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SPACE RADIATION LABORATORY

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SEMI-ANNUAL STATUS REPORT

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Grant NGR 05-002-160*
"RESEARCH IN PARTICLES AND FIELDS"

for

1 April 1982 - 30 September 1982

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SEMI-ANNUAL STATUS REPORT

NASA Grant NGR 05-002-160

Space Radiation Laboratory (SRL)
California Institute of Technology

1 April 1982 - 30 September 1982

This report covers the research activities in Cosmic Rays, Gamma Rays, and Astrophysical Plasmas supported under NASA Grant NGR 05-002-160. The report is divided into sections which describe the activities, followed by a bibliography.

This group's research program is directed toward the investigation of the astrophysical aspects of cosmic radiation and of the radiation and electromagnetic field environment of the Earth and other planets. We carry out these investigations by means of energetic particle and photon detector systems flown on spacecraft and balloons.

1. Cosmic Rays and Astrophysical Plasmas

This research program is directed toward the investigation of galactic, solar, interplanetary, and planetary energetic particles and plasmas. The emphasis is on precision measurements with high resolution in charge, mass, and energy. The main efforts of this group, which are supported partially or fully by this grant, have been directed toward the following two categories of experiments.

1.1. Activities in Support of or in Preparation for Spacecraft Experiments

These activities generally embrace prototypes of experiments on existing or future NASA spacecraft or they complement and/or support such observations.

1.1.1. The High Energy Isotope Spectrometer Telescope (HEIST 2)

HEIST-2 is a large area (0.25 m^2sr) balloon borne isotope spectrometer designed to make high-resolution measurements of isotopes in the element range from neon to nickel ($10 \leq Z \leq 28$) at energies of about 3 GeV/nucleon. The instrument consists of a stack of 12 NaI(Tl) scintillators, two Cerenkov counters, and two plastic scintillators, S_t and S_b. Each of the 2-cm thick NaI disks is viewed by six 1.5-inch photomultipliers whose combined outputs measure the energy deposition in that layer. In addition, the six outputs from each disk are compared to determine the position at which incident nuclei traverse each layer to an accuracy of ~2 mm. The Cerenkov counters,

which measure velocity, are each viewed by twelve 5-inch photomultipliers using light integration boxes.

HEIST-2 determines the mass of individual nuclei by measuring both the change in the Lorentz factor ($\Delta\gamma$) that results from traversing the NaI stack, and the energy loss (ΔE) in the stack. Since the total energy of an isotope is given by $E = \gamma M$, the mass M can be determined by $M = \Delta E/\Delta\gamma$. The instrument is designed to achieve a typical mass resolution of 0.2 amu.

Major components, including the aerogel array, are integrated into a form close to flight configuration. These components will be tested and calibrated on a beam of relativistic $_{56}$Mn at the Bevalac in November. It is anticipated that the experiment will be flown from Palestine during the spring 1983 high-altitude-wind turnaround.

1.2. Experiments on NASA Spacecraft

The SR&T grant program of the Space Radiation Laboratory is strengthened by and contributes to the other programs described here. Activities related to these programs are primarily funded by mission-related contracts but grant funds are used to provide a general support base and the facilities which make these programs possible.

1.2.1. An Electron/Isotope Spectrometer (EIS) Launched on IMP-7 on 22 September 1972 and on IMP-8 on 26 October 1973

This experiment is designed to measure the energy spectra of electrons and positrons (0.16 to ~6 MeV), and the differential energy spectra of the nuclear isotopes of hydrogen, helium, lithium, and beryllium (~2 to 50 MeV/nucleon). In addition, it provides measurements of the fluxes of the isotopes of carbon, nitrogen, and oxygen from ~5 to ~15 MeV/nucleon. The measurements from this experiment support studies of the origin, propagation, and solar modulation of galactic cosmic rays; the acceleration and propagation of solar flare particles; and the origin and transport of energetic magnetospheric particles observed in the plasma sheet, adjacent to the magnetopause, and upstream of the bow shock.

The extensive EIS data set has been utilized in comprehensive studies of solar, interplanetary, and magnetospheric processes. Correlative studies have involved data from other IMP investigations and from other spacecraft, as well as direct comparisons of EIS data from IMP-7 and IMP-8. These studies have resulted in the following recent talks and papers:

- "Plasma Behavior During Energetic Electrons Streaming Events: Further Evidence for Substorm Associated Magnetic Reconnection," J. W. Bieber et al., *Geophys. Res. Ltrs.* **9**, 664-667 (1982).

- "Reconnection - Associated Energization of Plasma Sheet Electrons," J. W. Bieber et al., *EOS Trans. AGU* **63**, 418 (1982).

1.2.2. An Interstellar Cosmic Ray and Planetary Magnetospheres Experiment for the Voyager Missions Launched in 1977.

This experiment is conducted by this group in collaboration with F. B. McDonald, J. H. Trainor, and A. W. Schardt (Goddard Space Flight Center), W. R. Webber (University of New Hampshire), and J. R. Jokipii (University of Arizona), and has been designated the Cosmic Ray Subsystem (CRS) for the Voyager Missions. The experiment is designed to measure the energy spectra, elemental and (for lighter elements) isotopic composition, and streaming patterns of cosmic-ray nuclei from H to Fe over an energy range of 0.5 to 500 MeV/nucleon and the energy spectra of electrons with 3 - 100 MeV. These measurements will be of particular importance to studies of stellar nucleosynthesis, and of the origin, acceleration, and interstellar propagation of cosmic rays. Measurements of the energy spectra and composition of energetic particles trapped in the magnetospheres of the outer planets are used to study their origin and relationship to other physical phenomena and parameters of those planets. Measurements of the intensity and directional characteristics of solar and galactic energetic particles as a function of the heliocentric distance will be used for *in situ* studies of the interplanetary medium and its boundary with the interstellar medium. Measurements of solar energetic particles are crucial to understanding solar composition and solar acceleration processes.

The CRS flight units on both Voyager spacecraft have been operating successfully since the launches on August 20, 1977 and September 5, 1977. The CRS team participated in the Voyager 1 and 2 Jupiter encounter operations in March and July 1979, and in the Voyager 1 and 2 Saturn encounters in November 1980 and August 1981. The Voyager data represent an immense and diverse data base, and a number of scientific problems are under analysis. These investigation topics range from the study of galactic particles to particle acceleration phenomena in the interplanetary medium, to plasma/field energetic particle interactions, to acceleration processes on the sun, to studies of elemental abundances of solar, planetary, interplanetary, and galactic energetic particles, and to studies of particle/field/satellite interactions in the magnetospheres of Jupiter and Saturn.

The following publications and papers for scientific meetings, based on Voyager data, were generated:

- E. C. Stone, "The Voyager Encounter with Uranus," , 275-291 in *Uranus and the Outer Planets*, ed. G. Hunt, Cambridge University Press, Cambridge, England (1982).

- "An Analysis of the Structure of Saturn's Magnetic Field Using Charged Particle Absorption Signatures," D. L. Chenette and L. Davis, Jr., *J. Geophys. Res.* **87**, 5267-5274 (1982).

- "An Analysis of the Structure of Saturn's Magnetic Field Using Charged Particle Absorption Signatures," D. L. Chenette and L. Davis, Jr., Talk given at Tucson Saturn Conference, 1982, Tucson, Arizona.

- "The Companions of Mimas: Charged Particle Absorption Signatures and a Comparison with Recent Imaging Discoveries.," D. L. Chenette et

al., Talk given at Tucson Saturn Conference, 1982, Tucson, Arizona.

• "Voyager Observations of Saturn's Rings: An Overview," E. C. Stone, Invited talk given at I.A.U, Colloquium No. 75, 1982, Toulouse, France.

• "Voyager Observations of the Uranian Rings: A Preview," E. C. Stone, Invited talk given at I.A.U., Colloquim No. 75, 1982, Toulouse, France.

1.2.3. A Heavy Isotope Spectrometer Telescope (HIST) Launched on ISEE-3 in August 1978

HIST is designed to measure the isotope abundances and energy spectra of solar and galactic cosmic rays for all elements from lithium to nickel ($3 \leq Z \leq 28$) over an energy range from several MeV/nucleon to several hundred MeV/nucleon. Such measurements are of importance to the study of the isotopic constitution of solar matter and of cosmic ray sources, the study of nucleosynthesis, questions of solar-system origin, studies of acceleration processes and studies of the life history of cosmic rays in the galaxy.

HIST was successfully launched on ISEE-3 and provided high resolution measurements of solar and galactic cosmic ray isotopes until December 1978, when a component failure reduced its isotope resolution capability. Since that time, the instrument has been operating as an element spectrometer for solar flare and interplanetary particle studies.

During the past six months J. D. Spalding completed his Ph.D. thesis on the isotopic composition of heavy nuclei observed during the 9/23/78 solar flare.

This study, and our work on galactic cosmic ray isotopes, has resulted in the following recent talks and papers.

• "Isotopic Studies of Heavy Nuclei in the 9/23/78 Solar Flare Event," R. A. Mewaldt et al., *Bull. Am. Phys. Soc.* **27**, 571 (1982).

• "Samples of the Milky Way," R. A. Mewaldt et al., *Scientific American* **247**, 100-109 (1982).

• "Isotopic Anomalies in Galactic Cosmic Rays," R. A. Mewaldt, *Bull. Am. Astron. Soc.* **14**, 645 (1982).

• "The Elemental and Isotopic Composition of Galactic Cosmic Ray Nuclei," R. A. Mewaldt, *Rev. Geophys. Space Phys.* (1982 in press).

• "The Isotopic Composition of Energetic Particles Emitted from a Large Solar Flare," J. D. Spalding, Ph.D Thesis, California Institute of Technology (1982).

1.2.4. A Heavy Nuclei Experiment (HNE) Launched on HEAO-C in September 1979

The Heavy Nuclei Experiment is a joint experiment involving this group and M. H. Israel, J. Klarmann, W. R. Binns (Washington University) and C. J. Waddington (University of Minnesota). HNE is designed to measure the elemental abundances of relativistic high-Z cosmic ray nuclei ($17 \leq Z \leq 130$). The results of such measurements are of significance to the studies of nucleosynthesis and stellar structures, the existence of extreme transuranic nuclei, the origin of cosmic rays, and the physical properties of the interstellar medium. HNE was successfully launched on HEAO-3 and operated until gyro failure in late May 1981.

A paper dealing with the ratio of the s-process elements $_{50}$Sn and $_{56}$Ba to the r-process elements $_{52}$Te and $_{54}$Xe is ready for submission. This paper will show that this charge region, like the 30-42 region and the actinides, is not dominated by r-process nuclei. A more detailed analysis of this result will be the topic of a doctoral thesis by K. E. Krombel.

Preparations for a calibration of the HEAO HNE DVU (development unit) at the Lawrence Berkeley Lab Bevelac have been largely completed. The SRL will furnish its PACE data acquisition system to the collaborative effort. The SRL will also take the lead in analysis of the data after the calibration, as it has with flight data.

The following talks and papers have been presented recently:

- "The Abundance of the Actinides in the Cosmic Radiation as Measured on HEAO-3," W. R. Binns et al., *Ap. J. (Lett.)* **261**, L117-L120 (1982).

- "Abundances of Cosmic Ray Sn, Te, Xe, and Ba Nuclei," E. C. Stone et al., *Bull. Am. Phys. Soc.* **27**, 534 (1982).

- "The Abundance of the Actinides in the Cosmic Radiation as Measured on HEAO-3," C. J. Waddington et al., *Bull. Am. Phys. Soc.* **27**, 534 (1982).

- "Secondary/Primary Ratios in Ultraheavy Cosmic Rays Measured on HEAO-3," W. R. Binns et al., *Bull. Am. Phys. Soc.* **27**, 534 (1982).

1.2.5. A Magnetometer Experiment on Pioneer 11

The Pioneer 11 Vector Helium Magnetometer Experiment is a joint investigation involving several research centers, with E. J. Smith (JPL) as Principal Investigator. Leverett Davis, Jr. (SRL) is the Caltech Co-Investigator on the experiment. A careful reanalysis of the magnetometer data inside 8 Saturn radii shows that the field is predominantly axisymmetric and that the dipole, quadrupole, and octupole terms are required for its accurate description. Non-axial dipole terms are definitely present but they are very small and may be ignored for most purposes.

2. Gamma Rays

This research program is directed toward the investigation of galactic and solar gamma rays with spectrometers of high resolution in both energy and angle carried on spacecraft and balloons. The main efforts of the group, which are supported partially or fully by this grant, have been directed toward the following two categories of experiments.

2.1. Activities in Support of or in Preparation for Spacecraft Experiments

These activities generally embrace prototypes of experiments on existing or future NASA spacecraft and they complement and/or support such observations.

2.1.1. Gamma-Ray Imaging Program

The development of gamma-ray detectors with high angular resolution and imaging capability is being vigorously pursued. During the time period of this report the initial laboratory simulation of coded aperture systems, which had begun early in 1982, was completed, hardware development was begun on an imaging NaI gamma-ray telescope for balloon exposure, and plans were formulated and proposed for a joint effort with the Jet Propulsion Laboratory in high resolution imaging gamma-ray astronomy.

a) Laboratory tests of coded-aperture imaging

To test coded-aperture imaging using the hexagonal uniformly redundant arrays developed in our laboratory, we employed a 12" diameter, 1/2" thick NaI plate configured as an Anger camera with nineteen 2" photomultiplier tubes. A resolution of 4.5 mm FWHM was obtained with a beam of 122 keV ($_{57}$Co) gamma-rays.

The tests confirmed our predictions of the capabilities of coded aperture imaging and verified our analytic and Monte Carlo calculations of detector and mask performance. This gives us confidence in extrapolating our calculations to other detector/mask configurations such as those to be employed in the imaging gamma-ray telescope balloon experiment described below. Specifically, the laboratory tests demonstrated the following capabilities: imaging with a stationary hexagonal uniformly redundant array mask, imaging with a rotating mask, imaging of a field of view with multiple point sources, detection and localization of sources in a low signal-to-noise condition, and imaging of a weak point source in the presence of a strong point source.

b) Hardware development for an imaging gamma-ray telescope balloon experiment

Building on the experience gained in the laboratory simulations of coded aperture imaging, we have begun hardware implementation of an imaging gamma-ray telescope for balloon exposures. This instrument will use as its primary sensor a 16" diameter, 2" thick NaI crystal operated as an Anger camera viewed by nineteen 3" photomultiplier tubes. It will be surrounded by a shield consisting of a second identical NaI plate directly behind the primary NaI detector and 12 plastic scintillator modules sur-

rounding the primary detector on the sides.

During the period covered in this report the dimensions of the two NaI detectors were fixed and the Anger camera with its complement of photomultiplier tubes was designed and procured. Design work was also initiated on the plastic scintillator shield and the signal processing electronics for the NaI detectors. Ground support electronics configured around a central PDP 11/24 processor were designed and procured during this period using CIT funds. Our goal is to have a functioning shield, detector, and signal processing system early in the second quarter of 1983.

c) High resolution gamma-ray imaging program

For the purpose of developing gamma-ray telescopes with both high angular and energy resolution, we have joined with the High Energy Astrophysics Group of the Jet Propulsion Laboratory to propose a program in high resolution gamma-ray spectroscopy. This program will be evolutionary in nature, leading to the development of an imaging gamma-ray telescope employing segmented, position sensitive Ge detectors and a hexagonal coded aperture mask. The program was proposed to NASA OSSA in August 1982.

2.1.2. Detector Technology Investigation

In addition to our laboratory studies of NaI Anger camera detectors, we also completed an initial study of mercuric iodide (HgI_2) detectors using two dimensional pulse processing techniques. Significant progress was made in enhancing the energy resolution of HgI_2 devices. Typical reductions of a factor of 3-5 in FWHM resolution were achieved at 662 keV. A best case resolution of 4% FWHM was obtained at this energy, which is better than that of a typical NaI detector (7-8%). There remain however barriers to further improvement in energy resolution for these devices as well as limits to the effective useful thickness. The HgI_2 studies were carried out under the JPL Director's Discretionary Fund in collaboration with JPL and EG&G of Santa Barbara.

2.2. Experiments on NASA Spacecraft

2.2.1. HEAO C-1 Gamma-Ray Spectrometer

During the time period covered in this report, work was completed on a data analysis project involving data from the HEAO C-1 experiment carried out under the HEAO Guest Investigator Program. This project involved a search for gamma-ray lines from the Virgo Cluster of galaxies, in particular the lines at 0.847 and 1.238 MeV resulting from the decay chain of Ni^{56} to Fe^{56} via Co^{56}. Such emission is thought to occur in Type I supernova ejecta at early times. As part of this investigation, a new analysis method for HEAO C-1 data was investigated which involved the use of coincident events in multiple detectors to increase the signal to noise ratio of the sample of data for energies near 1 MeV. No significant emission was found and a 3 σ upper limit of 6×10^{-4} ph/cm2 s was placed on a 0.847 MeV line having a width less than or equal to 25 keV. The HEAO analysis work was carried out in collaboration with the High Energy Astrophysics group at the Jet Propulsion Laboratory

under the direction of Allan Jacobson, Principal Investigator on the HEAO C-1 experiment.

2.2.2. Solar Maximum Mission Spacecraft

The Solar Maximum Mission (SMM) spacecraft was launched in March 1980 to observe the sun at a variety of wavelengths. On board was a gamma-ray spectrometer employing seven NaI detectors to measure the gamma-ray spectra of solar flares from 0.3 to 100 MeV and to detect solar energetic neutrons. The principal investigator on the experiment is Prof. Edward Chupp of the University of New Hampshire.

Following up earlier work by our group on 2.22 MeV emission from neutron capture on hydrogen in solar flares as observed by the HEAO C-1 spacecraft, a collaborative effort was undertaken with the University of New Hampshire to study in detail the 2.22 MeV emission from a number of flares observed by the SMM spacecraft during the period 1980-1982. Of particular interest was an extremely intense solar flare on 3 June 1982 which yielded over 10^4 2.22 MeV line photons and provided a statistically well defined time history extending over more than 1000 seconds. Preliminary results indicate that the decay time of 2.22 MeV emission is consistent with a value of 100 seconds. Work is continuing on the 3 June 1982 flare and a number of other solar gamma-ray flares.

3. Other Activities

A. Buffington is serving as chairman of the APS Division of Cosmic Physics.

E. C. Stone continues to serve as NASA's Project Scientist for the Voyager Mission. He is also a member of the Space Science Board, of the High Energy Astrophysics Management Operations Working Group, and of the Cosmic Ray Program Working Group. He is currently a member of the Division for Planetary Sciences Committee of the American Astronomical Society.

T. A. Prince has been awarded Caltech's R. A. Millikan Fellowship for the two-year period 1981 and 1982.

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