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SEMI-ANNUAL STATUS REPORT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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"RESEARCH IN PARTICLES AND FIELDS"

for

1 October 1973 - 31 March 1974

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Coinvestigators

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SEMI-ANNUAL STATUS REPORT

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The present report covers the research activities in Cosmic Rays and Theory of Particles and Fields in Space supported under NASA Grant NGR 05-002-160.*

The report is divided into sections which describe the various activities, followed by a bibliography.

I. Cosmic Rays (Vogt, Stone and Mewaldt)

This group's research program is directed toward the investigation of the astrophysical aspects of cosmic radiation and of the radiation environment of the Earth by means of particle-detector systems flown 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.

A. EXPERIMENTS ON NASA SPACECRAFT

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 differential energy spectrum of electrons (0.18 to 2.8 MeV) and the differential energy spectra of the nuclear isotopes of hydrogen, helium, lithium, and beryllium (0.5 to ~ 50 MeV/nucleon). This experiment will allow studies of solar and galactic cosmic rays and of magnetospheric acceleration of charged particles and the interrelation of those particles to the particles trapped in and precipitated from the magnetosphere.

* The NASA Technical Officer for this grant is Dr. A. G. Opp, NASA HQ., Physics and Astronomy Programs.

Both the IMP-7 and IMP-8 instruments are completely functional, providing simultaneous measurements at two well separated locations. This combination of measurements should be particularly useful in the separation of spatial and temporal effects in studies of the interplanetary propagation of solar flare particles, in studies of the access of solar flare particles into the magnetotail, and in studies of local acceleration processes in the magnetotail.

Results from two IMP-7 studies were presented at the Tucson meeting of the APS Cosmic Physics Division in December 1973. One of the topics, the observation of the isotopes of H and He in solar cosmic rays, will be the basis of G. J. Hurford's doctoral dissertation. At Tucson, a preliminary report was made of the continued observation of "^{3}He-rich" solar particle events which had no corresponding enrichment in the deuterium or tritium fluxes. One such flare occurred on 14 February 1973 with a ^{3}He/^{4}He ratio of 0.21. This ratio is comparable to the ratio observed with the Caltech OGO-6 experiment during the 14 October 1969 and the 24 November 1969 events.

These results have stimulated theoretical calculations by several other groups in an effort to understand the nuclear interaction and solar acceleration processes which could be responsible for the "^{3}He-rich" events.

The other Tucson report was of observations of low energy H and He nuclei during solar quiet times. The observations were made in the 1.3 to 40 MeV/nucleon interval during several selected quiet periods from October, 1972, through March, 1973. The observed intensitites are lower than previously reported quiet time spectra by other observers in this energy region. No evidence was found for a low energy turnup in the He spectrum down to 2.4 MeV/nucleon, the lowest energy for which the sensor has two parameter particle identification. Although the minimum intensities observed below 2.4 MeV/nucleon exceed those at higher energy, it was not possible at that time to accurately estimate the contribution of instrumental background to the counting rates. However, the periods of minimum H and He intensity below 2.4 MeV/nucleon did not coincide, and the relative abundance of H and He was found to vary from period to period, with H/He ratios from $\lesssim 3$ to $\gtrsim 10$. These results should be contrasted to those reported by Simpson and Tuzzolino (Ap. J. Letters, 185, L 149, 1973) which indicated a constant H/He ratio of 5.0 ± 0.5. An understanding of the origin of this low energy component will be significantly influenced by a more extensive analysis of the variations in the H/He abundance ratio.

A paper, "The Energy Spectrum of 0.16 to 2 MeV Electrons During Solar Quiet Times" has been accepted for publication in the Astrophysical Journal.

2. A Heavy Nuclei Experiment (HNE) to be Launched on HEAO-C in 1979.

The Heavy Nuclei Experiment (HNE) is a joint experiment involving this group and M. H. Israel, J. Klarmann (Washington Univ.), W. R. Binns (McDonnell-Douglas), and C. J. Waddington (Univ. 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 interestellar medium.

Through December, 1973, the HNE Team, supported by Ball Brothers Research Corporation, continued studies of various experiment configurations as part of the spacecraft and payload compatibility evaluation which MSFC prepared for presentation to NASA HQ in late December, 1973.

In February, 1974, HNE was selected by NASA for the restructured HEAO-C mission. Preparation was initiated for a program review at MSFC in May, 1974.

3. An Interstellar Cosmic Ray and Planetary Magnetospheres Experiment for the Mariner-Jupiter-Saturn (MJS) Missions.

This experiment has been proposed jointly by this group and F. B. McDonald, B. J. Teegarden, and J. H. Trainor (Goddard Space Flight Cener) and W. R. Webber (University of New Hampshire) and was selected as the Cosmic Ray Subsystem (CRS) for the MJS77 missions. The experiment is designed to measure the energy spectra, elemental and isotopic composition, and streaming patterns of galactic cosmic-ray nuclei from H to Fe over an energy range of 500 keV to 500 MeV/nucleon, and the energy spectra of electrons from 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 Jupiter and (possibly) Saturn will be used to study their origin and relationship to other physical phenomena and parameters of these planets. Measurements of the intensity and directional characteristics of solar and galactic energetic particles as a function of heliocentric distance will be used for in situ studies of the interplanetary medium and its boundary with the interstellar medium.

The definition phase of the experiment has been completed and NASA Headquarters has confirmed its selection as the Cosmic Ray Subsystem (CRS) for the MJS77 missions. The CRS complement of detectors now includes TET, an electron telescope developed under this grant.

The CRS hardware phase has begun, and the major hardware/component subcontracts have been negotiated.

4. A Heavy Isotope Spectrometer Telescope (HIST) to be Flown on ISEE-C (Heliocentric).

HIST is designed to measure the isotopic 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.

The ISEE-C program is presently in the mission definition phase. Flight hardware work is scheduled to begin in FY 76, with launch planned for 1978.

This group's present activities for ISEE-C are exclusively supported by this grant.

B. ACTIVITIES IN SUPPORT OF OR IN PREPARATION OF SPACECRAFT EXPERIMENTS

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

1. The Positron-Negatron (e±) Experiment.

The e± instrument is a balloon-borne magnetic spectrometer for the investigation of the energy spectra of cosmic-ray negatrons and positrons in the momentum range of about 10 to 1000 MeV/c. Yearly observations of the long-term variations of electron spectra were performed between 1968 and 1971 with balloon-flights under the Skyhook program at Fort Churchill, Canada.

Further observations were scheduled for the 1973 Fort Churchill Skyhook program. The instrument was launched on 15 July 1973 and both it and the balloon performed well. However, the balloon control instrumentation used by the NASA/ONR flight contractor failed and the flight could not be terminated in the parachute release of the gondola. The balloon, with the suspended Caltech/contractor payload, went out of control and continued its westerly drift (altitude ~ 150,000 ft.) beyond the continental limits of North America into Siberia/USSR. According to representatives of INTER COSMOS, the flight terminated - in an undetermined fashion - near Yakutsk, Siberia (according to Caltech's analysis, on 20 July 1973), and pieces of the heavily damaged flight train were brought to Moscow where they were inspected by a Caltech representative.

The Caltech e± spectrometer gondola plus several flight barographs were totally destroyed. With it, the ongoing Caltech e± research program was terminally crippled. No funds are available to rebuild the spectrometer.

Post flight analysis clearly shows that this loss occurred due to technical and operational deficiencies in the NASA/ONR operated Skyhook program. It is particularly regrettable that a simple safety device for emergency termination of an out of control flight, allegedly for reasons of "economy", carried ordinary dry cells, whose operational temperature range was totally inadequate for typical environmental conditions, instead of the recommended Nicad devices. Thus, "savings" of a few dollars led to the irreplacable loss of an instrument worth several hundred thousand dollars and the termination of a productive and vigorous research project.

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

HEIST is a balloon-borne detector system designed to provide high-resolution isotopic measurements for cosmic ray nuclei with $3 \leq Z \leq 28$ in the energy interval $60 \leq E \leq 700$ MeV/nucleon, complementing the measurements which this group has been selected to make with the HIST instrument on ISEE-C.

Three parallel development activities have been pursued. As described below, these activities have concentrated on the multiwire proportional chamber, the CsI scintillators, and the position-determining electronics.

A small scale version of a multiwire proportional chamber has been designed and fabricated. This small chamber has been used to study the gas gain characteristics of a variety of filling gasses. In addition, a delay line has been contructed and coupled to the cathode wires of the counter so that the signal output characteristics of the delay line could be determined for actual particle signals in the proportional chamber.

A full scale version of one of the CsI scintillators was purchased and a variety of development tests have been completed. The scintillator has been coupled to a single photomultiplier through light integration boxes of several different geometries in order to measure both the signal amplitude and the signal uniformity for each configuration. As a result of these tests, it now appears feasible to eliminate the large light integration boxes which were originally envisaged. This makes possible a much more compact design for the crystal stack, yielding an increase in the geometrical factor of up to a factor of four.

The readout of the multiwire proportional chamber requires the development of special electronic circuitry. In particular, the position of an event in the chamber is determined by measuring the time difference in the arrival of the signal at the two ends of the delay line which is coupled to the chamber. This time difference must be measured to $\Delta t \sim 2$ ns in order to obtain the desired spatial resolution. The flight electronics to accomplish this measurement has been designed and breadboarded. The circuits are undergoing extensive testing prior to fabrication of the flight versions.

3. Other Activities.

E. C. Stone is serving as NASA's Project Scientist for the MJS77 Mariner Jupiter Saturn missions. He wrote the rapporteur paper "Cosmic Ray Isotopes" for the 13th International Cosmic Ray Conference, Denver, Colorado.

R. E. Vogt has been appointed to NASA's Physical Sciences Committee (PSC). He is presently also serving on NASA's Mariner Jupiter Uranus Science Advisory Committee (MJUSAC).

II. Theory of Particles and Fields in Space (Davis and Jokipii)

The research program of this group is directed toward investigations of the interplanetary medium, planetary magnetic fields, the cosmic ray interactions with the interplanetary and interstellar medium, radio-scintillation theory, and related problems.

A. PIONEER 10 ENCOUNTER WITH JUPITER

1. A rapid analysis of the quick look data in collaboration with E. J. Smith of JPL and D. E. Jones at Brigham Young University gave a fit of the magnetometer observations to an eccentric dipole source whose parameters were published in the 25 January, 1974 issue of Science. This gave a fair fit over the trajectory from 6 R_J (Jupiter radii) inbound to periapsis at 2.84 R_J and then outbound to 6 R_J. After further refinement of the input data including correction for the roll attitude of the spacecraft, a second least squares fit was made that has considerably smaller residuals inside 5 R_J and that is useable out to about 10 R_J. The characteristics of the two models are given in Table 1.

Table 1

Eccentric Dipole Sources of the Jovian Magnetic Field

Components are given in a right-hand XYZ coordinate system whose Z-axis is northward along the rotation axis and whose X-axis is at zero longitude in System III. Longitudes are given in System III, in which longitudes increase from the X-axis toward the minus Y-axis.

	Preliminary Model (D_1)	Improved Model (D_2)
Dipole Moment		
M_X	-0.630 Gauss R_J^3	-0.547 Gauss R_J^3
M_Y	0.781	0.494
M_Z	3.826	3.932
$\lvert M \rvert$	3.955	4.000
Tilt from Z-axis	14.°7	10.°6
System III Longitude	231°	222°
Dipole Location		
X	-0.19 R_J	-0.105 R_J
Y	-0.04	-0.008
Z	0.12	0.030
Distance from center	0.228	0.110
Latitude	31.°7	15.°9
System III Longitude	168°	176°
Square root of mean residual	0.153 Gauss R_J^3	0.085 Gauss R_J^3

The procedures for describing the data by means of a spherical harmonic analysis have been developed and yield results reasonably consistent with the D_2 model. Exploration is still in progress to determine the most appropriate range of data to use for the evaluation of the spherical harmonic coefficients.

2. In collaboration with E. J. Smith of JPL, the Pioneer 10 magnetometer data have been examined for clues as to the structure of Jupiter's outer magnetosphere. There is no doubt that it is very soft, the field strength changing relatively slowly with radius. Hence moderate changes in solar wind momentum density can lead to large changes in the position of the magnetopause and bow shock. The field lines inside the magnetopause in the regions at 10^h and 5^h local time appear to be directed mainly southward across the equator, implying that the field lines are closed in these regions and have the general topology of dipole field lines. Over much of the Pioneer 10 trajectory inside the magnetosphere the radial component of $\mathbf{B}$ is larger than expected on the dipole model. This observation is consistent with an outward stretching of the dipole field line loops by centrifugal effects in corotating plasma near the equatorial plane.

B. COSMIC RAY DIFFUSION

Jokipii continued his work on the fundamental theory of charged particle scattering by an irregular magnetic field. He has been able to show that, for reasonable types of fluctuations, the large non-resonant terms found by other workers have a simple explanation and disappear if the proper variables are used. In particular, if the pitch angle cosine $\mu = \mathbf{w}\cdot\mathbf{B}/wB$ relative to the local magnetic field is used, the usual Fokker-Planck, resonant expressions arise. Previous work was in terms of $\mu_A = \mathbf{w}\cdot\mathbf{B}_0/wB_o$, the pitch angle relative to the average magnetic field $\mathbf{B}_o$. Corrections to the Fokker-Planck formalism must come from terms of higher order in the fluctuating field. This work helps to clarify the applicability of the Fokker-Planck formalism. This work has been submitted for publication in the Astrophysical Journal.

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