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Center for Space Research

Progress Report No. 12, covering researches performed under NASA Grant NsG-386 (current number NGL 22-009-015) for the period from September 1, 1970 through September 30, 1971.

I. INTRODUCTION

This progress report covers researches performed under NASA grant NGL 22-009-015 during the period September 1970 through September 1971; i.e., it is roughly speaking an account of work done during calendar year 1971. Research carried out under this basic grant is closely related to some other NASA flight programs carried on by the Center for Space Research; these related activities are reported here as part of the basic research effort.

At the present time work performed under this grant is mainly in two broadly defined areas: (a) "high energy astronomy" or astrophysics and (b) properties of the interplanetary plasma.

II. RESEARCH ACTIVITIES RELATED TO HIGH ENERGY ASTROPHYSICS

During this past year work in experimental astrophysics has been mainly in areas of (1) balloon-borne cosmic x-ray experiments, (2) rocket-borne cosmic x-ray experiments, (3) high resolution x-ray spectroscopy, (4) preparation of the OSO-H x-ray experiment, (5) design and development of x-ray experiments for SAS-C and for HEAO-A, (6) optical measurements and observations related to the cosmic x-ray program, and (7) OSO-3 gamma-ray experiment. A description of these researches follows.

1. Balloon-Borne Cosmic X-ray Experiments

The M.I.T. high energy x-ray astronomy group has been actively observing in the southern hemisphere since October 1967. Six successful balloon flights were achieved during three expeditions to Australia (1967, 1969, 1970). We give here a brief account of the main results obtained to date.

The first observation of an x-ray flare from Sco X-1 was made on October 15, 1967. Similar flares from Sco X-1 have been observed subsequently by other groups. On the same date a very hard x-ray source was discovered in Centaurus (GX 304-1). By March 20, 1969, this source had decreased its intensity by at least a factor of seven.

During the October 15, 1967, as well as during the October 24, 1967, observations, several sources were detected near the galactic center. However, the sources could not be resolved (the angular resolution of the telescope in 1967 was 13° FWHM).

On April 16, 1969, a new source was discovered in Crux (GX 301-2). This source was absent (at least seven times weaker) approximately one month earlier. During the observations the source "flared up" and its intensity tripled in about one hour.

A new low background x-ray detector was built for the fall 1970 expedition in Australia. The detector was orientable in azimuth as well as zenith angle to an accuracy of approximately 0.3°. A pulsar-mode system was included which allowed the arrival time of each individual x-ray to be determined with an absolute accuracy of approximately one msec.

On October 16, 1970, this instrument was carried aloft from Mildura, Victoria, on a 34 million ft^3 balloon to a maximum altitude of 150,200 feet. During eight of the 10.5 hours the balloon was at altitudes above 144,000 feet. The x-ray sources near the galactic center were carefully scanned with a 1.5° x 15° FWHM slit-type collimator to obtain accurate position determinations which will allow unambiguous comparison with the x-ray sources previously pinpointed precisely from rocket observations by Bradt et al. and Schnopper et al. of M.I.T. The telemetry system worked flawlessly throughout the 10.5 hour float, and the observations were completely successful.

Two subsequent attempts to obtain a second flight failed; a 34 million ft^3 balloon burst on November 7, 1970, at approximately 40,000 feet, and an 18×10^6 ft^3 balloon showed holes and seam splits shortly after inflation of the balloon had started. A successful second flight was finally made from Parkes using a 10 million ft^3 balloon.

Most of the data from the 1970 flights have been analyzed and some of the results have been published. The discovery of three time variable x-ray sources, GX 1+4, GX 301-2 and GX 304-1, was a significant result. There is some indication that GX 1+4 shows a periodic variation with a period of 2.3 minutes. The existence of the sources GX 301-2 and GX 304-1 have been confirmed by observations from the Uhuru satellite. However, Uhuru has not yet detected GX 1+4.

Also we observed three sources in the region 330 < ℓ^{II} < 350° near the galactic equator; at least one of these is a new source. Spectra on all sources will be published shortly.

The Large Magellanic Cloud was observed and also Vela-X. No pulsar behavior was observed during the Vela observations. The data anlysis is still underway.

The telescope is now being modified to fly again in Australia during a February--May 1972 expedition. Again the largest possible balloons will be flown, varying in size from 36 to 46 million ft^3.

(W. Lewin, J. McClintock,
G. Ricker, W. B. Smith)

2. Rocket-Borne Experiments in X-ray Astronomy

We have continued our program of x-ray astronomy from sounding rockets in the 1-10 kev energy range. Our most recent experiment consisted of a modulation collimator (2' of arc FWHM) for precise x-ray source locations and an open bank of detectors with 1 ms timing resolution ($\sim$ 500 cm^2 area) for an x-ray pulsar search. The payload was launched aboard an Aerobee 170 rocket on May 1, 1971. The region just south of the galactic center, 335° < ℓ^{II} < 355°, and Cyg X-1 were observed during this flight.

The celestial positions of Cyg X-1, GX 349+2 and GX 340+0 were determined with a precision of $\sim$ 1' of arc. The location of Cyg X-1 has greatly aided in the identification of of a weak radio source as the radio counterpart of Cyg X-1. Radio searches of the error boxes for GX 349+2 and GX 340+0 will be carried out at NRAO by members of our group in collaboration with NRAO personnel.

Cyg X-1 was shown to exhibit rapid fluctuations in x-ray intensity. Changes in intensity by factors of 2 or more in time scales of 50 ms to several seconds were observed. No evidence was found for true x-ray pulsar activity in the frequency range 0.2 Hz to 100 Hz despite the interpretations of Uhuru data to the contrary. No flaring or pulsing activity was found in the x-ray signal from GX 349+2 or GX 340+0.

Presently we are constructing a new rocket payload for the study of very soft celextial x-ray sources (0.1--1.0 kev). This experiment will utilize a one-dimensional x-ray concentrator made from a nested set of parabolically curved glass plates. We are planning to map the angular structure of Vela X and the Cyg loop supernova remnants.

(S. Rappaport)

3. High Resolution X-ray Spectroscopy

A. Bragg Spectrometer for the Large Orbiting X-ray Telescope*. The M.I.T. focal plane Bragg spectrometer was among the instruments proposed by the LOXT Consortium and approved for Phase B study by NASA. The consortium, consisting of American

* Most of the funds for this work have been provided by the Marshall Space Flight Center under contract No. NAS 8-24585.

Science and Engineering, Inc., Columbia University, Goddard Space Flight Center and M.I.T., has proceeded with the formulation and submission of a technical and management proposal for such a study leading to a flight program aimed at the launch of the large orbiting x-ray telescope in 1977. Meanwhile, preliminary design studies and laboratory breadboard development of the focal plane spectrometer have continued at M.I.T. A summary of current work follows.

i. Precision measurements of the rocking curves of several crystals suitable for use in the LOXT and ANS spectrometers have been made with a computer-controlled, two-crystal spectrometer and data processor. For low energy studies, the spectrometer is housed in a large vacuum system which also has a built-in x-ray tube. This tube can be differentially pumped for windowless operation. The x-ray tube is also demountable, and a wide range of screw-in targets are available for complete wavelength coverage. In a preliminary investigation, L x-rays from titanium were detected with a sealed titanium window proportional counter and M x-rays from the same target were detected with a Bendix channeltron multiplier. Both of these were non-dispersive measurements, but in each case the onset of detectable events occurred at the appropriate excitation potential. The vacuum chamber also contained a flow proportional-counter tube system. The counter tube window is demountable and a variety of materials are available for use at low energies.

Novel features of the spectrometer in addition to the automated control and data acquisition system are:

(a) A laser alignment system featuring co-aligned x-ray and laser beams. This system can also be used without the spectrometer in cases where co-aligned beams are required for payload alignments such as will be required on SAS-C and ANS.

(b) A fixed x-ray tube geometry in which the instrument is pivoted about the axis of the first crystal. This eliminates the cumbersome arrangements usually required for moving x-ray tubes, especially when they require an attached vacuum system.

(c) The unit is portable and can be transported to field locations such as Brookhaven and the National Magnet Laboratory.

A payload testing facility has also been constructed. The unit consists of a motorized x-y table upon which is mounted a motorized rotary table. The axis of rotation can be either vertical or horizontal. Stepping motors provide the motion and the entire system is under the control of the same computer used for the spectrometry system. This unit will be used to study the optical and x-ray properties of the modulation collimators to be used in the SAS-C payload. In addition, the complete alignment (both optical and x-ray) of the ASE/MIT ANS payload will be made on this unit.

In anticipation of some of the spectroscopy requirements in the Alcator and heavy ion programs and as an update of the work towards the LOXT curved crystal spectrometer, we have designed and built a new instrument which combines the best features of our previous instruments. The new instrument can be used with detectors either off or on the focussing circle and with flat, singly or multiple bent crystals of any radii.

For all of our work an extensive library of software has been developed. The computer system has been interfaced with a wide variety of peripheral equipment. Many of the interface circuits were designed and developed within the group.

A complete range of crystal materials ranging from quartz (2d = 4.25 Å) to OHM (2d = 64 Å) is available.

(H. Schnopper, J. Delvaille, T. Egan, A. Epstein, K. Kalata, A. Libertini, R. Sohval)

ii. A 24" diameter, stainless steel, diffusion pumped vacuum system has been set up to provide a test bed for a laboratory prototype of the LOXT curved crystal Bragg spectrometer. The prototype has been designed and is now under construction. An oil-cooled x-ray gun has been installed in one of the ports of the feed-through collar, and soft x-rays generated by this gun have been detected by a flow proportional counter with a 1 μ polypropylene window and a channeltron photoelectric detector. Measurements are being made to determine the relative efficiencies of the two detectors. Meanwhile, a multiwire proportional counter for use in the prototype curved crystal spectrometer is being designed.

(C. Canizares, D. Bardas,
G. Clark)

iii. A dipping tank for preparation of multilayer lead stearate diffractors has been designed and is in construction. The design is adapted from that of B. Henke (University of Hawaii). The multilayers will have a 2d spacing of 100 Å. They will be deposited on a spherically curved substrate to match the geometrical requirements for a spherically curved diffraction, i.e., the Rowland circle.

(D. Bardas, E. Dietz,
C. Canizares, G. Clark)

B. New Spectrometer Developments. A new instrument which is based on a combination of a Baez reflection optics concentrator and Bragg crystal spectroscopy has been designed. The design eliminates the interaction between the focussing geometry and the spectrometer aberrations. The two are essentially divorced. A proposal for an instrument based upon this design will be submitted during the competition for the remaining space on board LOXT (HEAO-C)

(H. Schnopper, K. Kalata)

C. Laboratory X-ray Experiments Related to Astrophysics.

i. A series of experiments has been carried out using beams of heavy ions available at High Voltage Engineering. A series of thin foil targets are irradiated with beams of heavy ions from a Van de Graaff accelerator. The stripped ions emit characteristic x-rays as they emerge from the irradiated foil. In the experiments performed so far, ions of bromine and iodine with energies between 3 and 15 mev were allowed to collide with various target materials, and the energy spectra of soft x-rays produced in these collisions were studied using non-dispersive solid state detectors. The data from these initial experiments are being analyzed and a new series of experiments is planned for the Tandem Van de Graaff Laboratory at Brookhaven National Laboratory where ion energies up to 30 mev/ionic charge are available.

(H. Schnopper, J. Delvaille,
K. Kalata, R. Sohval)

ii. A new fusion machine, the Alcator (high field torus) is being constructed at the National Magnet Laboratory and is scheduled for operation sometime in 1972. High resolution x-ray spectroscopy will be used to study x-rays emitted from the hot plasma produced by this device. Design and construction of the necessary instrumentation are being carried out in collaboration with the Alcator staff.

(H. Schnopper, K. Kalata)

4. OSO-H X-ray Astronomy Experiment

The Orbiting Solar Observatory OSO-H was successfully launched on September 29, 1971, and is now expected to remain in orbit for about 600 days. All of the six scientific instruments, including the M.I.T. "Multicolor Survey of the Positions, Spectra and Time Variations of Cosmic X-ray Sources," are functioning well as are the spacecraft systems except for a failure of one of the two tape recorders. At present the prospect is for at least a year of successful orbital operation which will provide over 10^9 bits of x-ray data from the M.I.T. experiment.

Immediately after the launching we began analysis of "quick-look" data received on tapes sent daily by air mail from the GSFC OSO Control Center where they are recorded from the Rossman and Fort Myers passes. Aspect solutions derived from the star sensor data are being obtained that agree within $\pm$ 0.1° with those obtained at GSFC.

Background counting rates are significantly lower than those which were used in the preflight estimates of minimum source detectability. As expected, in those orbital revolutions that carry the satellite through the region of the South Atlantic normally, the trapped radiation swamps the detectors before the radiation monitor automatically turns off the high voltage. The effects of sporadic bursts of low energy charged particles at near -90° pitch angles are also frequently seen. These effects are sometimes confined to only a few azimuthal bins so that they do not necessarily interfere with the x-ray observations. All together, about 30 percent of the data are lost due to trapped particle interference.

Among the sources which have been identified in the quick-look data so far are the Crab Nebula, Sco X-1, M-87, Ser X-1, and several sources in the galactic center region.

During the first week of November the spin axis will be maneuvered so as to maintain Sco X-1 within the scan band of the 3° collimator. Simultaneous radio observations will be made with the interferometer at NRAO in collaboration with R. Hjelming and S. Rappaport.

(G. Clark, G. Sprott, H. Bradt,
W. Lewin, H. Schnopper)

5. Future Satellite-Borne Experiments in X-ray Astronomy

A. SAS-C: M.I.T. X-ray Observatory for the Third Small Astronomy Satellite. The engineering effort toward the preparation of the scientific payload for the SAS-C is now paced for a launch in late 1973, based on the most recent funding schedule proposed to NASA.

Flight prototypes of all the sealed counters have been procured and their gains have been monitored regularly for many months with a standard precision testing procedure. No serious problems with the counters have been encountered.

A soft x-ray vacuum test facility has been completed. It provides an 8" diameter beam of fluorescent x-rays at a distance of 25 feet from the target. Various targets provide monochromatic x-rays at various wavelengths from 8 to 70 Å. Intensities at 25 feet are typically several hundred photons per cm^2 sec. The facility has been used to measure the energy response of the thin titanium window counters of the Sco Monitor Experiment (SME), the transmission curves of the 1μ polypropylene windows for the soft x-ray detectors in the Galactic Absorption Experiment (GAE) and the reflectivity of coated surfaces at glancing incidence in connection with the x-ray optics for the GAE and a soft x-ray rocket experiment.

The facility has a fluorescent x-ray generator adapted from the designs furnished by R. Novick of the Columbia University Astrophysics Laboratory. The generator consists of a high power copper target x-ray tube which irradiates one or another of eight selectable fluorescent targets with copper L radiation. The generator section of the facility is pumped by a vac-ion and sorption system to eliminate contamination of the targets by oil from the diffusion-pumped experiment section. The latter section is two lengths of 8" diameter aluminum pipe terminating in a cylindrical metal chamber mounted on a horizontal track. The experimental section is pumped by two 8" diffusion pumps.

Experimental studies of the use of rise time discrimination in background rejection have been conducted with the aim of establishing the criteria for evaluation of the flight circuits now in development.

Engineering prototypes of the modulation collimators have been completed and tested successfully for mechanical and thermal stability.

The laboratory prototype of the soft x-ray extension to the galactic absorption experiment has been completed and is undergoing final evaluation in the soft x-ray test facility. For these tests the unit is mounted in the vacuum chamber of the test facility on a digitally-controlled rotatable table specially constructed for this purpose.

Various computer systems have been evaluated for use in the data analysis system. A scientific proposal based on the Nova 800 has been submitted to the project office and is now awaiting action.

(H. Bradt, G. Clark, J. Delvaille, D. Hearn, W. Lewin, J. McClintock, G. Murthy, S. Rappaport, J. Sachs, H. Schnopper, W. Shaw, W. Smith)

B. <u>HEAO-A</u>

i. <u>Integrated modulation collimator experiment (AXR-2)</u>. The plan B definition study for this experiment has been completed and the hardware proposal will be submitted about November 1. The M.I.T. portion of this effort will consist of scientific direction of the program and preparations for data analysis of the flight data. The hardware will be fabricated by American Science and Engineering (Dr. H. Gursky of AS&E is the co-principal investigator).

The scientific objectives of the experiment are:

(a) Determination of positions and structure of galactic x-ray sources with a precision of 5 to 10 arc seconds.

(b) Detection of faint extragalactic x-ray sources.

The purpose of the Integrated X-ray Modulation Collimator experiment (IMC) is to establish accurate information as to location, structure and size of galactic and extragalactic sources.

The experiment consists of two x-ray detection units. One, the scanning modulation collimator (SMC), views in the +X direction and has the capability of measuring angular structure of detected objects as well as size. It will view the entire sky during the HEAO mission. The objectives of the SMC are:

(a) Determination of the celestial positions of selected cosmic x-ray sources to a precision of about 5 arc seconds.

(b) Determination of the angular size of cosmic x-ray sources to a precision of about 5 to 10 arc seconds in the energy range of 1.0 to 15 kev.

(c) Study of the structure of the x-ray emission to a precision of 10 arc seconds in the energy range of 1.0 to 15 kev.

The other x-ray detection system is a rotating modulation collimator (RMC). It views along the spin axis in the antisolar direction. It will view about one-seventh of the sky during the HEAO mission. The scientific objectives of the RMC are:

(a) To detect extragalactic x-ray sources over an energy range from 1.0 to 15 kev at levels of sensitivity of 4×10^{-5}, the intensity of the Crab Nebula.

(b) To measure the celestial position of these sources with a potential accuracy of better than 45 arc seconds.

General description of the IMC. The instrument will contain six modulation collimator banks, each consisting of series of wire grids. Two of these are scanning modulation collimators (SMC) which view in the +X direction. Four are rotating modulation collimators (RMC) looking along the spin axis (-Z). Associated with each collimator bank is an array of four sealed beryllium window proportional counters.

The two SMCs have four-grid collimators, each grid consisting of a set of equally spaced wires, the spaces being equal to the wire diameters. As the instrument is rotated past a point source of x-rays, the acceptance of the outer grid has a repeating triangular pattern, varying from 0 to 50 percent. Each successive grid removes one-half of the triangles, so that the acceptance pattern of the four-grid collimator consists of triangles of half-width δ, spaced 8 δ apart. The grid wires of the two SMCs are oriented at 20° to one another, each being at 10° to the plane swept out by the normal to the face. In addition to the collimator grids, each SMC has an egg-crate collimator to limit the field of view to 4 x 4° (full width at half-maximum, FWHM). The FWHM of the triangular resolution elements is 30 arc seconds for one collimator, 60 arc seconds for the other. Total viewing area is 0.5 square meter.

The x-ray detectors for both the RMC and the SMC are proportional counters with 25 μ beryllium windows, filled to a pressure slightly greater than one atmosphere, with a mixture of 90 percent argon and 10 percent CO_2. The counter window becomes transparent above 1 kev. The high energy cutoff is 15 kev, where the counter gas becomes transparent.

The pointing direction of the SMCs is determined with a set of star sensors. There are two fine aspect sensors. One possible configuration is a set of slits parallel to one of the sets of grid wires. The slits are 8 arc minutes apart, and the sensor can measure the pointing angle with an accuracy of 3 arc seconds. In addition, as an alternate, imaging star-field sensors are being considered.

The four RMCs point along the spin axis in the antisolar direction. Each has two grids, a field of view of 15 x 15° FWHM. The total viewing area is 1 square meter. Two of these units have an angular resolution (FWHM) of 4 arc minutes and the other two have 4.04 arc minutes resolution. The principle of operation is the same as for the SMC except that an x-ray source now travels in a circle in the field of view instead of crossing it along a straight line. This face of the experiment has two fine aspect sensors of the imaging starfield type.

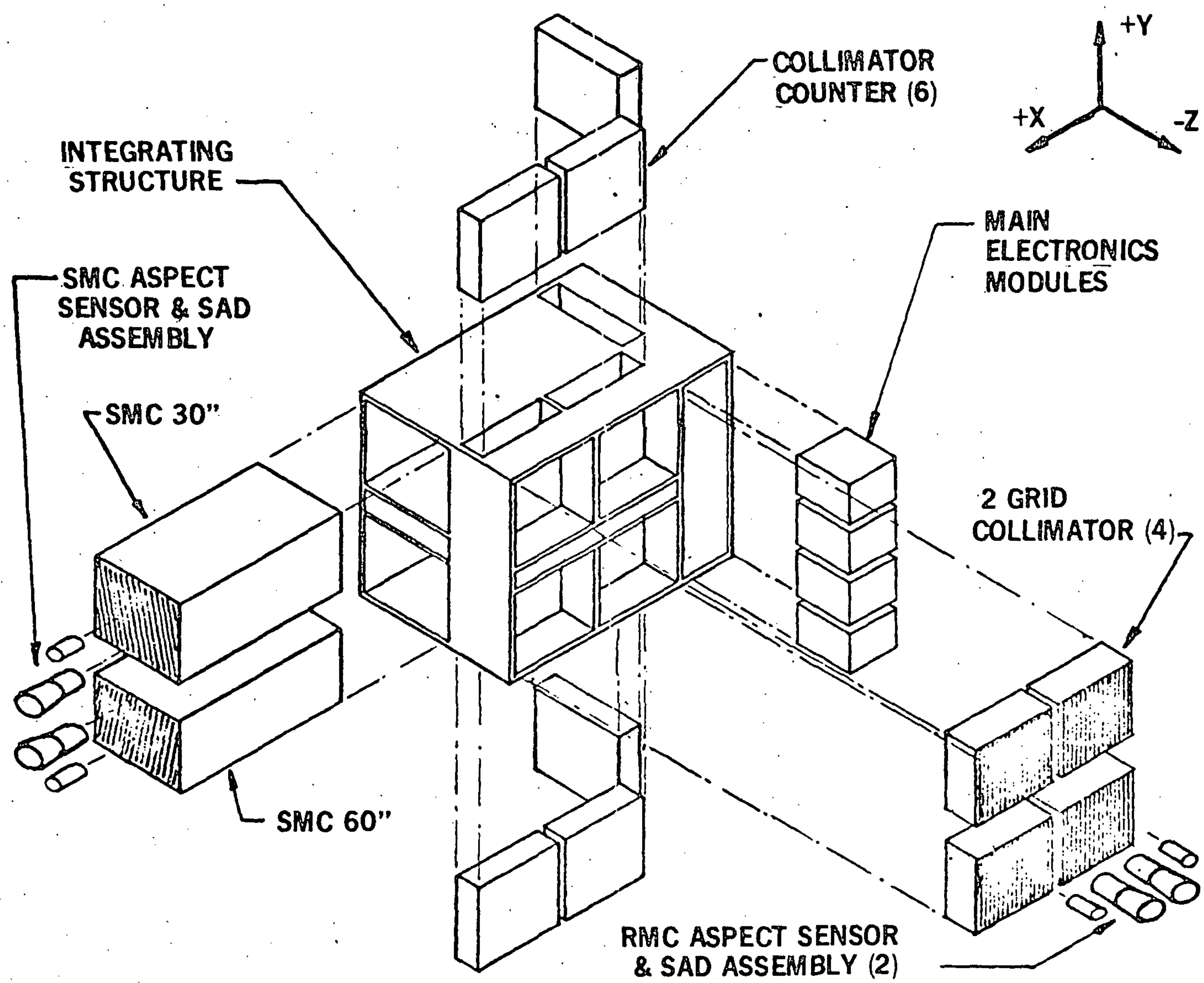
The x-ray electronics will amplify the signals from the proportional counters, provide rejection of unwanted pulse by means of anticoincidence detection and pulse shape discrimination, analyze pulse height and provide digital processing and control of the data for output to telemetry. Housekeeping monitors and in-flight calibration control will be provided.

The aspect sensor electronics will similarly amplify and process aspect data for output to telemetry.

(H. Bradt, G. Spada, S. Rappaport, W. Lewin, G. Clark of M.I.T., H. Gursky of AS&E)

ii. High energy x-ray experiment (AGR-5). The scientific objectives of the AGR-5 experiment are to detect extragalactic x-ray sources over an energy range from approximately 13 kev to 150 kev, at levels of sensitivity of 6×10^{-4} the intensity of the Crab Nebula. The experiment is designed to measure the celestial positions of these sources with a maximum uncertainty of 45 arc seconds in order to establish the unambiguous association of these sources with their low energy x-ray and optical counterparts.

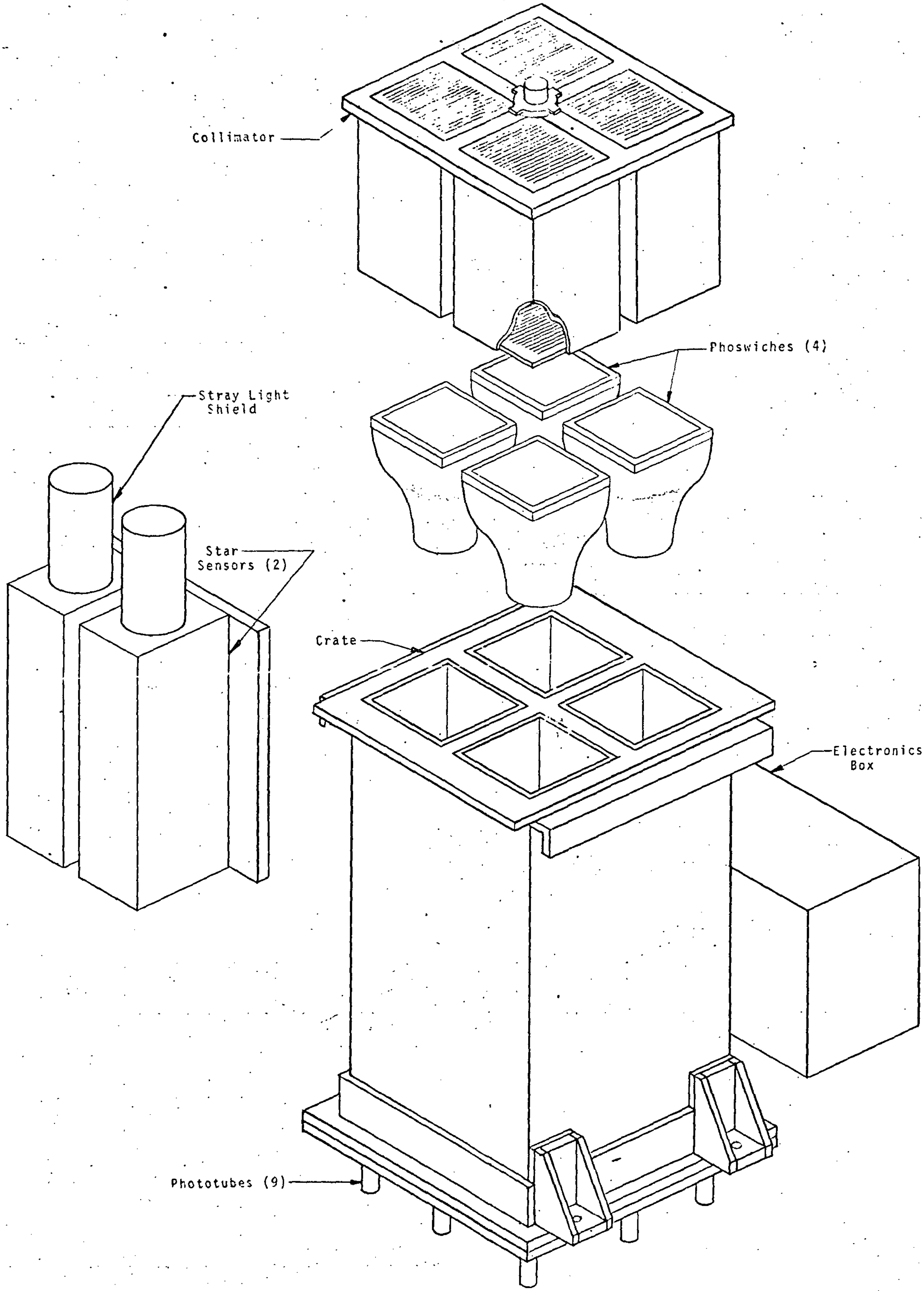
INTEGRATED MODULATION X-RAY EXPERIMENT



Galactic x-ray sources will also be detected (over the same energy range, with potentially the same accuracy in position determinations and levels of sensitivity) when the spin axis of the spacecraft is pointing in the general direction (within 10° or so) of the galactic equator.

The following drawing illustrates the configuration of the equipment hardware. The experiment detects, accumulates and provides temporal and positional data for x-ray events in the energy range of 13 kev to 150 kev through the use of a modulation collimator, a Crate detector system, data accumulation electronics and processing electronics. The Crate contains four Phoswich assemblies (x-ray detectors) which interface with the data accumulation electronics. An active shield structure forms the walls of the Crate and is monitored by nine photomultiplier tubes which provide anticoincidence information to the data accumulation electronics. The data accumulated is transferred to the spacecraft data storage and telemetry system.

Aspect determination is provided to the experiment by two star trackers (one of which is a redundant spare). The aspect data provides X and Y positional coordinates of star sources to an accuracy of better than 30 arc seconds within the 15° x 15° FWHM field of view. The relative view directions of the star trackers and the x-ray detectors is known through pre-flight and in-flight calibration, thereby permitting post-flight determination of the positions of x-ray sources to better than 45 arc seconds.



HEXRAY EXPERIMENT

The data generated, processed and transferred to the spacecraft by the AGR-5 experiment may be characterized as follows:

(a) Pulse height data is quantized to six energy channels within the 13 kev to 150 kev energy range of x-ray events.

(b) Anticoincidence data is generated by the reaction of the CsI(Na) shield material to charged particles. The pulses generated are used as inhibit gates to the accumulation of simultaneous events in the x-ray detectors.

(c) Veto count data is generated by the CsI(Tl) crystals of the Phoswich x-ray detectors. These pulses are separated from the NaI(Tl) crystal pulses generated by true x-ray events by means of the pulse shape discriminator circuits, and are a measure of the shielding action of the CsI(Tl) anti-coincidence shield.

(d) Aspect data is provided by the star tracker. Aspect data, digitized in X and Y coordinates to 12 bits, provides positional reference information for the AGR-5 experiment.

The experiment operates in three data modes. In two of these, the fast timing mode and the normal event time tag mode, the pulse height data is tagged with a time-of-occurrence word and energy channel designation. These two modes of operation provide high time resolution for x-ray events but differ in data rates. The remaining mode of operation designated as the normal mode does not time tag each event but accumulates x-ray events in each energy channel over a 40 millisecond period before transfer to the spacecraft data accumulation system.

The experiment will weigh less than 600 pounds. A power budget of 15 watts is allocated to the experiment and will be provided by the spacecraft power distribution system; the data rate allocated the experiment is 600 bits per second.

(W. Lewin, J. Barker,
P. Andra)

6. Optical Instrumentation and Optical Observations Related to X-ray Astronomy

A. Optical Photon Spectrum Analysis. Work on the digital logic and computer interfaces was completed with the exception of the magnetic tape recorder interface which remains to be debugged. Preliminary tests were conducted of the entire system consisting of the EMI intensifier, SEC vidicom camera tube and the NOVA computer control and display system. A number of problems were encountered in connection with high voltage insulation and in the electronic manipulation of the SEC camera tube. These have been solved, and further tests are underway to evaluate the efficiency with which individual quanta incident on the input photosurface will be detected.

(G. Gilbert and G. Clark)

B. Optical Studies of X-ray Sources and X-ray Source Regions. (H. Bradt on sabbatical leave at Cerro Tololo Inter-american Observatory)

X-ray source positions reported by AS&E from their Uhuru satellite data were searched extensively at optical wavelengths at Cerro Tololo Interamerican Observatory (CTIO) by H. Bradt in collaboration with staff members of CTIO. No positive identifications were forthcoming.

During the same period, Sco X-1 was monitored optically for about 12 continuous days while it was being simultaneously observed at x-ray and radio wavelengths by Uhuru and the NRAO interferometer, respectively. This optical data together with that obtained at Kitt Peak National Observatory and at McDonald Observatory during the same period are being compiled at M.I.T. for early publication.

Finally, near infrared observations of the complex galaxy NGC 5128 (Centaurus A), in collaboration with W. Kunkel of CTIO, led to the identification of its nucleus.

(H. Bradt)

7. OSO-3 Gamma Ray Experiment

The final paper describing the results from the OSO-3 gamma ray experiment has been completed and will be submitted for publication in the near future. It includes all the results derived from 16 months of orbital operation. Additional work was performed during the past several months to evaluate the galactic and extragalactic contributions based on the assumption that the galactic gamma ray intensity is proportional to the columnar density of atomic hydrogen as derived from radio observations. This model does, in fact, give a satisfactory account of the observed direction distribution in all parts of the sky except for the region near the galactic center where the concentration of events implies a rate of production per hydrogen atom that exceeds the general galactic average by a factor of three or four.

(G. Glark, R. Borken of M.I.T.,
W. Kraushaar, U. of Wisconsin,
G. Garmire, CalTech)

III. RESEARCH RELATED TO THE INTERPLANETARY PLASMA

Research in this area has concentrated on data reduction and analysis from past and on-going programs, related theoretical work and preparation of experiments for future launches. In the following section the status of the data analysis program for each mission is summarized, and a short account is given of the related theoretical work during the past year. The work falls naturally into two categories: (1) Plasma studies in the interplanetary region and (2) plasma studies in the magnetosphere and geomagnetic tail. Section (3) summarizes some general theoretical studies not related to specific flight programs and (4) gives the status of the flight programs.

1. Plasma Studies in the Interplanetary Region

A. Explorer 33 and Explorer 35. Explorer 33 (AIMP-D) was launched in July 1966 into a highly eccentric earth orbit with apogee beyond the orbit of the moon. Explorer 35 (AIMP-E) was launched one year later and achieved a successful lunar orbit which carries it around the earth once every 28 days. Data reduction and analysis was started for each experiment shortly after launch and is continuing at the present time.

i. Experimental status. The Explorer 33 experiment continues to operate properly, but periodically changing viewing directions limit the data coverage of Explorer 33 to roughly two ten-week periods a year. A malfunction of the high voltage modulation on our Explorer 35 experiment caused a termination of useful plasma data after July 14, 1968. Since the end of 1969, the tracking of Explorer 33 has been incomplete; nevertheless useful data were obtained in 1970 and 1971.

ii. Data reduction and analysis. Data are again being received from Explorer 33, and they are being reduced and processed. We expect to continue receiving these data for an equivalent of four months of tracking during 1971. The reduction and analysis procedures are now routine. Data from previous years have been submitted to NSSDC in the form of both tapes and 27-day plots of one hour averages of plasma parameters. The tapes contain data on a time scale of 2.5 minutes; this is the highest time resolution provided by the experiment and represents the basic data output of the experiment.

iii. Scientific studies. A major study was completed by Howe for his thesis. The location of the shock boundary and its shape were determined between the subsolar point and 115 earth radii downstream. At 115 R_e the shock was still well defined. The magnetopause shape was determined to 80 R_e downstream, and it shows general agreement with the fluid calculations of Sprieter and Alksne except that it flares out more in the dawn-dusk meridian.

The availability of data from both Explorer 33 and 35 provides an opportunity to use two satellites to study the response of the magnetosphere to changes in external solar wind conditions: one satellite measures conditions within the magnetosphere while the other monitors the incident wind. Using this method it was found that the shock responds to upstream changes in flow direction by realigning its orientation and expanding or contracting in response to upstream pressure changes. Most probably these changes in the shock boundary reflect changes in the size and orientation of the magnetospheric cavity. The magnetopause responds to upstream pressure changes also; there is some indication of a delay in response to external conditions.

Evidence was also found for magnetopause motion even in apparently quiet solar wind conditions. The average motion appeared to have two superimposed components with periods of roughly fifteen minutes and one hour. A model simulating such motion suggests that the longer period motion has an amplitude roughly three times larger than that of the shorter period motion. A model with a magnetopause boundary layer thickness of approximately two R_e is consistent with the observed boundary crossing duration times; that thickness is somewhat larger than thicknesses calculating using various theoretical assumptions.

The plasma flow in the magnetosheath was also studied in the region 20 to 60 R_e downstream from the earth and was found to be in good agreement with the predictions of hydrodynamics. The availability of upstream data was clearly crucial to the study.

All of these studies were accomplished without knowledge of the magnetic field. Together with GSFC we have developed a merged plasma and magnetic field data tape which will be used for further studies.

(H. Howe, J. Binsack)

B. Pioneer 6 and 7. The reduction of data from Pioneer 6 was started in January 1966. This work and a similar program related to Pioneer 7 were supported under NASA contract NAS 2-3793 administered by Ames Research Center. The original contract expired on June 30, 1968, and support for continuation of the work has been given under NASA grant NGR 22-009-372 and NGL 22-009-015.

i. Experiment status. Pioneer 6 is still sending back data of excellent quality. It is now close enough to Earth to allow tracking with the 84-foot antennae at DSN stations.

Pioneer 7 is not in good condition. Its orbit is such that tracking can be done only with the 210-foot antennae. The sun pulse failure has made our data difficult to analyze though still usable, but magnetic field data are no longer available.

ii. Data reduction and analysis. The major portion of the data received from Ames has been processed to the point of obtaining plasma parameters. The graphical display of data received this calendar year has been somewhat delayed by an effort, now completed, to devise a more efficient processing system which converts newly received data tapes to permanent output format in one week.

We have already submitted to NSSDC 27-day plots of one-hour averages of solar wind speed, number density and thermal speed for data from both spacecraft over a three-year period. Since the submission of that data, we have recovered significantly more data from that same time period, received and analyzed data from two more years of tracking, and completed our analysis of solar wind flow directions. We have discussed with NSSDC the possibilities of publication and distribution of these more complete data, and the plans are at the stage where we expect to be ready to proceed shortly.

iii. Scientific studies. During the past year our attention has been focussed on waves and discontinuities in the interplanetary solar wind. Chao completed his thesis work which investigated a number of shock-like discontinuities observed in the data from Pioneer. He showed that the discontinuities satisfied the Rankine-Hugoniot relations by combining plasma, magnetic field, and transit time information. Chao's analysis also supported a model in which there is generally a significant decrease in the anisotropy of thermal pressure behind shocks. In cooperation with Burlaga at GSFC, a reverse slow shock and a forward slow shock were found.

Martin, Belcher and Lazarus have completed an investigation of abrupt changes in plasma and magnetic field data from Pioneer 6. This study extends the direct plasma-field evidence for outwardly propagating Alfvénic fluctuations and discontinuities to time scales of one minute in the spacecraft frame (scale lengths on the order of 20,000 km). The frequency of occurrence of Alfvénic or rotational discontinuities was found to be higher in high speed streams. A large number of events were found whose ratio of field to velocity change was such as to exclude their being Alfvénic, but which still had vector changes in field and velocity nearly parallel. This observation suggests the presence of some type of magnetoacoustic disturbance and is being investigated further.

(A. Lazarus, J. Belcher,
J. Chao, R. Martin)

C. Mariner 5. The data analysis from Mariner 5 was supported by grant NGR 22-009-289 for a period of two years. Since then it has been supported under NGR 22-009-372. As will be discussed below, most of the data reduction and analysis have been completed.

i. Experiment status. The Mariner 5 spacecraft transmitted data for a period of about five months, from mid June to mid November 1967.

ii. Data reduction. The original data tapes have been used to produce summary tapes which contain our measured currents ready for analysis. The reduced data have been analyzed under the assumption of a convected isotropic Maxwellian velocity distribution. Alpha particle number density, bulk speed and thermal speed parameters have beeen obtained for approximately half the spectra taken. Flow directions have been obtained with accuracies of better than 1°. A combined plasma magnetic field and trajectory tape has been made with the cooperation of the magnetic field experimenters from CalTech and JPL. One-hour averages of solar wind parameters have been plotted on a 27-day basis. These graphs are intended to be the initial submission to NSSDC and will be followed by more detailed plots and the tape of merged parameters.

iii. Scientific studies. Turner, in work leading to his dissertation, studied the nature of discontinuities in plasma parameters. He required steady state conditions in the neighborhood of the discontinuities and was thus studying a somewhat lower frequency portion of the spectrum than the studies of Belcher et al. referred to earlier in connection with Alfvénic changes. Turner found both Alfvénic and tangential discontinuities. The tangential discontinuities had surfaces found to be preferentially parallel to the spiral direction and perpendicular to the ecliptic plane. The Alfvénic discontinuities were more prevalent in high speed streams.

Goldstein did an extensive analysis of the cross and power spectra of plasma and magnetic field parameters observed from Mariner 5. He found that for periods up to one day, the power in the field and plasma components was proportional to $(\text{period})^n$ where n was between one and two. The dependence on the period was weaker for periods from one to ten days, and cross spectra showed that a distinct change in behavior occurred at a period of approximately one day. For periods less than one day, the results are mostly accounted for by outwardly propagating Alfvén waves, but additional processes are required to account for all the fluctuations. For periods greater than one day, models of corotating structure and symmetrically expanding solar wind can account for the observed coherences and phases.

Lazarus and Goldstein used the flow angle determinations to estimate the angular momentum flux carried off from the sun by the solar wind. The magnitude of the flux was found to be sufficient (if continuous) to slow the solar rotation period to 1/e of its present value in the age of the sun. Thus the solar wind is an important mechanism for increasing the solar rotation period.

Belcher (to be published) has developed a variation of the method of Davis and Smith (Trans. AGU 49, 257, 1968) used for inflight determination of spacecraft field zeroes on Mariner 5. The new method is based on the premise that during periods of primarily transverse (Alfvénic) fluctuations, the direction of maximum variation of the field is perpendicular to the average field direction. The basis and results of the new method are the same as those of Davis and Smith, but in practice it requires less computing time and fewer initial assumptions about the size of the spacecraft field, and also utilizes the hindsight available from the extensive wave studies of combined Mariner 5 plasma and field data.

(A. Lazarus, J. Belcher,
J. Turner, B. Goldstein)

2. Plasma Studies in the Magnetosphere and Geomagnetic Tail

A. OGO-1 and OGO-3

i. Experiment status. OGO-1 was launched on September 4, 1964, and OGO-3 on June 6, 1966; both satellites were deactivated late in 1969. At that time the proton and electron experiments on both satellites were still operating.

ii. Data reduction and analysis. All data received from OGO-1 and OGO-3 up to mid 1967 were processed at M.I.T. on an IBM 7044. This machine was replaced by an IBM 360-65 in March 1968, leaving about one year's data from OGO-3 unprocessed. These data have been of particular interest because the orbit of OGO-3 in 1967 and 1968 had precessed to a high inclination and afforded an opportunity to measure electron distributions in a previously unexplored and particularly interesting region of the magnetosphere.

However, the problem of rewriting the 7044 OGO programs for the 360 is a formidable one and, despite good intentions, has not been done. Recently we became aware that a 7044 was still operating in the Boston area and, through the cooperation of Dr. Paul Fougere of the Air Force Cambridge Research Laboratories, we have been able to process most of the remaining raw data.

OGO-3 data from the period August 1967 through August 1968 have been processed and plotted. These data provide the first detailed mapping of the electron distribution in the predawn sector of the magnetosphere; when their analysis is completed, they will fill in the gap in the average picture of the electron distribution previously derived from OGO data (Vasyliunas: J. Geo. Res. 73, 7519, 1968).

The study of the relation between the plasma sheet and the auroral oval was continued; the earlier statistical analysis was extended, and simultaneous observations by OGO-1 and by ground-based all-sky cameras were analyzed in collaboration with Y. I. Feldstein of Izmiran, Moscow. The inner edge of the plasma sheet is observed to coincide with magnetic field lines passing through the equatorward edge of the auroral oval (as defined statistically for a given degree of geomagnetic activity). To test whether this relation holds instantaneously or merely in an average sense, a comparison of inner edge observations by the OGO-1 satellite with simultaneous all-sky camera pictures was made. In all the available cases of simultaneous observations, an auroral arc is found at the instantaneous position of the inner edge of the plasma sheet; additional arcs are sometimes present at higher latitudes. The intensity and energy spectrum of the isotropic plasma sheet electrons, when mapped to the ionosphere, correspond to the observed average auroral precipitation. The beam component of the plasma sheet electrons, recently reported by Hones and co-workers, may be associated with individual auroral forms.

A comparison of OGO-3 observations in the magnetotail during the period April--July 1969 with low altitude observations by the polar-orbiting satellite OV1-18 is being undertaken in collaboration with R. D. Sharp and colleagues of Lockheed Palo Alto Research Laboratory.

(V. Vasyliumas)

B. Explorer 35. See Section III.1.A for status of experiment and data reduction.

Data taken in the distant geomagnetic tail (lunar distances) reveal low fluxes of positive ions with flow vectors pointing toward the earth. Isolated instances of flow away from the earth are also seen. These results with a discussion of the theoretical implications are being prepared for publication.

(A. Prakash)

3. Theoretical Studies

A. Theoretical Studies of Magnetospheric Plasma

i. A model of auroral arcs and auroral particle acceleration. This work was completed and submitted as a Ph.D. thesis by William J. Burke. The assumption of strong pitch angle diffusion within the plasma sheet predicts an approximately uniform electron precipitation over the auroral oval. To explain the occurrence of individual auroral arcs, we postulate that the return currents associated with the uniform precipitation maintain large parallel electric fields, through anomalous resistivity. We show that magnetospheric convection leads to strong localized electron acceleration where there are horizontal gradients in the parallel electric field. The model predicts, in agreement with observations: (a) long thin regions of enhanced precipitation, aligned with the auroral oval, (b) an electron energy spectrum with a sharp peak superimposed on a continuous background, (c) a field-aligned current carried by precipitating electrons within the arc, with a return current outside of the arc, (d) coincidence of the equatorwardmost arc with the inner edge of the plasma sheet.

(V. Vasyliunas, W. Burke)

ii. Some implications of Liouville's theorem for magnetospheric processes. In the absence of wave-particle interactions, Liouville's theorem states that the distribution function remains constant along particle trajectories. Wave-particle interactions result in mixing of trajectories and hence can reduce but not increase the distribution function. If it is proposed that particles in a certain region originate from some other region, a necessary (but not sufficient) condition for the validity of the proposal is that the final value of the distribution function be less than or equal to the initial value. Applying this test to the proposed origin of various particle populations in the magnetosphere, it is found that: (a) plasma sheet particles may come from the solar wind, but considerable heating is required; (b) ring current protons may originate from the plasma sheet but only by a nearly adiabatic process; (c) electrons in the "trough" region must be at leastly partly of ionospheric origin; (d) suprathermal (∿ 10 kev) protons in the solar wind can be completely ruled out as significant contributors to the ring current; (e) electrons within the "monoenergetic" peak of the auroral spectrum may originate from the plasma sheet but only by a nearly adiabatic process; the low energy part of the auroral spectrum must be of ionospheric origin.

(V. Vasyliunas)

iii. Effect of the ring current on magnetospheric convection. The self-consistent approach to the modelling of magnetospheric processes [described in V. M. Vasyliunas: "Mathematical Models of Magnetospheric Convection and Its Coupling to the Ionosphere," in Particles and Fields in the Magnetosphere (B. M. McCormac, ed., 1970)] was extended to include a ring current, consisting of adiabatically behaving protons convected inward from the magnetotail. The ring current has the same effect as a region of enhanced Hall conductivity in the ionosphere; quantitatively the effect is very large (corresponding to a conductivity value of some 300 mhos) and the convection is almost completely terminated at the inner edge of the ring current. Observations of convection at lower latitudes must, therefore, be transient effects; the relevant time scales and a possible connection with substorms are being studied.

(V. Vasyliunas)

B. Theoretical Studies of the Solar Wind.

i. Propagation of large scale, transverse waves in solar wind. The investigation of the propagation of large scale transverse disturbances originating in the solar corona has been carried out. This investigation represents, in some respects, a generalization of the work of Belcher on the propagation of Alfvén waves in the solar wind. The concept of an Alfvén wave is only tenable when the wavelength is very small in comparison with the scale of the system, i.e., when the WKB approximation is applicable. It has been shown that, when the scale length of a transverse disturbance becomes an appreciable fraction of the scale of the system, the familiar relations characterizing the Alfvén waves [e.g., the equality between the magnetic energy density of the wave, $\delta B^2/8\pi$, and the kinetic particle energy density, $(1/2)\ \rho\ \delta V^2$, associated with the wave] no longer hold. In fact, for a given radial distance from the sun, one can define a critical wavelength and a critical frequency which separate the Alfvén wave regime from that of the large scale transverse disturbances. One of the important features of the latter regime is the following. In contrast to the Alfvén waves, the large scale disturbances transfer a comparatively small amount of their energy directly into the streaming motion of the solar wind plasma. In the limit of very low frequencies (say, periods of the order of a few days) their energy flux is essentially conserved. The other interesting feature of these disturbances is that they exhibit a certain kind of dispersiveness, i.e., the wave numbers are no longer locally proportional to the frequency.

The above outlined studies have been carried out both analytically (when some simplifications were permissible) and numerically (when it was clear that the simplifications for analytical purposes would remove us too far from the real situation). The results have been applied to test the consistency between the theoretical predictions and the empirical profiles of the solar wind velocity, density and temperature. It was concluded that, as far as the transverse fluctuations are concerned, only the Alfvén wave (i.e., the relatively high frequency) regime can play an important role in the acceleration of the solar wind. Our findings in the regime support strongly the ideas put forward independently by J. Belcher, and Arazraki and Couturier (see the next report).

(B. Goldstein and S. Olbert)

ii. <u>Wave driven stellar winds</u>. Analysis of plasma and magnetometer data from Mariner 5 has demonstrated the frequent occurrence of large amplitude, outwardly propagating Alfvén waves in the solar wind. The waves are most probably generated at or near the sun. In an effort to determine the effects of these waves on the dynamics of the solar wind, Belcher (Ap. J. 168, 509, 1971) and, independently, Alazraki and Couturier (Astron. & Astrophys. 13, 380, 1972) have developed idealized models which include energy fluxes due to coronal Alfvén waves, assuming no wave damping, a polytrope relation between density and pressure, and a non-rotating sun. The waves exert an effective pressure on the expanding solar corona, analogous to a radiation pressure, and the inclusion of fluxes due to Alfvén waves can cause significant changes in solar wind streaming properties at 1 AU for reasonable conditions at 10^6 km. These wave-modified wind models have two notable features: (a) all of the wave energy flux across the base of the corona is eventually converted to kinetic streaming motion of the wind, with the majority of the energy conversion taking place relatively close to the sun ($< 30\ R_{\odot}$); (b) when sufficiently energetic, the waves alone, with no additional energy sources, can drive the solar wind.

The thrust of recent work has been the application of the above theoretical model to the general stellar wind problem, in particular to stars with magnetic fields much higher than solar fields (but still radial), and coronal temperatures much lower than the solar corona. The stellar wind models considered are purely wave-driven in the sense that the stellar coronal expansion is taken to be purely adiabatic, with the only energy flux driving the wind due to outwardly propagating Alfvén waves (presumably generated in a convective zone). In the most general case, the non-relativistic model must be extended to include the possibility of Alfvén velocities and stellar wind streaming velocities close to the speed of light. Stars with cool, tightly bound atmospheres and strong magnetic fields will have $H^2/4\pi c^2 > \rho$ (or $V_{Alfvén} \simeq c$) near the top of the atmosphere since H falls as γ^{-2} with ρ falling exponentially. Also, stellar wind solutions with very small mass fluxes may become extremely energetic far from the star since individual particle energies at infinity are proportional to the ratio of the initial wave energy flux to the mass flux (this quantity may be very large for small mass fluxes).

Accordingly, a relativistic extension of the earlier model has been developed, including a relativistically correct expression for the conserved energy flux and the differential equation of motion for the wind. A machine program has been developed to solve these equations numerically for given initial conditions close to the star. At the present, a wide class of "wind" solutions is being generated for a variety of stellar conditions. In many situations, we obtain stellar wind solutions essentially similar to the solar wind case. In some cases, we can obtain extremely energetic winds ($V_\infty \simeq c$) although with very low mass fluxes. Also, for some ranges of initial conditions, "wind" solutions to the equations do not exist. We are actively engaged in investigating the astrophysical applicability and significance of these numerical results.

(J. Belcher, S. Olbert)

iii. Corotating structures in the solar wind.

Digital computer procedures have been used to solve numerically the hydrodynamical equations for the following model of the solar wind: (a) The short term fluctuations and the magnetic field are ignored. (b) The solar wind is assumed to be stationary in the frame of reference corotating with the sun. (c) The radial and the azimuthal components of the streaming velocity as well as the density and the pressure are allowed to have, at a properly chosen reference surface around the sun, various longitudinal variations of finite amplitude. With such assumptions the problem is intrinsically non-linear and cannot be solved by analytical means. Our computer studies of the spatial behavior of such corotational structures lead us to the following conclusions: (a) Positive longitudinal gradients in the radial wind velocity steepen as the radial distance increases. (b) The compression of the plasma occurs in the steep gradient region; the sharpness and the height of the compressed density profile along the azimuth increase with distance from the sun. (c) Typical large scale solar wind streams seem to require formation of forward and reverse shock pairs at large radial distances. (d) The phase angle relations between the density, the streaming velocity and the thermal speed of the solar wind can be made to agree with the observed phase angle relations for a reasonable choice of inner boundary conditions.

(B. Goldstein, G. Siscoe)

iv. Modification of shock structure by Alfvén waves. Scholer and Belcher (Solar Physics 16, 472, 1972) have considered the effects of Alfvén waves on the structure of fast MHD shocks in the "sudden" approximation (wavelengths long compared to the shock transition region). Their results are being extended to the "adiabatic" approximation (wavelengths short compared to the transition region). These theoretical studies are suggested by Mariner 5 observations of Alfvén waves as they interact with and are amplified by shocks and compression regions in the solar wind. A detailed study of these interactions, both theoretically and phenomenologically, is in progress.

(J. Belcher)

4. Status of Flight Program

A. IMP H and J. The flight unit for IMP H has been completed. Prior to delivery of the unit, extensive tests and calibrations were performed in our plasma test facility. Environmental testing at the subsystem level has been completed at GSFC, and the experiment has been integrated into the spacecraft. Environmental and systems testing of the spacecraft has begun, and launch is scheduled for mid 1972.

The IMP J unit is being assembled and tested.

(H. Bridge, J. Binsack,
A. Lazarus, R. Butler)

B. MVM-73. Design of the instrument for the Venus-Mercury flyby is complete in most areas and fabrication of mechanical components is under way. Prototypes of the two electrostatic analyzers have been built.

(H. Bridge, R. Butler of M.I.T.,
S. Bame of Los Alamos,
K. Ogilvie of GSFC)

IV. TALKS AND PUBLICATIONS

Talks

J. W. Belcher: "Coronal Alfvén Waves in the Solar Wind," Solar Wind Conference, Asilomar, March 1971.

"A Wave-Driven Model of the Solar Wind," Trans. AGU 52, 335, 1971.

"Interplanetary Sector Boundaries," Trans. AGU 52, 337, 1971 (with E. J. Rhodes and E. J. Smith of JPL).

J. H. Binsack: "Magnetosheath Plasma Observations Normalized to Interplanetary Conditions Using Simultaneous Observations from Explorer 33 and 35," Trans. AGU 51, 809, 1970.

"Possible Lunar Surface Fossil Magnetism," Trans. AGU 51, 774, 1970 (with J. D. Mihalov and C. P. Sonett of NASA Ames Research Center).

H. V. Bradt: "The Present State of X-ray Astronomy," Am. Astron. Soc. 133rd Meeting, Tampa, Florida, Dec. 7, 1970.

"X-ray Astronomy," Colloquium at Kitt Peak National Observatory, Tucson, Arizona, December 1970.

"Review of X-ray Astronomy," Cerro Tololo Interamerican Observatory, Jan. 7, 1971.

"Report on the Tampa AAS and 5th Texas Conferences," Cerro Tololo Interamerican Observatory, Jan. 11, 1971.

"Gravitational Waves," Cerro Tololo Interamerican Observatory, Jan. 27, 1971.

"Diffuse X-ray and Gamma-ray Background," Cerro Tololo Interamerican Observatory, Feb. 1, 1971.

"3° K Radiation," Cerro Tololo Interamerican Observatory, Feb. 8, 1971.

"Pulsars," Cerro Tololo Interamerican Observatory, Feb. 15, 1971.

"Gamma-ray Astronomy," Cerro Tololo Interamerican Observatory, Feb. 22, 1971.

"Techniques in Radio Astronomy," Cerro Tololo Inter-american Observatory, Feb. 28, 1971.

"Galaxies, Especially NGC 5128," Cerro Tololo Inter-american Observatory, Mar. 16, 1971.

"X-ray Astronomy," University of Buenos Aires, Buenos Aires, Argentina, Apr. 13, 1971.

W. J. Burke and V. M. Vasyliunas: "A Model of Auroral Arcs and Auroral Particle Acceleration," Trans. AGU 51, 809, 1970.

M. Gerassimenko: "Balloon Observations of High Energy X-ray Sources in the Region of the Galactic Center," Am. Phys. Soc., Tampa, Florida, Dec. 7, 1970.

I. Glass: "A Balloon Observation of Pulsed X-rays from the Crab," Am. Astro. Soc., Washington, Dec. 10, 1970.

B. E. Goldstein: "Power Spectra and Cross Spectra of Solar Wind," (with G. L. Sisco of UCLA), Trans. AGU 52, 335, 1971.

H. C. Howe: "Magnetopause Motion and Structure at Lunar Distance," (with G. L. Sisco of UCLA), Trans. AGU 52, 317, 1971.

A. J. Lazarus: "Flow Directions of the Solar Wind," Trans. AGU 51, 816, 1970.

"Angular Momentum Carried by the Solar Wind," Solar Wind Conference, Asilomar, Mar. 24, 1971.

W. H. G. Lewin: "X-ray Astronomy," Technion, Haifa, Israel, Mar. 26, 1971.

"Variable X-ray Sources," Tel Aviv University, Tel Aviv, Israel, Mar. 28, 1971.

"Proportional Counters," Institute of Physics, University of Palermo, Palermo, Sicily, Apr. 1, 1971.

"New Results in High Energy X-ray Astronomy," Institute of Physics, University of Palermo, Palermo, Sicily, Apr. 2, 1971.

"Balloon High Energy X-ray Observations in the Southern Sky," Am. Phys. Soc., Washington, Apr. 27, 1971.

"A Newly Born Science," National Physical Observatory, New Delhi, India, Sept. 4, 1970.

"Why Ballooning? Why Mildura?" Mildura Technical School, Mildura, Victoria, Australia, Oct. 29, 1970.

"X-ray Astronomy," Radio Physics Div., CSIRO, Sydney, Australia, Nov. 13, 1970.

"High Energy X-rays from Centaurus," Am. Phys. Soc., Washington, Apr. 27, 1971.

"Variable X-ray Sources," Furman University, Greenville, S. C., May 21, 1971.

"The Near Future of X-ray Astronomy," Furman University, Greenville, S. C., May 21, 1971.

"X-ray Astronomy, A Rapidly Expanding Frontier," University of North Carolina, Chapel Hill, N. C., July 12, 1971.

"A New Way of Doing Physics," Furman University, Greenville, S. C., July 15, 1971.

"X-ray Astronomy, An Exciting Adventure," Furman University, Greenville, S. C., July 19, 1971.

"Problems in X-ray Astronomy," Furman University, Greenville, S. C., July 26, 1971.

"X-ray Astronomy," 12th International Conference on Cosmic Rays," University of Tasmania, Hobart, Tasmania, Australia, Aug. 24, 1971.

A. Prakash: "Low Energy Electrons Detected by Explorers 33 and 35 up to 80 Earth Radii, I." (with J. H. Binsack), Trans. AGU 52, 326, 1971.

B. B. Rossi: "History and Prospects of X-ray Astronomy," CSR Astrophysics Seminar, M.I.T., Cambridge, Mass., Oct. 5, 1970.

H. W. Schnopper: "Interpretation of the 1-4 μ Spectra of Some C Stars," International Conference on Infrared Astronomy, Liege, Belgium, July 1971.

G. L. Siscoe: "Orientations of Tangential Discontinuities, Rotational Discontinuities and Interaction Fronts in the Solar Wind," Trans. AGU 51, 818, 1970 (with J. M. Turner, A. J. Lazarus and C. Solodyna).

V. M. Vasyliunas: "Self-consistent Models of Magnetospheric Convection," Space Plasma Seminar, M.I.T., Sept. 29, 1970.

"Thermal and Suprathermal Plasmas in the Magnetosphere," Air Force Cambridge Research Laboratory, Bedford, Mass., Sept. 30, 1970.

"Relation of the Plasma Sheet to the Auroral Oval," Trans. AGU 51, 814, 1970.

"Recent Research on Auroral Arcs," Radioscience Lab., Stanford University, Dec. 11, 1970.

"Interaction of the Solar Wind with the Magnetosphere," Symposium on Ionosphere-Magnetosphere Interactions, New Delhi, India, Feb. 8-11, 1971.

"Penetration of Magnetospheric Convection to Low Latitudes and the Nature of the Plasmapause," Symposium on Ionosphere-Magnetosphere Interactions, New Delhi, India, Feb. 8-11, 1971.

"Magnetospheric Convection," Physical Research Lab., Ahmedabad, India, Feb. 13, 1971.

"Effect of the Ring Current on Magnetospheric Convection," Institute for Space and Aeronautical Science, U. of Tokyo, Tokyo, Japan, Feb. 16, 1971.

"The Inner Boundary of the Plasma Sheet," Annual Japanese Symposium on Magnetospheric Physics, Tokyo, Japan, Feb. 20, 1971.

"Some Implications of Liouville's Theorem for Magnetosphere Processes," Trans. AGU 52, 329, 1971.

"Magnetic Merging Mechanisms," Dept. of Space Science, Rice University, Houston, Texas, June 28, 1971.

"Magnetic Merging Mechanisms," Summer Institute on Planetary Magnetospheres and Auroras, U. Colorado, Boulder, Col., July 1, 1971.

"Effect of the Ring Current on Magnetospheric Convection," Space Science Lab., U. California at Berkeley, July 14, 1971.

"The Interrelationship of Magnetospheric Processes," Summer Advanced Institute, 9th ESRO Summer School on "Earth's Particles and Fields," Cortina d'Ampezzo, Italy, Aug. 30-Sept. 10, 1971.

Publications

A. Published

B. H. Andrew, C. R. Purton, S. A. Rappaport, H. V. Bradt and H. W. Schnopper: "A Search for Radio Emission from Four X-ray Sources near Sagittarius," Ap. J. 161, L173, 1970.

J. W. Belcher: "Alfvènic Wave Pressures and the Solar Wind," Ap. J. 168, 509, 1971.

H. Bradt, B. Burnett, W. Mayer, S. Rappaport and H. Schnopper: "The 1-10 KeV X-ray Sky near the Galactic Center," Nature 229, 96, 1971.

J. Chao and S. Olbert: "Observation of Slow Shocks in Interplanetary Space," J. Geophys. Res. 31, 6394, 1970.

G. W. Clark: "Studies of Discrete Cosmic X-ray Sources at M.I.T.," IAU Symposium No. 37, Non-solar X- and Gamma-ray Astronomy, 54-58, L. Gratton (ed.), Rome, Italy, May 1969. D. Reidel Publishing Co., Dordrecht, Holland, Oct. 1970.

M. Forman: "The Equilibrium Anisotropy in the Flux of 10 MeV Solar Flare Particles," J. Geophys. Res. 75, 3147, 1970.

E. W. Greenstadt, I. M. Green, G. T. Inouye, J. H. Binsack, D. S. Colburn, E. F. Lyon: "Dual Satellite Observations of Earth's Bow Shock; I: The Thick Pulsation Shock; II: Field Aligned Upstream Waves; III: Field Determined Shock Structure," Cosmic Electrodyn. 1, 160, 1970.

W. Kunkel, P. Osmer, M. Smith, A. Hoag, D. Schroeder, W. A. Hiltner, H. Bradt, S. Rappaport and H. W. Schnopper: "An Optical Search for the X-ray Sources GX 3+1, GX 5-1, GX 9+1 and GX 17+2," Ap. J. 161, L169, 1970.

W. E. Kunkel and H. V. Bradt: "Identification of the Nucleus of NGC 5128," Ap. J. 170, L7, 1971.

A. J. Lazarus, K. W. Ogilvie and L. F. Burlaga: "Interplanetary Shock Observations by Mariner 5 and Explorer 34," Solar Physics 13, 232, 1970.

A. J. Lazarus and B. E. Goldstein: "Observation of the Angular Momentum Flux Carried by the Solar Wind," Ap. J. 168, 571, 1971.

W. H. G. Lewin, J. E. McClintock, S. G. Ryckman and W. B. Smith: "Detection of a High Energy X-ray Flare from a Source in Crux," Ap. J. 166, L69, 1971.

W. H. G. Lewin, J. E. McClintock and G. R. Ricker: "X-rays from a New Variable Source GX 1+4," Ap. J. 169, L17, 1971.

W. H. G. Lewin, J. E. McClintock, S. G. Ryckman, I. S. Glass and W. B. Smith: "Continual Variations in the High Energy Flux of X-rays from Scorpius X-1," Ap. J. 162, L109, 1970.

J. E. McClintock, G. R. Ricker and W. H. G. Lewin: "Rapid Fluctuations in the High Energy X-ray Flux from a Source in Crux," Ap. J. 166, L73, 1971

M. D. Moutsoulas, J. D. Mihalov, C. P. Sonett and J. H. Binsack: "Possible Fossil Lunar Magnetism Inferred from Satellite Data," Science 171, 892, 1971.

S. Rappaport, H. Bradt and W. Mayer: "X-ray Observations of Pulsars," Nature 229, 40, 1971.

B. Rossi and S. Olbert: Introduction to the Physics of Space, McGraw-Hill Book Co., 1970.

B. Rossi: "An X-ray Pulsar in the Crab Nebula," IAU Symposium No. 37, Non-solar X- and Gamma-ray Astronomy, 183-184. L. Gratton (ed.), Rome, Italy, May 1969. D. Reidel Publishing Co., Dordrecht, Holland, Oct. 1970.

B. Rossi: "Introductory Remarks," IAU Symposium No. 37, Non-solar X- and Gamma-ray Astronomy, 1-4. L. Gratton (ed.), Rome, Italy, May 1969. D. Reidel Publishing. Co., Dordrecht, Holland, Oct. 1970.

B. Rossi: "The Crab Nebula. Ancient History and Recent Discoveries," Evolution of Particle Physics, M. Conversi (ed.). Volume dedicated to E. Amaldi on his 60th birthday. Academic Press, New York and London, Feb. 1971.

H. W. Schnopper, R. I. Thompson and W. K. Rose: "Evidence for Hydrogen-to-Carbon Ratios in Accordance with CNO Bi-Cycle in Several Carbon Stars," Ap. J. 163, 533, 1971.

H. W. Schnopper, H. V. Bradt, S. A. Rappaport, E. Boughan, B. Burnett, R. Doxsey, W. Mayer and S. Watt: "Precise Location of Sagittarius X-ray Sources with a Rocket-borne Modulation Collimator," Ap. J. 161, L161, 1970.

G. L. Siscoe: "The Solar Wind Problem with Fluctuations," Cosmic Electrodynamics 1, 51-66, 1970. D. Reidel Publishing Co., Holland.

G. L. Siscoe, F. L. Scarf, I. M. Green, J. H. Binsack and H. S. Bridge: "Very Low Frequency Electric Fields in the Interplanetary Medium: Pioneer 8," J. Geophys. Res. 76, 828, 1971.

G. L. Siscoe, F. L. Scarf, D. S. Intriligator, J. H. Wolfe, J. H. Binsack and V. M. Vasyliunas: "Evidence for a Geomagnetic Wake at 500 R_e," J. Geophys. Res. 75, 5319, 1970.

G. Subramanian: "Amplitude of Diurnal Anisotropy of Cosmic Ray Intensity," J. Geophys. Res. 76, 1093, 1971.

J. M. Turner and G. L. Siscoe: "Orientations of 'Rotational' and 'Tangential' Discontinuities in the Solar Wind," J. Geophys. Res. 76, 1816, 1971.

V. M. Vasyliunas: "Low Energy Particle Fluxes in the Geomagnetic Tail," The Polar Ionosphere and Magnetospheric Processes, G. Skovli (ed.). Gordon & Breach Science Publishing Co., New York, 1970.

V. M. Vasyliunas: "Mathematical Models of Magnetospheric Convection and Its Coupling to the Ionosphere," Particles and Fields in the Magnetosphere, B. M, McCormac (ed.). D. Reidel Publishing Co., Dordrecht, Holland, 1970.

V. M. Vasyliunas: "Deep Space Plasma Measurements," Methods of Experimental Physics, IX (Plasma Physics), H. R. Griem and R. H. Lovberg (eds.). Academic Press, New York, 1970.

V. M. Vasyliunas: "Thermal and Suprathermal Plasma in the Magnetosphere," Comments on Astrophysics and Space Physics 3, 48, 1971.

V. M. Vasyliunas: "Interplanetary Fields and Plasmas," Trans. AGU 52, IUGG 490, 1971.

C. G. Wang, H. Lee and G. Leung: "Properties of Hadron Matter; I. The Equation of State," Ap. J. 166, 387, 1971.

To Be Published

J. Chao and B. E. Goldstein: "Thermal Anisotropies in the Vicinity of Solar Wind Shocks," submitted to JGR Letters.

B. E. Goldstein: "Non-linear Corotating Solar Wind Structure," submitted to JGR.

H. C. Howe, V. M. Vasyliunas and J. H. Binsack: "Explorer 33 and Explorer 35 Plasma Observations of Magnetosheath Flow," submitted to JGR.

R. N. Martin, J. W. Belcher and A. J. Lazarus: "A Study of Interplanetary Discontinuities Using Pioneer 6 Plasma and Field Data," submitted to JGR.

G. L. Siscoe: "Structure and Orientations of Solar Wind Interaction Fronts: Pioneer 6," submitted to JGR.

J. M. Turner: "Rotational Discontinuities in the Solar Wind," submitted to JGR.

J. M. Turner: "Tangential Discontinuities in the Solar Wind," submitted to JGR.

Theses

W. J. Burke: "A Theoretical Investigation of Small Scale Auroral Zone Electric Fields and Their Relation to Particle Precipitation Patterns," Ph.D. Thesis in Physics, June 1971.

B. E. Goldstein: "Analysis of Fluctuations in the Solar Wind," Ph.D. thesis in Mathematics, June 1971.

H. C. Howe: "Explorer 33 and Explorer 35 Plasma Observations of the Interaction Region between the Solar Wind and the Magnetic Field of the Earth," Ph.D. Thesis in Physics, June 1971.

J. M. Turner: "An Examination of Magnetohydrodynamic Discontinuities in the Solar Wind and An Investigation of Their Origin," Ph. D. Thesis in Physics, February 1971.

G. R. Ricker, Jr.: "High Energy Cosmic X-ray Sources in the Southern Sky," Ph.D. Thesis in Physics, September 1971.

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