing her fifth year as a graduate student in the Astronomy Department under the guidance of Drs. Richard Mushotzky (GFSC) and Andrew Wilson (MD). Throughout the past year, Weaver has been heavily involved with the calibration of the Broad Band X-ray Telescope detectors and is presently completing the final set of detector response matrices which will be used for publication purposes. Her thesis research, entitled "Broad Band X-ray Spectroscopy of Seyfert Galaxies" includes BBXRT data for 5 Seyfert galaxies and she is presently completing the first in a series of BBXRT related papers entitled "BBXRT Observations of NGC4151 I. Iron Line Diagnostics." Weaver is also analyzing data on the Seyfert galaxies NGFC4051 and NGC2110. Results on the soft X-ray excesses in these objects will be presented at the upcoming AAS meeting in Columbus, Ohio. In addition, she is writing a paper describing the calibration efforts for the BBXRT detectors. Kim recently gave a talk on her thesis work at the Washington Area Astronomers Meeting.

Takamitsu Miyaji is working on a number of projects related to the large scale structure of the universe and clusters of galaxies. With Drs. E. Boldt (GSFC), M. Persic (SISSA, Trieste) and Y. Rephaeli (UCSD/Tel Aviv), he is investigating the core region of the supercluster BB18 with the ROSAT PSPC in order to detect or set an upper limit on the diffuse X-ray emission from the intrasupercluster gas. After excluding regions around sources, surface brightness of the northern half of the field is found to be enhanced by $\sim$ 12% and $\sim$ 7% in 0.2–0.4 keV and 0.4–2.5 keV bands respectively. This enhancement may be due to the intrasupercluster gas. Careful consideration on the contribution from the diffuse galactic X-ray emission is being made. With Drs. O. Lahav (IoA), K. Jahoda, and E. Boldt (GSFC), he is investigating cross-correlation functions between X-ray selected AGNs and optical galaxies from UGC and ESO catalogs. He has found a small correlation between X-ray selected AGNs and both optical samples for the angular separations smaller than $\sim$ 10 degrees. Inverting this angular relation to a three dimensional correlation function using known redshifts for the X-ray AGNs and diameter functions of UGC/ESO samples would give estimates of relative bias parameters between optical galaxies and X-ray AGNs. He has analyzed the BBXRT spectra of the cluster of galaxies Abell 2256 (with Dr. R. Mushotzky and BBXRT Science Team). Extra absorptions are found at positions where ROSAT found a cool component and around the east peak. These absorptions suggest an existence of $\sim 10^{12}$ solar masses of warm-cool gas which could be generated by shockwaves caused by a merging of clusters.

Damian Audley has been working with Dr. Richard Kelley on the use of kinetic inductance thermometers in X-ray microcalorimeters. Present day microcalorimeters use ion-implanted thermistors to measure the temperature rise associated with the absorption of an X-ray photon. Kinetic inductors which are superconducting devices promise a substantial improvement in resolution because of the elimination of Johnson noise. Audley has investigated the properties of two of these devices operating at 1.2 K and 0.8 K and has measured their kinetic inductance. He is currently working on new methods for reading out these devices. He is also analyzing the X-ray spectrum of Cen. X-3. This is a binary X-ray pulsar which was observed by BBXRT in December 1990.

David Davis is currently working on identifying X-ray substructure in a flux limited sample of galaxy clusters for his thesis project. Most of the clusters in this sample have been observed with the Einstein Observatory's IPC detector. The search for substructure in these clusters involves fitting the surface brightness with elliptical isophotes and subtracting this component from the brightness distribution to find residual structure associated with a merger event. So far this has resulted in the discovery of substructure in two clusters. David is also involved in the analysis of ROSAT observations of clusters which have been identified as having substructure using optical data. The new ROSAT data confirm the substructure seen in the optical data and reveal new structure in these clusters not suspected on the basis of the optical data. Another project related to his thesis is the analysis of ROSAT observations of distance clusters with an excess of blue galaxies. X-ray observations of two of these clusters show that they have multiple X-ray peaks, and are most likely being formed from the merger of one or more individual clusters.

Chris Lanczycki has been carrying out an analysis of surface brightness fluctuations in the X-ray background, as observed with HEAO-1 A2. The goal of this project is to infer the range of acceptable power law models of the N(S) distribution for all point sources from HEAO 1-A2 data by measuring the fluctuations in the X-ray background. It is intended to tightly constrain both the normalization of the model, setting the overall scale of the source counts, and the power law's exponent, that informs us of the relative number of sources with different fluxes. Unique to this analysis is the ability to obtain information on sources too faint to be seen individually, but whose collective effects can be readily measured in how the observed background is perturbed. Chris has been developing a code to test a full range of N(S) models and to determine which are consistent with the data. And of late, much effort has been made to make allowances for cutoffs due to the finite 3–10 kev band in which our data reside and to minimize numerical problems associated with formal divergences in the power law models of N(S).

Warren Focke has recently been involved in postflight calibration of the BBXRT solid-state detector elements. A particular area of interests in regards to this is a recently discovered and yet to be understood variation in the gain relation with counting rate. Much of this work is being performed on the X-ray monochromator at NIST in Gaithersburg. Other work in the last year has involved modeling the interactions of X-rays with the upper atmosphere. These interactions include attenuation of rays from celestial sources through absorption and scattering and contamination of celestial spectra by solar X-rays through Thompson and Rayleigh scattering and fluorescence. This modeling has been primarily directed at applications to BBXRT data.

Working with Rob Petre, Jeonghee Rho is starting to study the X-ray structure and spectrum of the evolved supernova remnant W44. This remnant is prototypical of the class of "mixed morphology" remnants, whose shell-like structure in the radio is at odds with a center-filled X-ray morphology. Ms. Rho is combining newly taken data from ROSAT with archival Einstein Imaging Proportional Counter and Solid State Spectrometer data, and Exosat Medium Energy proportional counter data. In addition, she is incorporating into her analysis recent optical images in lines of H$\alpha$ and [S II]. She has found that the complex X-ray morphology of W44 is the result of both temperature and density variations within the remnant and variations of the column density of material along the line of sight, and that the mixed morphology is probably the consequence of a supernova remnant blast wave propagating through a cloudy interstellar medium.

## 2.3 Low Energy Gamma-Ray Astronomy

The main focus of this research is high resolution gamma-ray spectroscopy of celestial sources in the 20 keV to 10 MeV energy range. The principal experimental objective of this program is to search for and study narrow lines in the low-energy gamma-ray spectrum. Such lines can be produced by 1) cosmic ray induced emission from nuclear excited states, 2) remnant

radioactivity from nucleosynthesis, 3) positron annihilation, and 4) cyclotron line emission from the strong magnetic field regions near the poles of a neutron star. Observational evidence exists at present for processes 2), 3), and 4). The technique of nuclear spectroscopy applied to astrophysics promises to be a powerful new diagnostic tool for probing high-energy astrophysical processes such as are known to exist in the vicinity of neutron stars and black holes. This is a young field, but already results are in hand that conclusively demonstrate the potency of the method. The principle experimental activity within this program is the development and operation of balloon- and satellite-borne instrumentation that perform high-resolution gamma-ray spectroscopy using Germanium detectors. In addition, ground based optical instrumentation is being developed to support the balloon and satellite observations. The individual programs are described briefly as follows:

**2.3.1 Gamma-Ray Imaging Spectrometer (GRIS)** GRIS is a very sophisticated and powerful gamma-ray telescope that is carried above the earth's atmosphere on high altitude balloons. The basic experiment consists of an array of seven large high-purity Germanium detectors to make precise measurements (E/ΓE ~ 500) of gamma-ray energies in the 20 keV to 10 MeV range. The detector array is surrounded by a thick massive anti-coincidence shield to suppress the strong atmospheric and instrumental gamma-ray background flux. In addition there is an active NaI coded-aperture mask that will produce gamma-ray images over a 9x x 15x field of view. GRIS measures gamma-ray fluxes that are five to ten times weaker than could be detected by the best previous instruments. GRIS was first flown successfully in 1988 from Alice Springs, Australia. Exciting new results were obtained on the Galactic Center arc SN 1987. It will be flown 1 - 2 times yearly over the next 5 - 6 years.

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### 2.3.3 Rapidly Moving Telescope (RMT)

RMT is a ground based optical telescope capable of slewing to any target on the sky in less than one second, tracking the target with sub-arcsecond stability, and imaging it with one arcsecond resolution. It can see objects as faint as 15-th magnitude with one second exposures. Its purpose is to locate and identify the optical counterpart flash to Gamma Ray Burst events. It will operate in conjunction with the MIT Explosive Transient Camera. The RMT instrument is able to move so quickly, because unlike a traditional telescope, only the mirror assembly moves (an azimuth-elevation mechanism); thereby picking out a patch of the night sky and reflecting it into a fixed telescope. Imaging is done with a CCD camera. The instrument is designed to operate totally automated. The observing program and data analysis is all computer controlled. Currently the instrument is undergoing integration and shakedown operation at Kitt Peak. First sky observations will occur in 1991.

## 2.4 Gamma-Ray Astronomy

The EGRET instrument on the Compton Gamma Ray Observatory covers the energy range from about 20 MeV to 30 GeV and has made a number of significant discoveries in both galactic and extra-galactic gamma ray astronomy. To continue these advances, the Advanced Gamma-ray Astronomy Telescope Experiment (AGATE) is currently being designed. This will be a larger "2m-class" instrument with increased sensitivity and angular resolution. Large area, 2m x 2m drift changers are being developed for the imaging detector for this instrument. In addition to the large area imaging detector, large area anti-coincidence, coincidence and energy measuring systems will be required to complete the design of this instrument. Two approaches, using plastic scintillator strips or tiles, are being studied for the design of the coincidence system. The mechanical design of a segmented anti-coincidence dome is complete. The electronics which combines the logic signals from these two systems and generates the instrument trigger is being developed. The mechanical design of the energy measurement system, a Cesium Iodide calorimeter, is complicated by the mass of the system. Modern avalanche photodiodes (APDs) are under extensive study as a viable alternative for phototubes, for use with all three of theses systems. The design of high gain amplifiers to sum the output signals from the photodiodes viewing each piece of scintillator needs to be done. This must, however, be done with a minimum of power to be usable on a satellite instrument. Summer research opportunities for graduate students include studying and testing combinations of various scintillators and available APDs, including amplifier design and identifying approaches to the mechanical attachment of photodiodes to scintillators. Other research opportunities include operation and optimization of a small area drift chamber gamma ray telescope, including gas mixture/voltage studies, instrument calibration and data analysis.

## 2.5 Theoretical Astrophysics

Theoretical studies are essential in order to determine the most important directions to pursue in future measurements, the interpretation of existing observations within a self-consistent framework, and in the development of new experimental techniques. Theoretical research is pursued in x-, gamma- and cosmic ray astrophysics, as well as in extragalactic astronomy, cosmology, compact object astrophysics, and solar physics.

Research relevant to x- and gamma-ray astrophysics is carried out by Drs. Harding, Kazanas, Kallman, Ramaty and Stecker. .. Dr. Jones is pursuing a program in cosmic ray astrophysics with particular emphasis on acceleration and solar modulation problems. Particular emphasis is given to the physics and radiation mechanisms in compact sources both on stellar and galactic scales, such as pulsars and active galactic nuclei. A significant fraction of this research is the study of gamma ray spectroscopy associated with $e^+e^-$ annihilation lines, both in active galactic nuclei (including the galactic center) and in gamma ray bursts (Drs. Ramaty, Kazanas, and Harding). Research in high energy radiation from pulsars and gamma-ray bursts, with particular emphasis on processes in superstrong magnetic fields, is conducted by Dr. Harding, [and R. Sina, a graduate student].

R. Preece completed his thesis is work on non-thermal synchrotron — pair cascades in strong maganetic field as an emission model for gamma-ray bursts.

Dr. Kazanas is modeling the emission of similar radiation from active galactic nuclei with particular emphasis on the observational effects of relativistic neutrons on the spectrum of these objects. It has in fact been shown that the latter particles could indeed have unique signatures, which are apparently present in the spectra of "radio loud" active galaxies.

Dr. Kallman is examining in detail the physics of broad emission line clouds of the latter objects and also the UV and optical line radiation associated with compact galactic x-ray sources. Also in collaboration with K. Ko, a graduate student, they are studying the effects of X-ray irradiation on the structure and the dynamics of accretion disks in galactic X-ray sources. Along with J. Taylor, a graduate student, also modeling the optical and uv line emission from active galaxies, (under the assumption that these lines are due to reprocessing of non thermal radiation by red giants near the active nucleus)

Dr. Harding, in collaboration with Dr. De Jager of the University of Putchefstroom, South Africa, is examining the gamma-ray emission due to inverse Compton scattering by high energy particles accelerated in the Crab nebula. Research pertaining to cosmology and the interplay between the latter discipline and particle physics is performed by Dr. Stecker in collaboration with Dr. Shafi of the Bartol Research Foundation. This research emphasizes the impact that our knowledge of high energy physics has on understanding the largest scale features of the universe, such as the formation of the large scale structure, the nature of the unseen (dark) matter in galaxies and clusters of galaxies, the fluctuations of the microwave background, and the production of matter- antimatter asymmetry in the universe.

Solar flare research is carried out by Drs. Kozlovsky, Ramaty, and J. Miller, emphasizing particle acceleration and transport of the gamma-ray line and neutron production in these events as well as interpretation of data from the Solar Maximum Mission and Gamma-Ray Observatory.

## 2.6 Active Galaxies

Zlatan Tsvetanov studied the ionizing radiation field in Seyfert galaxies by means of observing spatially resolved phenomena. Two observational techniques were explored–narrow band imaging and long-slit spectroscopy. Images centered on redshifted positions of bright emission lines and on adjacent continua used to study the morphology of the high excitation gas. Extended emission-line regions in selected objects are mapped spectroscopically by a grid of slit positions, which provides both kinematical (velocity map) and ionization mechanism information (line-ratio diagrams) for studying the impact of the nuclear radiation on the ISM in the host galaxy. Observed line ratios are compared with a photoionizing code to estimate model dependent parameters, such as the ionization parameter U, and to put constraints on the angular distribution of the ionizing flux.

### Observations

Observing runs completed in this period included: (1) Three nights in December 1990 at the 2.5m Nordic Optical Telescope (NOT) on La Palma, were used for narrow-band imaging of early type Seyfert galaxies. Most of this time was wiped out by bad weather, but some useful images were taken. This project is in collaboration with A. Wilson (UMD), M. Valtonen (Turku Observatory, Finland) and I. Perez-Fournon (IAC, Spain). (2) Four more nights were given at NOT for the same project in April 1991. Half of this time was clear and several more objects were imaged through [OIII]~5007 filters. (3) Four nights at the 4.2-m William Herschel Telescope at La Palma were given for detailed long-slit spectroscopy of nearby Seyfert galaxies. This project is in collaboration with A. Wilson and I. Perez-Fournon. We use emission-line maps, obtained by somebody of us, to guide the slit position and to cover the entire extended emission region effectively. Unfortunately, a serious technical problem on the mountain almost wiped out the first two nights in April, 1991. Nevertheless, one object was partially covered in the 3.5 hours left. Data reduction is in progress.

### Photoionization Code

A state-of-the-art photoionization code–MAPPINGS, written by L. Binette (CITA)–is used to model the observed emission line ratios in order to get an estimate of some of the model dependent parameters, such as the ionizing parameter U. Currently MAPPING is used extensively for comparison of the line ratios in several of our objects as function of position with respect to the nucleus.

### Individual Objects

Complex observational data has been collected for several individual objects to be studied in detail. Current status of the individual projects is as follows:

Mkn 573. The observations of this Seyfert 2 radio galaxy were collected at La Silla, Chile. These include narrow-band images in [OIII]$\lambda$5007, H$\alpha$ and [SII]$\lambda\lambda$6716 + 31 and a grid of slit positions excitation peak is offset by ~4 arcsec in the same direction to the southeast. A simple geometric model (in collaboration with J.R. Walsh, ST-ECF), is used to study effects of various parameters on the observed picture. The best fit is achieved when a bi- conical radiation field illuminates the ISM of the host galaxy that takes part in a normal galaxy rotation and has some radial motion component close to the nucleus. Line diagnostic diagrams are modeled using the photoionization code MAPPINGS. It is shown that the ionizing spectrum of a thin accretion disk or hot black body produces a better fit to the line ratio diagrams than a simple power-law spectrum does. On the other hand, the general trend of the line ratios requires that the ionizing parameter U decreases with radial distance up to approximately 2 arcsec and then increases further outwards. The density measured from the sulphur ratio is used in conjunction with U from the models to estimate the angular dependence of the ionizing flux. It is shown that the number of ionizing photons is higher along the axis than in perpendicular direction. A paper is submitted to Ap.J., and a poster is presented at the Heidelberg conference on Physics of AGN (June 3-7). High Resolution Imaging of a Volume Limited Sample of Seyfert Galaxies. Project in collaboration with R. Fosbury (ST-ECF) and C. Tadhunter (RGO). This is a program for high resolution emission-line imaging of a distance limited sample (czs3600 km/s) of southern Seyfert galaxies. The main scientific aim of the project is to study the morphology of the ENLR and how it relates to Seyfert type and other properties, such as host type, X-ray emission, radio emission, etc. We also plan to use the data to look for systematics in the excitation maps as a function of angle from the cone axis and to search for signatures of an obscuring torus. About 20 objects were observed in March 1990 with the ESO 3.5-m NTT telescope and data has been reduced. Several objects known to have extended emission were observed in subarcsecond seeing and some new ENLRs were detected. More than 1/3 of the objects show clear signatures that the circumnuclear gas is ionized by the hard nuclear radiation, while another 1/3 of the galaxies are rich of HII regions, suggesting that gas properties are dominated by young stars rather than the active nucleus. Four more nights have been allocated for this project at the ESO 3.6-m telescope at La Silla. Preliminary results were presented at the AAS meeting in January, 1991 in Philadelphia. Two Dimensional Spectroscopy of the ENLR in Nearby Seyfert Galaxies. Project in collaboration with A.S. Wilson (U. of Maryland) and L. Perez-Fournon (IAC, Spain). They have used emission-line images and excitation maps to guide long-slit observations. The ENLR is covered by a grid of slit positions. This allows measuring both line intensities and velocities at various positions with respect to the nucleus. Line ratios are then compared with photoionization models. The main goals are to study the kinematics of the high excitation gas and to put constraints on the angular dependence of the ionizing spectrum on the angle from the cone axis. Complete data sets on NGC 3516 and Mkn 3 and to lesser extent, on NGC5506 were collected using telescopes at La Palma and Kitt Peak. Our hihg dispersion spectra reveal several kinematically distinct components to the extended emission line gas in NGC 3516 (in collaboration with J. Mulchaey, graduate student, UMD). The analysis of the data favours an explanation by a bipolar outflow, which is essentially in the plane of the sky close to the nucleus and it is gravitationally bended further away. There are clear indications that the ionizing flux is higher along the axis. Preliminary results were presented at the AAS meeting in January in Philadelphia. Work on NGC 3516 is in advanced stage and a paper is expected to be submitted later this summer. Narrow Band Imaging of a Sample of Early Type Galaxies. Project in collaboration with A. S. Wilson, M. Valtonen (U of Turku, Finland) and I. Perez-Fournon (IAC).

This is a program for emission-line imaging of a complete sample of Seyferts in early type galaxies. The project was stimulated by the fact that all best examples of the cone geometry of the ionizing field are found in Seyferts residing in SO/Sa galaxies. We have been given six nights at the 2.5 Nordic Optical Telescope at La Palma.

1992/93

## 2. Proposed Joint Effort of the University of Maryland and the NASA Goddard Space Flight Center Laboratory for High Energy Astrophysics

This grant supports activities conducted by University personnel both on campus and at the Goddard Space Flight Center. Work will be concentrated in the following areas:

1) Detection of cosmic rays and studies of the solar modulation of galactic cosmic rays
2) Support work for several past and upcoming X-ray satellites
3) High resolution gamma-ray spectroscopy of celestial sources
4) Theoretical astrophysics
5) Active galaxies

This section describes the work accomplished to date and the proposed joint effort for the next grant period for each of these areas within the overall research program. During the upcoming year, we propose to continue our joint efforts in the areas listed above.

### 2.1 Cosmic Rays

Cosmic rays are the only samples of matter which reach earth from outside the solar system. As such, they carry information on their origin, acceleration, and subsequent propagation.

#### 2.1.1 Cosmic Ray Detection

Between the present low energy antiproton measurements, which extend up to about 1 GeV and the higher energy measurements of Golden (around 5 GeV) there are no antiproton measurements except those old Bogomolov, which have error bars extending over an order of magnitude. In the summer of 1992, we flew the Isotope Matter Antimatter Experiment (IMAX) which took data on antiproton fluxes from 100 MeV to about 3 GeV. The experiment utilized the NASA Balloon Borne Magnet Facility (BBMF).

Another experiment in which this group is involved is the MASS (MATTER-Antimatter Spectrometer experiment, which had a flight in the fall of 1992. This experiment has taken data on antiprotons in the 5 - 10 GeV range, as well as making positron measurements up to about 20 GeV.

#### 2.1.2 Low Energy Cosmic Rays

Ian Richardson has continued to undertake various studies using the comprehensive data base of charged particle data from the NASA/Goddard Space Flight Center experiments on ISEE-3/ICE, IMP-8, and Helios-1 and -2.

Study of bidirectional ion flows (BIFs) has continued. A paper on BIFs observed by the IMP-8 and ISEE-3/ICE spacecraft has been published in Astrophys. J. (Suppl.) (April 1993) and a further paper, on Helios 1 and 2 observations, submitted to Astrophys. J. The association of BIFs with various solar wind structures is discussed in the latter paper. It is found that around one third of BIFs occur in shock drivers, some 20% in non-compressive density enhancements, and the others in various solar wind regions such as corotating high-speed streams, corotating interaction regions, and upstream of shocks. Thus although some BIFs are clearly associated with the passage of material from coronal mass ejections (CMEs) apparently containing closed or looped magnetic field lines, there is not an exclusive association. In particular, there is evidence that some post-shock BIFs are not associated with shock driver entry but may occur on open field lines connected to the shock. In a related study in conjunction with H.V. Cane (GSFC/University of Tasmania) (to appear in J. Geophys., Res.), the relationship of the presence of post-shock driver signatures in solar wind plasma, magnetic field and particle data to the location of the solar event initiating the shock is discussed. The general absence of such signatures following shocks from events further than 50° from the spacecraft heliolongitude suggests that shock drivers typically extend up to ~50° from the source. Again there are some shocks (principally from far eastern sources) which are followed by bi-directional ion streaming on field lines outside of the driver but connected to the shock. Aspects of this work will be reported at the AGU meeting in Baltimore (May 1993) and at the Int. Cosmic Ray Conf. in Calgary (July 1993).

Two papers have been written with C.J. Farugia (GSFC/LEP) on BIFS in individual magnetic clouds. The first (J. Geophys. Res., May 1993) includes discussion of a solar particle injection into a magnetic cloud which suggests that magnetic field lines in the cloud were still rooted at the Sun. The second (submitted to J. Geophys. Res.) considers particle observations at IMP-8 (in the Earth's tail lobe and magnetosheath) and ISEE-3 (at the upstream libration point) during the encounter of a magnetic cloud with magnetosphere. Following a solar event which occurs close to the time at which the magnetic cloud encounters the Earth, the arrival times of particles inside and outside the cloud are consistent with the considerably longer path-length along spiral flux-rope-like magnetic field lines within the magnetic cloud predicted by the magnetic field observations. The particle flows in the magnetosphere indicate the entry of these particles via the cloud magnetic field lines which in turn are apparently rooted at the Sun.

A paper (with Daniel Winterhalter, JPL) on ICE spacecraft observations off the west limb of the Sun in 1989 will be presented at the Int. Cosmic Ray Conf. Although the spacecraft data are intermittent, we have studied the association between CMEs observed by the SMM spacecraft in August 1989 and signatures of the passage of CME material at ICE a few days later.

The relationship of shocks and shock drivers to cosmic ray decreases and low energy particle acceleration has been discussed in a paper (to appear in J. Geophys. Res.) with H.V. Cane and T.T. von Rosenvinge (GSFC). It is argued that low energy particle observations may provide useful information on solar wind structures (such as shocks) remote from the spacecraft (which does not therefore encounter the structure) which may modulate the cosmic ray flux.

The structure of the geomagnetic tail has been investigated (with J.A. Slavin and C.J. Owen GSFC/LEP) in a paper (to appear in J. Geophys. Res.) describing the first survey of data from the GSFC experiment on ISEE-3 during the spacecraft's excursion into the deep geomagnetic tail in 1982-3. Brief (< 30 min duration) bursts of 0.2-2 MeV electrons are observed, predominantly in the plasma sheet on closed field lines connected to the Earth. The near absence of such events beyond 80 $R_e$ downtail provides evidence of predominantly open rather than closed magnetic structures in the plasma sheet beyond this distance downtail, completely consistent with evidence of a neutral line at this distance downtail found previously in studies of ISEE-3 plasma, magnetic field and energetic ion data. The bursts also appear to be associated with substorm onsets though further study of this topic is continuing.

Papers have also been published on diffusion coefficients of energetic water group ions near comet Giacobini-Zinner (in collaboration with L.C. Tan (U. of MD/Dept. of Physics) (J. Geophys. Res., March, 1993) and on corotating MeV/amu ion enhancements at ≤ 1 AU from 1978 to 1986 (J. Geophys. Res., January 1993).

**2.2 X-ray Astronomy**

Scientists associated with the University of Maryland currently conducting research in X-ray astronomy at NASA/Goddard Space Flight Center consist of Dr. Keith Arnaud, as an Assistant Research Scientist, and seven graduate students: Damian Audley, Damian Christian, David Davis, Warren Focke, Takamitsu Miyaji, Jeonghee Rho, and Kim Weaver. In addition, a number of University of Maryland students worked with the X-Ray group over the Summer.

Keith Arnaud has spent the last year commuting between GSFC, ISAS (Tokyo) and IoA (Cambridge, UK) in preparation for the Astro-D mission. This was successfully launched on Feb. 20, 1993 from Kagoshima Space Center in souther Japan. Once in orbit it was renamed ASCA (Advanced Satellite for Cosmology and Astrophysics). Arnaud is already at work analyzing data and writing and testing software for this ground-breaking mission. Preliminary analysis indicates that the telescopes and instruments are working as expected and exciting data is being collected. In his spare moments Arnaud has continued his analysis of BBXRT and ROSAT data. Of particular interest is the ROSAT PSPC observation of the cluster A1795. This very long exposure shows the cluster to be isothermal out to more than one Mpc but with a cool region in the inner 100 kpc. This cool region also shows excess absorption, thus confirming the results obtained using the Einstein Observatory SSS.

Damian Audley has been working with Dr. Richard Kelley, both on hardware and data analysis. In the lab he has been testing kinetic inductors as part of a project to build a quantum calorimeter which uses a kinetic inductor rather than a thermistor as a temperature sensor. Since the kinetic inductor is superconducting this will improve the calorimeter resolution significantly. Damian has also been analyzing the BBXRT observation of Centaurus X-3, a binary X-ray pulsar. These data show the previously unresolved iron line to consist of a broad line at 6.7 keV and possibly a narrow line at 6.4 keV. The 6.7 keV line intensity appears to be varying out of phase with the continuum.

Damian Christian has completed his degree under the watchful eye of Dr. Jean Swank. His thesis is entitled "Spectral and Temporal Behaviour of Low Mass X-Ray Binaries Observed with the Einstein SSS and MPC, and the Broad Band X-Ray Telescope". His thesis used simultaneous observations of 50 LMXRBs obtained by the Einstein SSS (0.5-4.5 keV) and MPC (1.0-20.0 keV and several observations from BBXRT. Christian showed the X-ray continua of these sources to be generally complex, requiring combinations of thermal bremsstrahlung and blackbody spectra or optically thick disk models for the bright Z sources and power-law models for the bursters. He confirmed the strongest of the previous reports of lines due to O VIII or Fe L transistions. In particular, X0614+091 was found to have a large emission feature at an energy consistent with that of O VIII, showing that a relatively low luminosity disk accretor can have a disk corona.

In between newspaper interviews David Davis has been continuing his work on the X-ray structures of clusters of galaxies under the supervision of Dr. Richard Mushotzky. His paper with Mushotzky on the substructure in the Coma and A2256 clusters has been published in Ap.J. Davis provided the highlight of the January AAS meeting when his work with Mulchaey (UMd), Mushotzky, and Burstein (ASU) was presented. A ROSAT PSPC image of the very poor group of galaxies around NGC 2300 showed extensive hot gas. The only way that this gas can be contained in the group is if the mass to light ratio of the group is ~25. This large a fraction of dark matter has never been seen before and is the amount required to close the universe (and predicted by most inflationary cosmology models).

Warren Focke is studying the dynamics of accretion disks. With Dr. Jean Swank he is attempting to model the time lags between low and high energy X-ray lightcurves observed in Cygnus X-1. This project will be expanded to other sources believed to consist of accretion disks around black holes of approximately stellar mass.

Takamitsu Miyaji is working with Dr. Elihu Boldt on a number of projects relating to clusters of galaxies and the large scale structure of the universe. He has submitted a paper (to Ap.J.) describing the results of the BBXRT observation of the cluster A2256. This work measured the gravitating mass of the cluster and showed the existence of spectral features consistent with the shockwaves caused by the merger of two clusters, believed to be occurring in A2256. Miyaji is also measuring the correlation between the X-ray background (XRB) surface brightness, as determined by the HEAO-1 A2 experiment, and the IRAS galaxies. This will provide as estimate of the contribution of local galaxies to the XRB.

Jeonghee Rho is working with Dr. Rob Petre on a study of the X-ray emission from composite SNRs. She has analyzed ROSAT PSPC observations of W44 and presented the results at the AAS and the "Back to the Galaxy" conference. Rho is also working on IC443 using ROSAT (PSPC and HRI), BBXRT, and shortly, ASCA observations. The results will be presented at an IAU meeting this summer. Her thesis will consist of a study of the X-ray morphologies and spectra of a sample of 30 Galactic SNR and 6 SNR in the LMC.

Kim Weaver is in the final stages of her thesis under the guidance of Drs. Richard Mushotzky and Andrew Wilson (UMd). She has published (in Ap.J.) the BBXRT results on the Fe K emission line feature in the Seyfert I galaxy NGC 4151. This paper showed that, contrary to previous assumptions, the Fe K emission line is narrow and cannot come from the inner regions of the accretion disk around a massive black hole, but instead is probably produced in the Broad Line Region. A second paper on NGC 4151, to be submitted this month, demonstrates that the conventional wisdom about the spectrum of the low energy X-rays is also wrong and that the source must be more complicated than assumed heretofore.

### 2.3 Low Energy Gamma-Ray Astronomy

The main focus of this research is high resolution gamma-ray spectroscopy of celestial sources in the 20 keV to 10 MeV energy range. The principal experimental objective of this program is to search for and study narrow lines in the low-energy gamma-ray spectrum. Such lines can be produced by 1) cosmic ray induced emission from nuclear excited states, 2) remnant radioactivity from nucleosynthesis, 3) positron annihilation, and 4) cyclotron line emission from the strong magnetic field regions near the poles of a neutron star. Observational evidence exists at present for processes 2), 3), and 4). The technique of nuclear spectroscopy applied to astrophysics promises to be a powerful new diagnostic tool for probing high-energy astrophysical processes such as are known to exist in the vicinity of neutron stars and black holes. This is a young field, but already results are in hand that conclusively demonstrate the potency of the method. The principle experimental activity within this program is the development and operation of balloon- and satellite-borne instrumentation that perform high-resolution gamma-ray spectroscopy using Germanium detectors. In addition, ground based optical instrumentation is being developed to support the balloon and satellite observations. The individual programs are described briefly as follows:

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Transient Camera. The RMT instrument is able to move so quickly, because unlike a traditional telescope, only the mirror assembly moves (an azimuth-elevation mechanism); thereby picking out a patch of the night sky and reflecting it into a fixed telescope. Imaging is done with a CCD camera. The instrument is designed to operate totally automated. The observing program and data analysis is all computer controlled. Currently the instrument is undergoing integration and shakedown operation at Kitt Peak. First sky observations occurred in 1991.

### 2.4 Gamma-Ray Astronomy

The EGRET instrument on the Compton Gamma Ray Observatory covers the energy range from about 20 MeV to 30 GeV and has made a number of significant discoveries in both galactic and extra-galactic gamma ray astronomy. These include the measurement of the high energy gamma ray emission properties from pulsars, quasars, and BL Lac objects. Observations of gamma ray bursts have led to the discovery of surprising aspects of these mysterious events. A detailed study of the galactic diffuse radiation to study the galactic cosmic ray distribution and galactic dynamics is also in progress.

To continue these advances, the Advanced Gamma-ray Astronomy Telescope Experiment (AGATE) is currently being designed. This will be a larger "2m-class" instrument with increased sensitivity and angular resolution. Large area, 2m x 2m drift changers are being developed for the imaging detector for this instrument. In addition to the large area imaging detector, large area anti-coincidence, coincidence and energy measuring systems will be required to complete the design of this instrument.

Summer research opportunities and Ph.D. thesis possibilities exist for students interested in these areas.

### 2.5 Theoretical Astrophysics

Theoretical studies are essential in order to determine the most important directions to pursue in future measurements, the interpretation of existing observations within a self-consistent framework, and in the development of new experimental techniques. Theoretical research is pursued in X-, gamma- and cosmic ray astrophysics, as well as in extragalactic astronomy, cosmology, compact object astrophysics, and solar physics.

Research relevant to X- and gamma-ray astrophysics is carried out by Drs. Harding, Kazanas, Kallman, Ramaty and Stecker. Dr. Jones is pursuing a program in cosmic ray astrophysics with particular emphasis on acceleration and solar modulation problems. Particular emphasis is given to the physics and radiation mechanisms in compact sources both on stellar and galactic scales, such as pulsars and active galactic nuclei. A significant fraction of this research is the study of gamma ray spectroscopy associated with e+e- annihilation lines, both in active galactic nuclei (including the galactic center) and in gamma ray bursts (Drs. Ramaty, Kazanas, and Harding). Research in high energy radiation from pulsars and gamma-ray bursts, with particular emphasis on processes in superstrong magnetic fields, is conducted by Dr. Harding. Dr. Kazanas is modeling the emission of X-rays and gamma-rays from active galactic nuclei with particular emphasis on the observational effects of relativistic neutrons on the spectrum of these objects. It has in fact been shown that the latter particles could indeed have unique signatures, which are apparently present in the spectra of "radio loud" active galaxies. Dr. Kallman is examining in detail the physics of broad emission line clouds of active galaxies and also the UV and optical line radiation associated with compact galactic x-ray sources. Research pertaining to the interplay between cosmology and particle physics is performed by Dr. Stecker. This research emphasizes the impact that our knowledge of high energy physics has on understanding the largest scale features of the universe, such as the formation of the large scale structure, the nature of the unseen (dark) matter in galaxies and clusters of galaxies, the fluctuations of the microwave background, and the production of matter- antimatter asymmetry in the universe.

Solar flare research is carried out by Drs. Kozlovsky, Ramaty, and J. Miller, emphasizing particle acceleration and transport of the gamma-ray line and neutron production in these events as well as interpretation of data from the Solar Maximum Mission and Gamma-Ray Observatory.

The theory group presently supports three graduate students doing thesis research at Goddard Space Flight Center:

Yuan-Kuen Ko, working with Dr. Tim Kallman, is expected to complete her thesis work this year. She has been studying the effects of X-ray irradiation on the structure and dynamics of accretion disks in galactic X-ray binary sources.

Ramin Sina is working with Dr. Alice Harding on a thesis project involving the investigation of the triplet pair production process in strong magnetic fields. This past year, Sina completed an analytic calculation of the triplet pair production cross section, a third-order process, and has begun to evaluate the cross section numerically for a range of parameters. Preliminary results were presented in April at the APS Spring Meeting in Washington.

Jason Taylor is continuing his graduate work with Dr. Demos Kazanas on modeling the optical and UV line emission from active galaxies under the assumption that these lines are due to reprocessing of non-thermal radiation by red giant stars in a cluster near the active nucleus. Taylor has calculated the line profiles and the 1D and 2D line transfer functions for this system.