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SPACE RADIATION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY
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ANNUAL STATUS REPORT

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Grant NGR 05-002-160*
"RESEARCH IN COSMIC AND GAMMA RAY ASTROPHYSICS"

for

1 April 1988 - 31 March 1989

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R. A. Mewaldt, Coinvestigator
T. A. Prince, Coinvestigator

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Space Radiation Laboratory (SRL)
California Institute of Technology

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This report covers the research activities in Cosmic Rays, Gamma Rays, and Astrophysical Plasmas supported under NASA Grant NGR 05-002-160 at Caltech's Space Radiation Laboratory (SRL). 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 rays and gamma rays 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 Ray Astrophysics

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)

Over the past few years we have been developing a balloon-borne High Energy Isotope Spectrometer Telescope (HEIST) designed to make high resolution measurements of isotopes in the element range from H to Ni ($1 \leq Z \leq 28$) at energies from ~0.4 to 2.0 GeV/nucleon. The instrument, which is a collaborative effort with the Danish Space Research Institute and the University of New Hampshire, consists of a stack of 12 NaI(Tl) scintillators of total thickness 88 g/cm^2, two Cherenkov counters (C1 and C2), and two plastic scintillators. HEIST 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, and is designed to

achieve a typical mass resolution of 0.25 amu.

The energy range covered by HEIST can be "tuned" by choice of the index of refraction (n) of the two Cherenkov counters. In its initial configuration (HEIST-1), flown in 1984, the top counter (C1) was composed of aerogel (n=1.10), giving an energy range of ~1.5 to 2 GeV/nucleon. Recent results from this flight are described below. In its present configuration (HEIST-2) C1 is composed of Teflon (n = 1.33) and C2 is Pilot 425 (n = 1.50) and the instrument is capable of resolving isotopes from Be to Ni over the energy range from ~0.4 to ~1.1 GeV/nucleon, with both improved mass resolution and yield over the initial version of the instrument.

HEIST-2 was readied for balloon flight during the summer of 1986 and was launched from Ainsworth, Nebraska on September 7, 1986. Although the instrument was working well following launch, the balloon burst during ascent at ~70,000 feet, and the instrument suffered some damage on landing. A planned reflight of the instrument during 1987 had to be delayed because of the Australian balloon flights by our GRIP gamma ray experiment to image supernova 1987A, and we began working towards a flight of HEIST-2 from Canada during the summer of 1988.

During November of 1987 the two Cherenkov counters for HEIST-2 were calibrated at the Lawrence Berkeley Laboratory Bevalac in beams of N, Ne, Ar, and Fe nuclei. In particular, the response of the 16 individual photomultiplier tubes (PMTs) of both counters was "mapped" with 1700 MeV/nuc Fe nuclei, and the energy response of the counters was calibrated over the range from ~100 to ~1700 MeV/nuc with several different ions. During this Bevalac calibration we also investigated the response of several new test samples of aerogel with indices of refraction from 1.08 to 1.15 supplied by Ib Rasmussen of the DSRI. Among the properties that were tested were the overall light yield, the self-absorption of Cherenkov light, the uniformity of the index of refraction, and the amount of light produced by particles below the Cherenkov threshold. Figure 1 shows an example of the use of Bevalac data to map the index of refraction of an aerogel block in two separated locations. We have hired a Caltech undergraduate to help with the analysis of these data during the coming summer.
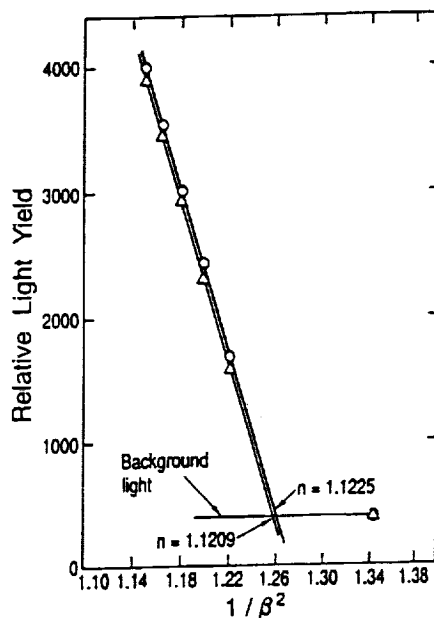

Figure 1: Use of Bevalac data to measure index of refraction variations in aerogel.

The refurbishment of HEIST-2 was completed during the spring of 1988. After several months of testing and calibration, the instrument was transported to Prince Albert, Saskatchewan, where it was launched on August 25, 1988. Following a flight that included more than 34 hours at float at an average altitude of ~118,000 feet, the instrument landed near Calgary. Unfortunately, the instrument was pulled on its side during the landing and some damage was suffered, including puncture of the pressure vessel, and loss of six photomultipliers (PMTs) and light-pipes associated with the top scintillator. In addition, subsequent laboratory testing with cosmic ray muons indicates an anomalous signal from one of the NaI layers. This latter problem is still under investigation.

During the flight the instruments apparently operated perfectly and more than 6×10^5 heavy nuclei were recorded. Analysis of these data is now underway by graduate student Stinson Gibner, and it appears that ~99% of the events are recoverable.

In preparation for computing trajectories and energy-losses for individual events Gibner has completed the production of new maps for the NaI layers that have resulted in improved energy-loss resolution. An example of such a map is shown in Figure 2. Employing these new maps the total-energy (sum of NaI layers) resolution for 1.75 GeV/nuc nuclei from the Bevalac has been reduced from ~0.7% to ~0.5%, when compared to that achieved with the old maps. Corresponding improvement is also expected in the position and trajectory resolution derived from the new maps.
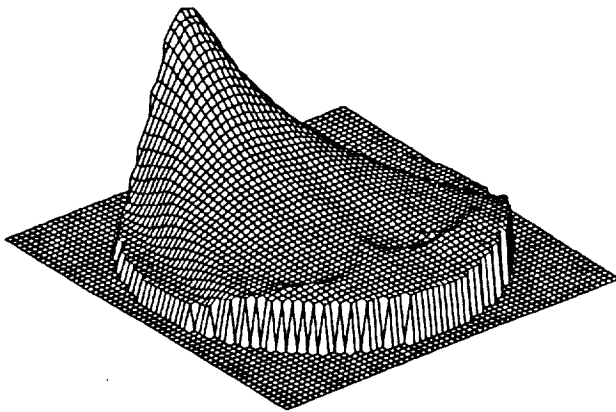
Figure 2: Response map for 1 of 6 PMTs viewing the first NaI layer in HEIST.

Once the NaI and Cherenkov maps have been applied to the flight data, Gibner will begin analyzing flight data on C and N isotopes in order to: 1) measure the interesting $^{13}C/^{12}C$ ratio in cosmic rays source material and search for possible galactic evolution effects, and 2) extend direct measurements of the $^{15}N/^{14}N$ ratio to higher energies in an effort to gain improved measurements of the depletion of ^{14}N in cosmic ray sources.

Our work on the 1984 flight of HEIST-1 has resulted in the following Ph.D. thesis:

● "A Balloon Measurement of the Isotopic Composition of Galactic Cosmic Ray Iron", Grove, J. E., PhD. Thesis, California Institute of Technology (1989).

We have also submitted three papers to the XXI International Cosmic Ray Conference in Adelaide:

"A Measurement of the Isotopic Composition of Cosmic-Ray Iron"

"The ^{54}Mn Clock and its Implications for Cosmic Ray Propagation and Fe Isotope Studies"

"Contribution to Cherenkov Resolution from Knock-on Electrons"

In addition, the following paper recently appeared in *Interplanetary Particle Environment*, which contains the proceedings of a conference held at JPL in March 1987 (JPL Publication 88-28).

"Toward a Descriptive Model of Galactic Cosmic Rays in the Heliosphere", R. A. Mewaldt et al.

A brief summary of the results presented in J. E. Grove's Ph.D. thesis follows.

A Balloon Measurement of the Isotopic Composition of Galactic Cosmic Ray Iron

The isotopic composition of galactic cosmic ray iron nuclei has been measured in the energy interval from ~1550 to 2200 MeV/nucleon. The measurements were made with a balloon-borne High Energy Isotope Spectrometer Telescope (HEIST) flown from Palestine, Texas in May 1984 for >35 hours at an average atmospheric depth of ~ 6 g/cm^2. This flight represented the first attempt to measure directly the isotopic composition of heavy cosmic rays at energies >1 GeV/nuc.

The masses of Fe nuclei that stopped in the HEIST-1 detector stack were derived by the Cherenkov-Energy technique. The Cherenkov counter contained a silica aerogel radiator with an index of refraction of n=1.1, which measured the velocity on incident nuclei with energies above /(ap1.5 GeV/nucleon. The total kinetic energy of stopping nuclei was measured in a stack of 12 NaI(Tl) scintillators, which also measured particle trajectories. Figure 3 shows a mass histogram of Fe nuclei that stopped in layers 5 to 12 of the NaI stack. Table 1 summarizes the ^{54}Fe/^{56}Fe and ^{58}Fe/^{56}Fe ratios obtained from a maximum likelihood fit to the data in Figure 3, as well as the resulting cosmic ray source abundances. The ensemble of the available data from this flight at high energies, and earlier measurements at lower energies, is consistent with the so-called "solar system" composition of Fe, although the uncertainties are still large enough that the predictions of models for the origin of cosmic rays, including the supermetallicity and Wolf-Rayet models, are not yet directly tested.

The observed mass resolution in Figure 3, as determined from a least squares fit to the data, is 0.67±0.17 amu, somewhat worse than the value of 0.52±0.01 amu obtained in a calibration of this instrument with ^{55}Mn at the Bevalac. A detailed analysis has shown that the principal contributions to the mass resolution during this flight were due to photoelectron statistics, mapping uncertainties, and block-to-block normalization in the mosaic of aerogel radiators. A major cause of the reduced resolution due to photoelectron statistics was the degradation of aerogel Cherenkov light that occurred between the Bevalac calibration and the flight - likely the result of contamination by evaporate from the high-reflectance BaSO$_4$ paint that was used. New high-reflectance coatings that can replace this paint are now under development. The
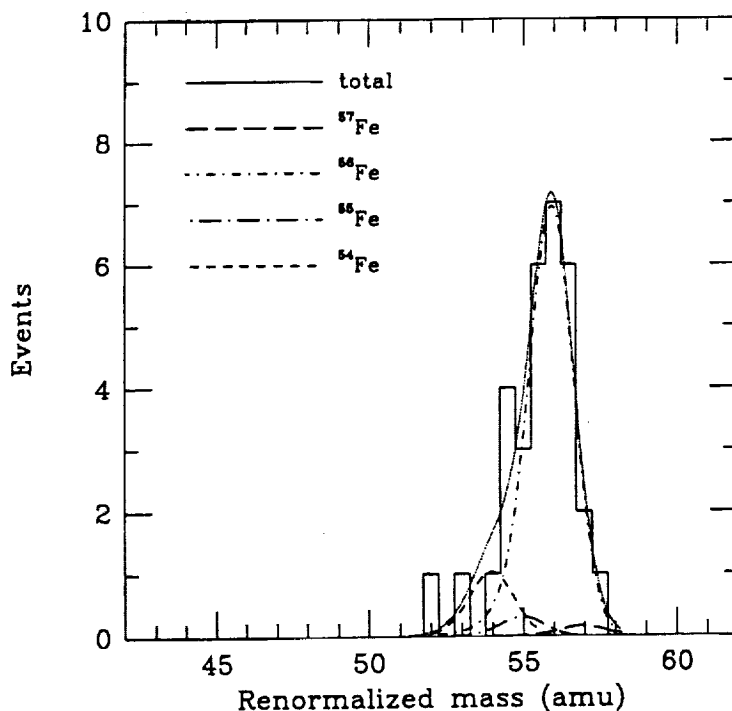
Figure 3: Mass histogram of Fe isotopes from the 1984 flight of HEIST.

Table 1: Fe abundance ratios ~1550-2200 MeV/nucleon		
Ratio	Top of Atmosphere	GCRS
$^{54}Fe/^{56}Fe$	$0.14^{+0.18}_{-0.11}$	$0.12^{+0.18}_{-0.11}$
$^{58}Fe/^{56}Fe$	≤ 0.07	≤ 0.07

Table 1

latter two limitations can be addressed by the development of larger area aerogel radiators for use in future instruments of this kind.

1.1.2. The Advanced Composition Explorer (ACE)

In February of 1988 we were selected to conduct a Phase-A study of an Advanced Composition Explorer (ACE), as part of the. Explorer Concept Study Program. This investigation was proposed jointly by this group, and by scientists from Applied Physics Lab/Johns Hopkins University, the University of Bern, the University of Chicago, Goddard Space Flight Center, Los Alamos National Laboratory, the University of Maryland, and the Max-Planck Institut. ACE would make

comprehensive measurements of the elemental and isotopic composition and the charge states of accelerated nuclei with increased sensitivity of several orders of magnitude, and with improved mass and charge resolution. It would observe particles of solar, interplanetary, and galactic origins, spanning the energy range from that of the solar wind ($\sim$ 1 keV/nucleon) to galactic cosmic ray energies (several hundred MeV/nucleon). Definitive studies would be made of the abundance of essentially all isotopes from H to Zn ($1 \leq Z \leq 30$), with exploratory isotope studies extending to Zr ($Z=40$).

The ACE study payload includes five high-resolution spectrometers, each designed to provide the ultimate charge and mass resolution in its particular energy range, and each having a collecting power 1 to 3 orders of magnitude greater than previous or planned experiments. Included in the study would be two spectrometers, a Solar Isotope Spectrometer (SIS), and a Cosmic Ray Isotope Spectrometer (CRIS), for which Caltech would play a leading role. E. C. Stone is the principal Investigator for this phase-A study, which began in May of 1988, with the final report due on July 2, 1989.

The following invited talks about ACE were given during the past year:

● "The Advanced Composition Explorer," Stone, E. C., *Bull. of the Amer. Astron. Soc.* **20**(4), 1077 (1988).

● "Advanced Composition Explorer," Mewaldt, R. A., Invited talk presented at AIAA Convention, Reno, Nevada, January 1989, *Aerospace America*, **26**, B35 (1988).

1.1.3. The Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX)

In March of 1989 we were informed that the Solar, Anomalous, and Magnetospheric Explorer (SAMPEX), on which we are co-investigators, had been selected to be launched into polar orbit as part of the new Small Explorer (SMEX) program. SAMPEX is a collaboration between scientists at the University of Maryland (with G. M. Mason as P. I.), The Aerospace Corporation, Caltech, Goddard, and the Max-Planck Institut, and includes four instruments. Caltech, along with GSFC, will be responsible for furnishing a Mass Spectrometer Telescope (MAST), and a Proton Electron Telescope (PET) originally under construction for the (cancelled) U.S. spacecraft of the International Solar Polar Mission (ISPM). These instruments will make new measurements of the isotopic composition of solar flare and anomalous cosmic rays with greatly improved collecting power, and will measure galactic cosmic ray isotopes and low-energy electrons. Among the unique measurements made possible by SAMPEX's polar orbit are a direct determination of the charge state of the anomalous cosmic ray component, and measurements of precipitating MeV electrons that may affect the atmospheric ozone balance. SAMPEX is scheduled for launch in 1992.

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 in 1972 and on IMP-8 in 1973

These experiments are 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 and interplanetary 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. We have recently been using data from our IMP-8 experiment to investigate the long term temporal history of anomalous oxygen at 1 AU over the years from 1972 to 1988, and we have been continuing our use of IMP data as a 1-AU baseline for collaborative gradient studies with the Pioneer and Voyager spacecraft in the outer heliosphere.

We are now participating in a collaborative proposal to the US/USSR Joint Working Group on Solar Terrestrial Physics. This study would combine data measured by Soviet spacecraft inside the magnetosphere from 1985 to 1988 with simultaneous IMP-8 measurements outside the magnetosphere in an effort to measure the transmission of anomalous oxygen nuclei through the geomagnetic field, and thereby determine whether they are singly-ionized, as predicted by the model of Fisk, Ramaty, and Koslovsky.

Our studies of IMP data were reported in the following recent talk:

● "Large-Scale Spatial Gradients of Anomalous Cosmic Rays," Stone, E. C. et al., *Bull. of Amer. Phys. Soc.* **33**(4), 1069 (1988).

In addition we have submitted four abstracts to the XXI International Cosmic Ray Conference in Adelaide:

"Anomalous Cosmic Ray Measurements in and outside the Magnetosphere -- Implications for the Charge State"

"Large-Scale Radial Gradient of Anomalous Cosmic Ray Oxygen from 1 to ~45 AU"

"Temporal Variations of the Anomalous Cosmic Ray Component over the Solar Cycle"

"A Continued Search for ^{2}H, ^{3}H, and ^{3}He in Large Solar Flares"

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

This experiment is conducted by this group in collaboration with F. B. McDonald and J. H. Trainor (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, in the Voyager 1 and 2 Saturn encounters in November 1980 and August 1981, and in the Voyager 2 Uranus encounter in January 1986. The Voyager data represent an immense and diverse data set, and a number of scientific problems are under analysis. These investigation topics range from the study of galactic cosmic-ray 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, Saturn, and Uranus.

Preparations are now being made for the Voyager 2 encounter with Neptune in August 1989.

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

● "Evidence for Anomalous Cosmic Ray Hydrogen," Christian, E. R. et al., *Ap. J. (Lett.)* **334**, L77 (1988).

● "Elemental Composition of the Anomalous Cosmic Ray Component and Implications for the Local Interstellar Medium," Cummings, A. C. et al., *Bull. of*

Amer. Phys. Soc. **33**(4), 1069 (1988).

● "Large-Scale Spatial Gradients of Anomalous Cosmic Rays," Stone, E. C. et al., *Bull. of Amer. Phys. Soc.* **33**(4), 1069 (1988).

● "Satellite Sweeping of Energetic Electrons in the Magnetosphere of Uranus," Cooper, J. F. and E. C. Stone, Talk presented at URANUS Conf., Pasadena, CA (1988).

● "Radial and Latitudinal Gradients of Anomalous Cosmic Rays," Cummings, A. C. et al., *EOS Trans. AGU* **69**(44), 1362 (1988).

● "Particle and Field Microsignatures at Uranus," Cooper, J. F. et al., *EOS Trans. AGU* **69**(44), 1399 (1988).

● "Solar Abundances as Derived from Solar Energetic Particles," Stone, E. C., *AIP Conf. Proceed. 183, Symp. on Cosmic Abundances of Matter (Minneapolis), C. Jake Waddington, Editor,* 72 (1989).

● "Evidence for Anomalous Cosmic Ray Hydrogen," Christian, E. R., Ph.D. Thesis, California Institute of Technology (1989).

We have also submitted abstracts to the XXI ICRC on the following topics:

"Elemental Composition of the Very Local Interstellar Medium as Deduced from Observations of Anomalous Cosmic Rays"

"Time Variation of Radial and Latitudinal Gradients of Anomalous Cosmic Ray Oxygen in the Outer Heliosphere"

"Large-Scale Radial Gradient of Anomalous Cosmic Ray Oxygen from 1 to ~45 AU"

"Anomalous Cosmic Ray Spectra and Density Gradients Produced by the Solar Wind Termination Shock"

"Re-acceleration of Galactic Cosmic Rays by the Solar Wind Termination Shock"

"Time Variation of Cosmic Ray Spectra and Density Gradients in Solar Cycles of Different IMF Polarity"

In addition, the following paper, based in part on Voyager data, recently appeared in *Interplanetary Particle Environment,* which contains the proceedings of a conference held at JPL in March 1987 (JPL Publication 88-28).

"The Anomalous Cosmic Ray Component", A. C. Cummings and E. C. Stone.

We describe below some of the work on anomalous cosmic ray hydrogen that was completed as part of the recent Ph.D. thesis by E. R. Christian.

Evidence for Anomalous Cosmic-Ray Hydrogen

Anomalous cosmic rays (ACR) are believed to be interstellar neutrals which are ionized near the Sun, convected outward by the solar wind, and accelerated at the termination shock. He, N, O, and Ne have long been known to have an ACR component, while the anomalous cosmic-ray components of argon and carbon are smaller and have only recently been reported.

It has been suggested that hydrogen, which is the most abundant neutral in the interstellar medium and which is easily ionized by photoionization or charge exchange with the solar wind, should also have an ACR component, although no observations have been reported. However, the likely peak energy and shape of an anomalous cosmic-ray hydrogen spectrum may be very similar to the modulated galactic cosmic-ray (GCR) hydrogen spectrum, thus making it difficult to distinguish between the two. We have examined the energy spectra of hydrogen observed near the time of maximum fluxes in 1985 to 1987 from instruments on the Voyager 1 (V1) and Voyager 2 (V2) spacecraft and find changes which represent the first evidence for the existence of anomalous cosmic-ray hydrogen.

All of the spectra in this analysis were obtained in the outer heliosphere ($\geq$ 18 AU) with the Cosmic Ray Subsystem (CRS) on the two Voyager spacecraft. Hydrogen energy spectra for the two time periods 1985/261 - 365 and 1987/209 - 313 are shown for Voyager 1 and Voyager 2 in Figure 4. The spectra have been divided by energy to accentuate the differences in spectral shape. The curves which have been drawn through the two 1985 spectra are also scaled up in flux to match the 1987 spectra at the highest energy and illustrate the change in spectral shape that has occurred between the two periods. The high energy points ($\geq$ 150 MeV) of these spectra are from the analysis of particles which fully penetrate the CRS high-energy telescopes (HETs) and have been corrected for a background which is less than 10% of the observed flux. Since the discussion here depends only on the relative differences between similar spectra, omitting this correction would result in only small quantitative differences in the results. The 10 - 72 MeV fluxes are from the analysis of protons that stop in the telescopes and require no correction.

The major difference between the two time periods in the spectra of Figure 4 is the increase in flux resulting from a decrease in the solar modulation level between 1985 and 1987. Both V1 and V2 spectra show a change in shape, which is more pronounced in V2. As discussed below, we believe that this change is evidence of the appearance of an anomalous hydrogen component during the period of minimum solar modulation.

To obtain an upper estimate for a presumed anomalous hydrogen flux in the 1987 spectra of Voyager 1 and Voyager 2, we subtract estimates of the GCR flux which were determined by normalizing the 1985 spectra to the 1987 spectra at the highest energy (363 MeV), as shown by the dashed lines in Figure 4. This approach might be expected to underestimate the anomalous cosmic-ray hydrogen flux by 10% - 20%, because the 1985 spectra should include an anomalous component which is about 10% - 20% of that in 1987, as is the case for ACR helium as shown in Figure 5. A further underestimate might be expected because there is likely a small anomalous contribution to the 1987 flux at the normalizing energy of 363 MeV. However, this
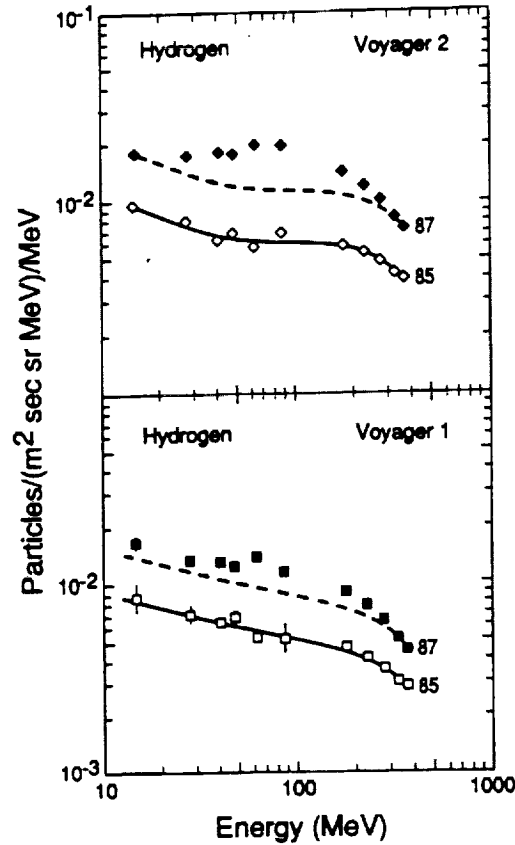
Figure 4: Observed H spectra (divided by energy) for 1985 and 1987.

approach will overestimate the anomalous flux to the extent that some of the change in spectral shape between 1985 and 1987 is due to changes in the spectrum of the modulated GCR flux.

Although modulation theory is not understood well enough to allow accurate calculations of spectra, we can use other observational evidence to estimate modulation induced changes in the spectra. For example, the peaks in the galactic cosmic-ray helium spectra in Figure 5 shifted downward by 21% between 1985 and 1987 on both Voyager 1 and Voyager 2. An energy shift of 21% for the V1 hydrogen spectra also results from a least-squares fit of the 1985 spectrum to that of 1987, assuming there is negligible anomalous flux in the V1 spectra. If it is assumed that there was a similar energy shift in the V2 GCR hydrogen spectra, then an upper estimate of the V2 1987 GCR hydrogen spectrum can be made by shifting the V2 1985 spectrum downward 21% in energy and normalizing it in flux to the V2 1987 spectrum at the highest energy measured. Subtracting this shifted spectrum from the observed V2 1987 hydrogen spectrum results in a lower estimate of the ACR hydrogen flux in Voyager 2. This approach underestimates the V2 anomalous cosmic-ray hydrogen flux in 1987 because it assumes that there was no anomalous contribution to the 1985 spectra and that there was negligible anomalous flux in the V1 1987 spectrum.

Figure 6 shows both this lower estimate and the previously derived upper estimates for the anomalous hydrogen spectra, as well as the observed 1987 energy
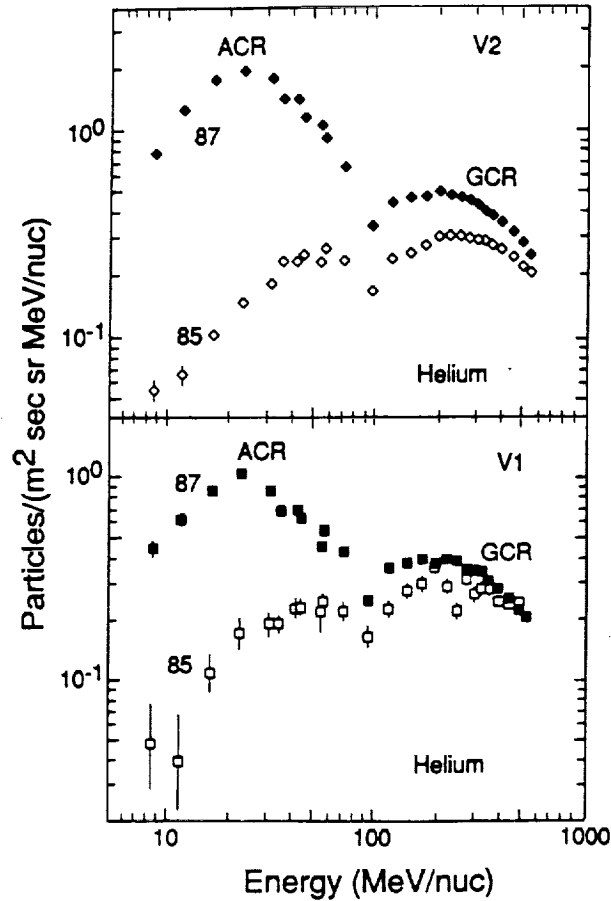
Figure 5: Voyager 1 and 2 He spectra for 1985 and 1987.

spectra. For Voyager 2 we estimate that the ACR hydrogen component is ~ 20% - 40% of the total hydrogen flux at ~ 60 MeV. The shape of the upper estimates of the Voyager 1 and Voyager 2 spectra are essentially the same, with the Voyager 1 fluxes a factor of 2 lower as expected from the large negative latitudinal gradients observed for the other ACR components.

In order to further investigate the possibility that the spectral changes in Figure 4 might be due to a peculiar modulation effect rather than to anomalous cosmic-ray hydrogen, we have examined the spectral shapes of other galactic cosmic-ray nuclei. Because modulation depends on the magnetic rigidity of the particle and hydrogen has only half the mass per charge of heavier nuclei, modulation related features will appear at higher energies in the hydrogen spectrum than in the others. Thus, the maximum GCR hydrogen flux in Figure 6 occurs at ~ 280 MeV, while the maximum GCR helium flux occurs at ~ 210 MeV per nucleon. As a result, if the excess hydrogen flux at 100 MeV was due to modulation, a similar excess would be expected at ~ 75 MeV per nucleon for heavier galactic cosmic-ray nuclei. Carbon is the only sufficiently abundant heavier nucleus that is relatively free of contamination by the anomalous component at this energy.

Figure 7 shows the carbon flux-divided-by-energy spectra for both Voyagers in the time periods 1985/261 - 1986/105 and 1987/105 - 313. The time periods are double
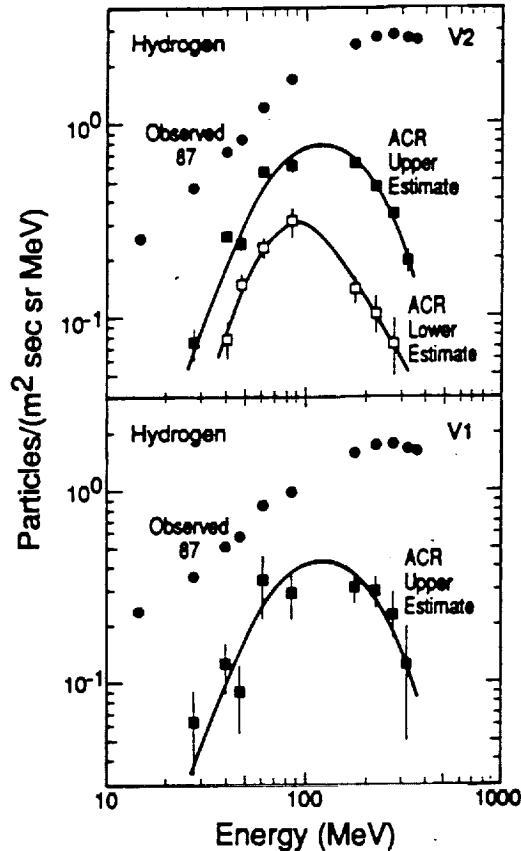
Figure 6: Estimates of anomalous H for 1987.

the length of those for hydrogen to reduce the statistical uncertainty. Averaging over these longer time periods for hydrogen would dilute the observed spectral shape change seen in hydrogen by only 10% - 15%. As in Figure 4, the curves from the 1985/1986 spectra are also scaled up in energy to match the 1987 spectra at the highest energy. Except for an increase in the ACR component at low energies, there is no apparent change in shape at ~ 75 MeV per nucleon between 1985 and 1987. The comparison of Figures 4 and 7 thus suggests that the excess flux in Voyager 2 hydrogen is not solely a result of the modulation of a purely galactic cosmic-ray spectrum.

Assuming that the excess flux is evidence for an anomalous component, we can then use the mean of the upper and lower estimates in Figure 6 as a measure of the anomalous cosmic-ray hydrogen flux at Voyager 2, with an uncertainty that includes both the lower and the upper estimate. When the peak anomalous hydrogen flux of Voyager 2 is compared with the peak V2 anomalous helium flux in Figure 5 we obtain an observed H/He flux ratio of 0.20 ± 0.08. The relative abundances of neutral atoms in the very local interstellar medium (VLISM) can be estimated from the relative ACR peak fluxes. This requires that the observed ACR ratio be corrected for differences in the fraction of H I and He I ionized in the heliosphere and for differences in the acceleration and subsequent modulation of the resulting ions arising from their differing mass per unit charge.
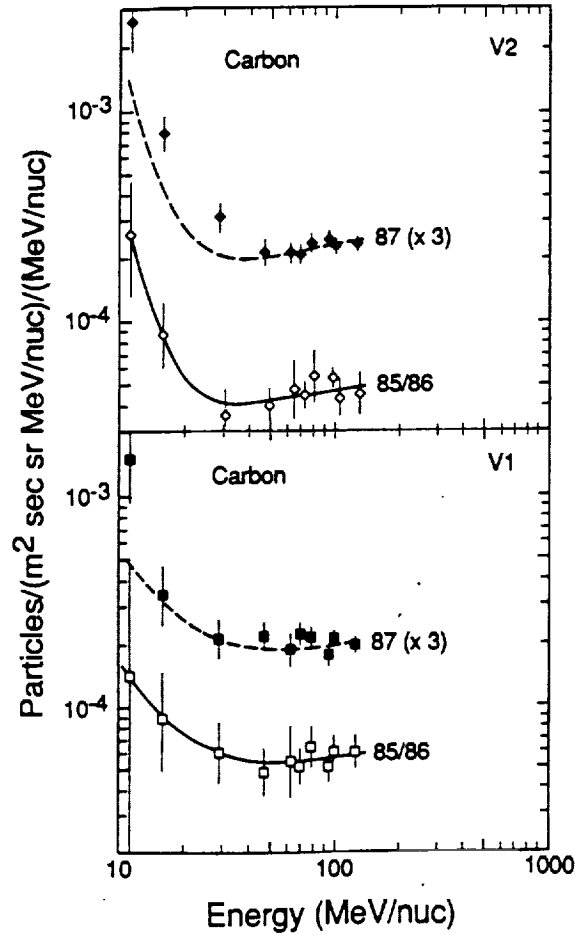
Figure 7: Observed carbon spectra (divided by energy).

In order to correct for the relative ionization fractions, we have used the values for ionization rates determined from the solar ultraviolet backscatter experiment on Prognoz 5 and Prognoz 6, which are $3 \pm 1 \times 10^{-7}$ s^{-1} and $1.25 \pm 0.23 \times 10^{-7}$ s^{-1} for H and He, respectively. The Prognoz 5 and Prognoz 6 measurements were made mainly in 1977 when the solar activity, as indicated by the 10.7 cm solar flux was similar to that during the 1987 time period of the Voyager measurements. When combined with a simple ionization model, these rates give ionization efficiencies of 0.073 ± 0.021 for hydrogen and 0.036 ± 0.006 for helium. Thus the correction factor for the relative ionization efficiencies, F_{ion}, is 0.49 ± 0.16.

Differences in the acceleration and modulation of the ions is more difficult to estimate accurately because of incomplete theoretical understanding. Cummings and Stone (1987 International Cosmic Ray Conf. Proceedings) examine acceleration correction factors for one acceleration model, finding that if equal abundances of hydrogen and helium ions are injected at the same velocity (e.g., the solar wind velocity), the peak fluxes of accelerated and modulated helium would be ~ 37 times that of hydrogen. Although the uncertainty in this value is difficult to assess, it is nevertheless illustrative to use this as the acceleration correction factor, F_{acc}. This results in a H I/He I abundance of 4 ± 2 in the VLISM, as given by

$F_{ion} \times F_{acc} \times (H/He)_{ACR}$, where the indicated uncertainty excludes the unknown uncertainty in F_{acc} and any variation in F_{ion} due to changes in solar activity. This H I/He I ratio is comparable to the ratio of ~7 derived from solar ultraviolet backscatter results. Although there are modeling uncertainties in this estimate of H I/He I, the agreement with previous values suggests that with further theoretical work it may be possible to derive accurate relative abundances of neutrals in the VLISM from observations of the composition of the anomalous cosmic-ray component.

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

Our work on solar flare, interplanetary, and galactic cosmic ray isotopes has resulted in the following recent talks and papers.

● "Solar Abundances as Derived from Solar Energetic Particles," Stone, E. C., *AIP Conf. Proceed. 183, Symp. on Cosmic Abundances of Matter (Minneapolis), C. Jake Waddington, Editor,* 72 (1989).

● "The Abundances of Isotopes in the Cosmic Radiation," Mewaldt, R. A., *AIP Conf. Proceed. 183, Symp. on Cosmic Abundances of Matter (Minneapolis), C. Jake Waddington, Editor,* 124 (1989).

In addition, the following paper, based in part on ISEE data, recently appeared in *Interplanetary Particle Environment,* which contains the proceedings of a conference held at JPL in March 1987 (JPL Publication 88-28).

"Elemental Composition and Energy Spectra of Galactic Cosmic Rays" by R. A. Mewaldt

An abstract of a review paper presented at the Minnesota Conference and published in the book "Cosmic Abundances of Matter" appears below.

The Abundances of Isotopes in the Cosmic Radiation - This paper reviews studies of the isotopic composition of nuclei in the cosmic radiation, including

abundances of the isotopes of elements from H to Ni (nuclear charge $1 < Z < 28$), and their implications for cosmic ray origin, acceleration, and transport in the Galaxy. The review focuses on determinations of the composition of cosmic ray source material, and the extent to which the isotopic composition of this material is different from, or similar to, typical solar system material and other samples of Galactic matter. Theoretical models that have been advanced to explain the observed overabundance of neutron-rich isotopes in cosmic rays are described. Also discussed are studies of various radioactive "clocks" that record the time-scales associated with the nucleosynthesis, acceleration, and transport of cosmic ray nuclei, and studies of the so-called "anomalous" cosmic ray component, thought to represent a sample of the neutral interstellar medium. Finally, the goals and prospects for future cosmic ray isotope spectrometers are described.

Table 2 represents a compilation of measurements of the composition of cosmic ray source material, based on a weighted average of a variety of balloon and spacecraft measurements.

Table 2: Composition of Cosmic Ray Source Material					
Established Results		Probable/Possible Require Confirmation		Other Limits	
Isotope Ratio	Cosmic Ray Source Solar System	Isotope Ratio	Cosmic Ray Source Solar System	Isotope Ratio	Cosmic Ray Source Solar System
$^{22}Ne/^{20}Ne$	3.3 ± 0.45[a] or 5.5 ± 0.75	$^{29}Si/^{28}Si$	1.5 ± 0.3	$^{13}C/^{12}C$	1.55 ± 1.25
$^{25}Mg/^{24}Mg$	1.6 ± 0.25	$^{30}Si/^{28}Si$	1.4 ± 0.35	$^{18}O/^{16}O$	≤4
$^{26}Mg/^{24}Mg$	1.5 ± 0.20			$^{34}S/^{32}S$	≤3
$^{14}N/^{16}O$	0.25 ± .10			$^{54}Fe/^{56}Fe$	1.15 ± 0.5
$^{12}C/^{16}O$	~2			$^{57}Fe/^{56}Fe$	≤4
				$^{58}Fe/^{56}Fe$	≤10
				$^{60}Ni/^{58}Ni$	1.9 ± 1.3
a) Depending upon whether neon-A or solar wind neon is used as a solar system standard.					

Table 2

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

The HNE is a joint experiment involving the Caltech SRL, Washington University (M. H. Israel, J. Klarmann, and W. R. Binns), and the University of Minnesota (C. J. Waddington). The HNE was designed to measure the elemental abundances of relativistic ultraheavy cosmic-ray nuclei ($17 \leq Z \leq 130$). These data are relevant to

studies of nucleosynthesis and stellar structures, the existence of extreme transuranic nuclei, the acceleration and propagation of cosmic rays, and the physical properties of the interstellar medium. HNE was successfully launched on HEAO-3 in 1979 and operated until late May 1981.

In addition to the data from the satellite itself, substantial amounts of data have been acquired in calibrations and cross-section measurements using heavy nuclei beams at the LBL Bevalac. The calibration data have been used to ensure confidence in our analysis of HNE data and have intrinsic interest in their relevance to scaling of ionization energy loss and Cherenkov radiation with charge. The cross-section measurements are important to the study of propagation of cosmic-rays through the interstellar medium. An understanding of this process is crucial to interpretation of many of the HNE results. This work is also improving our general understanding of the systematics of nucleus-nucleus interactions.

Caltech has contributed data processing support for all HNE team projects. Team participation in all the science data analysis continues. Caltech has led the team in two studies of elemental abundances; a study of abundances over the entire charge region from $_{26}$Fe to $_{92}$U (accepted for publication in Astrophys. J., November 1989), and a study of the abundances in the charge region up to Z=40 where the relatively high fluxes allow selection of the data with the very best charge resolution (submitted for the XXI ICRC). The latter study is described in more detail below.

The following talks and papers were presented during the reporting period:

● "The Abundances of the Heavier Elements in the Cosmic Radiation," Binns, W. R. et al., *AIP Conf. Proceed. 183, Symp. on Cosmic Abundances of Matter (Minneapolis), C. Jake Waddington, Editor*, 147 (1989).

● "Charge, Mass and Energy Changes During Fragmentation of Relativistic," Binns, W. R. et al., *To be published in Phys. Rev.* (1988).

● "Energy Dependence of the Release of Nuclei from Relativistic Nucleus-Nucleus Interactions," Waddington, C. J. et al., *Bull. Amer. Phys. Soc.* **33**(4), 1060 (1988).

● "Charge Pickup by Relativistic Nuclei in Nuclear Interactions," , J. R. Cummings et al., *Bull. of Amer. Phys. Soc.* **33**(4), 1060 (1988).

We have also submitted five abstracts to the 21st ICRC:

"Cosmic Ray Elemental Abundances for 26≤Z≤40 Measured on HEAO-3"

"Energy Spectra between 10 and several hundred GeV/nucleon for Elements from $_{18}$Ar to $_{23}$V: Results from HEAO-3"

"Measurement of Fragmentation Cross Sections of Relativistic UH Nuclei"

"Deduced Cross Sections for Fragmentation of Relativistic UH Nuclei"

"Response of Ionization Chambers and Cherenkov Counters to Relativistic Ultraheavy Nuclei"

Abundances in the $26 \leq Z \leq 40$ Charge Region. In the charge region extending up to $Z \sim 40$, the abundances are sufficient to allow the very tight quality selections on the data and still yield particle counts with reasonable statistics. Our earliest publications were based on a subset of this data; we are re-analyzing it now because we have additional flight time that was not included in the early publications, because we have much improved understanding of the instrument response and data, and because we have improved data analysis tools which allow a more careful study of statistical uncertainties.

One of the objectives of such an analysis is the abundance of the odd elements. In particular the element $_{37}$Rb is considered to be an indicator of r-process nucleosynthesis. An improved (smaller) upper limit on the Rb abundance will quantitatively strengthen the conclusion that the galactic cosmic ray abundances in this charge region are similar to those of the solar system.

Two types of events show the required high charge resolution. One, the low energy data set, includes those particles whose energy is low enough (~ 400 to 1000 MeV/nucleon) that the energy is well measured by the ratio of Cherenkov signal to ionization energy loss signal. Knowledge of the energy allows correction of the Cherenkov light signal for energy dependence and, hence, accurate measurement of the charge. The other data set, the high cutoff set, includes those particles observed at locations/directions of incidence where the geomagnetic cutoff rigidity is at least 8.8 GV. For these particles, the energy is high enough that the residual energy dependence of the Cherenkov light signal is small and no correction is necessary. The two data sets are comparable in size.

Figure 8 shows the measured charge histogram in the $Z = 30$ to 40 charge region for the sum of these two highest resolution data sets. Pronounced peaks at $Z = 32$, 34, and 38 are clearly visible. The best-fit resolution for these peaks scales with Z, with a sigma value of 0.31 charge units at Fe (not shown) and 0.48 charge units at Sr. Study of the shape of the Fe peak, calculations of the expected shape, and experience with our other data sets lends considerable confidence that the charge resolution function is gaussian and has no significant tails. We are in the process of fitting this histogram, investigating the sensitivity of the Rb abundance to the value of sigma and to the possibility that deviations from Z^2 scaling might produce offsets of the peaks from the integer values. (These offsets are known to be small; our larger data sets show peaks at even integer values up to $Z=60$.)

Comparison of the two data sets shows agreement, as expected, for those elements believed to be primaries. For the sub-Fe group ($Z=22$ to 25 in particular) and for $_{36}$Kr, below the $_{38}$Sr peak, the abundances are largely secondary, i.e., produced in nuclear interactions in the interstellar medium. A clear energy dependence is seen for the Kr abundance in the comparison of these two data sets. We hope to exploit this energy dependence to improve our calculation of the cosmic ray source abundance of the Kr, leading to a better understanding of the first ionization potential (FIP) fractionation effects commonly assumed in galactic cosmic-ray acceleration models. The high FIP of Kr makes it particularly interesting in this regard.
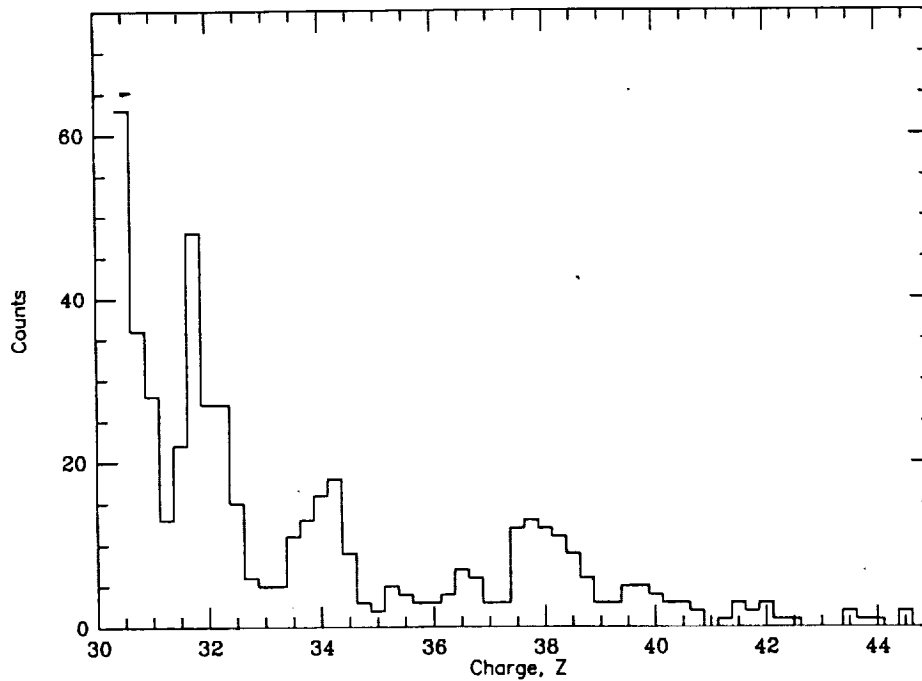
Figure 8: HEAO charge histogram from Z=30 to Z=44.

1.2.5. Galileo Heavy Ion Counter

The Galileo Heavy Ion Counter (HIC) was constructed by this group in collaboration with N. Gehrels at Goddard Space Flight Center. It will monitor penetrating (~10 to ~200 MeV/nucleon) sulfur, oxygen, and other heavy elements in the Jovian magnetosphere with the sensitivity needed to warn of potential "single-event upsets" (SEUs) in the spacecraft electronics. These upsets are changes in states of electronic components induced by ionizing radiation of a single energetic particle. Caltech is responsible for managing operations and data analysis for this instrument, which is based on repackaging the Voyager CRS prototype unit (the PTM). Although the primary mission is engineering support, the data are of significant scientific value and will allow us to continue our investigation of the spectra of trapped ions in the Jovian magnetosphere and their relation to the Jovian aurora. In addition, during cruise (to the extent that coverage is available) and in the outer Jovian magnetosphere, we will use the instrument to measure the elemental composition of solar flare events and of the anomalous cosmic ray component. The measurements at 5 A.U. will be especially useful in the study of the radial dependence of the gradient of the ACR oxygen.

The instrument and the spacecraft are at Kennedy Space Center being integrated into the Shuttle for launch in October 1989. Electronic checks and calibrations were performed at Caltech in November 1988 and the instrument is fully functional. Planning for data analysis is underway.

In May of 1988 a presentation was made to the Science Steering Group to encourage the acquisition of HIC data in the early phases of the mission, inside of 1 A.U. from the Sun, where such measurements have never been done. A no-cost

technique has been identified for acquiring this data, but no decision will be made by the project before launch.

1.2.6. Astrophysics Data Program

One of us (RAM), in collaboration with W. R. Webber of the University of New Hampshire, has been working on a guest-investigator grant under the Astrophysics Data Program to study "New Aspects of Heavy Cosmic Rays from Calcium to Nickel" using data from the HEAO-C-3 experiment. This investigation is applying newly measured cross sections and recent propagation models to the HEAO data set in an effort to search for evidence of cosmic ray re-acceleration in the interstellar medium.

This work has resulted in submission of the following abstracts to the Adelaide conference:

> "Cosmic Ray Source Abundances Derived from High-Energy Measurements of Fe-group Nuclei"
>
> "The ^{54}Mn Clock and its Implications for Cosmic Ray Propagation and Fe Isotope Studies"

2. Hard X-Ray and Gamma-Ray Astrophysics

This research program is directed toward the investigation of galactic, extragalactic, and solar hard X-rays and gamma rays with spectrometers of high angular resolution and moderate energy resolution carried on spacecraft and balloons. The main efforts 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 experiments.

2.1.1. Gamma-Ray Imaging Payload (GRIP)

The GRIP instrument is a balloon-borne imaging γ-ray telescope for galactic and extra-galactic astronomy observations. The telescope employs a rotating lead coded-aperture mask and a large-area shielded NaI(Tl) scintillation camera to achieve good flux sensitivity over the energy range from 30 keV to 5 MeV and an imaging resolution of 1.1° over a 14° field of view.

The primary detector is a position-sensitive NaI(Tl) scintillator viewed by 19 photomultiplier tubes (PMTs) which are individually pulse-height analyzed. Background in the primary detector is reduced by an active anti-coincidence shield. The side of the shield consists of 12 plastic scintillator modules which form a cylinder ~16 cm thick. Each module is viewed by a single 5" PMT. The lower shield section is identical to the primary camera plate.

The coded aperture is located 2.5 meters from the detector and is composed of 361 cells of which half are open and half contain a lead hexagon 2.8 cm thick and 4.8 cm flat to flat. The pattern of open and filled cells forms a hexagonal uniformly redundant array that is optimal for coded aperture imaging.

During an observation the mask is continuously rotated to impose a time modulation of the γ-ray signal at each location on the detector. Due to the antisymmetry of the coded-aperture pattern under 60 degree rotation (open and closed cell interchange for all but the central cell) the γ-ray signal at each detector position is modulated with a 50% duty cycle. This feature allows a complete background subtraction to be performed for each position on the detector, once every 20 seconds. In addition, the continuous rotation permits extension of the field of view to 20 degrees, increasing the number of pixels imaged by about a factor of ten.

The telescope is mounted on an elevation/azimuth pointing platform which utilizes active magnetometer feedback. Two magnetometers provide real-time aspect information. Two CCD cameras provide absolute aspect information, one for night-time imaging of star fields, and the other for day-time imaging of the sun. These permit post-flight correction for pointing inaccuracies. The telescope pointing system is under microprocessor control, allowing steering by ground command or the execution of a pre-programmed flight plan. Data are recorded on-board and can also be telemetered to the ground for real-time analysis and redundant recording. The on-board recording system was developed for high capacity (25 Gbyte) and bandwidth (1.4 Mbit/s) using commercial VCRs and audio digitizers.

Recent publications and presentations:

● "Imaging Observations of SN 1987A at Gamma-Ray Energies," Cook, W. R. et al., *Proceedings: Workshop on Nuclear Spectroscopy of Astrophysical Sources* (1987).

● "An Imaging Observation of SN 1987A at Gamma-Ray Energies," Cook, W. R. et al., *Ap. J. (Lett.)* **334**, L87 (1988).

● "Gamma-Ray Imaging of the Galactic Center Region," Cook, W. R. et al., *To be published in Proceed. of IAU Symp. #136 on the Galactic Center (Univ. of Calif. at Los Angeles)* (1988).

● "Gamma-Ray and Hard X-Ray Imaging of Solar Flares," Prince, T. A. et al., *Solar Physics* **118**, 269 (1988).

● "Gamma-Ray Imaging of the Galactic Center Region," Cook, W. R. et al., *Bull. of the Amer. Astron. Soc.* **20**(4), 1070 (1988).

- "Gamma-Ray Imaging Observations of SN1987A," Palmer, D. M. et al., *Bull. of the Amer. Astron. Soc.* **20**(4), 1069 (1988).

- "Coded-Aperture Timing Measurements of the Crab Nebula and Pulsar," Starr. C. H. et al., *Bull. of the Amer. Astron. Soc.* **20**(4), 1070 (1988).

The following abstracts have been submitted to the ICRC:

"Observations of Point Source Emission from the Galactic Center Region at Gamma-Ray Energies,"

"Hard X-ray and Gamma-ray Observations of SN1987A During the period 1987-1989,"

"Coded Aperture Timing Measurements of the Crab Pulsar,"

The GRIP payload has recently completed a series of flights from Australia to observe SN1987A and the galactic center region. We summarize below the results of the GRIP program over the period 1986-1989.

Technical Achievements

1) First use of large-area position sensitive Anger camera technology, including depth discrimination capability used to reject low energy background events occurring near the back of the detector (Cook et al., 1984).

2) Derivation and first use of rotating Hexagonal Uniformly Redundant Arrays (HURAs, Finger and Prince, 1985.

3) First demonstration of sub-degree, wide-field imaging at soft γ-ray energies of 30 keV to 2 MeV (Althouse et al., 1987).

4) First use of multi-gigabyte capacity video cassette recorders for in-flight digital data storage (Althouse and Cook, 1985).

Scientific Results

1) First coded-aperture imaging of the galactic center region at energies above 30 keV. An image (Figure 9) obtained during April 1988 for the 30-120 keV interval shows two γ-ray sources. The dominant source is consistent in location with the X-ray source 1E1740.7-2942, while the second source may be identified with the X-ray source GX354-0. Source 1E1740.7-2942 (also dominant at 20-30 keV in earlier images from) must be considered a prime candidate for the source of intense and variable 0.511 MeV line and MeV continuum radiation seen by previous non-imaging instruments (e.g.. Riegler et al., 1985), although such emission was not seen in our April 1988 observation. Our measured γ-ray spectrum for 1E1740.7-2942 and an upper limit on the 0.511 MeV line flux are given in Cook et al., 1988b. A second more extensive observation of the galactic center was performed in April 1989, and data analysis is now in progress.

Figure 9: Gamma-ray image of
the galactic center region for the
energy range 30 to 120 kev, based
on an eight hour observation
performed during April 1988,
from Alice Springs, Australia.
(contours indicate flux level,
calibrated in units of statistical
significance, beginning at 2σ and
spaced by 1σ.)
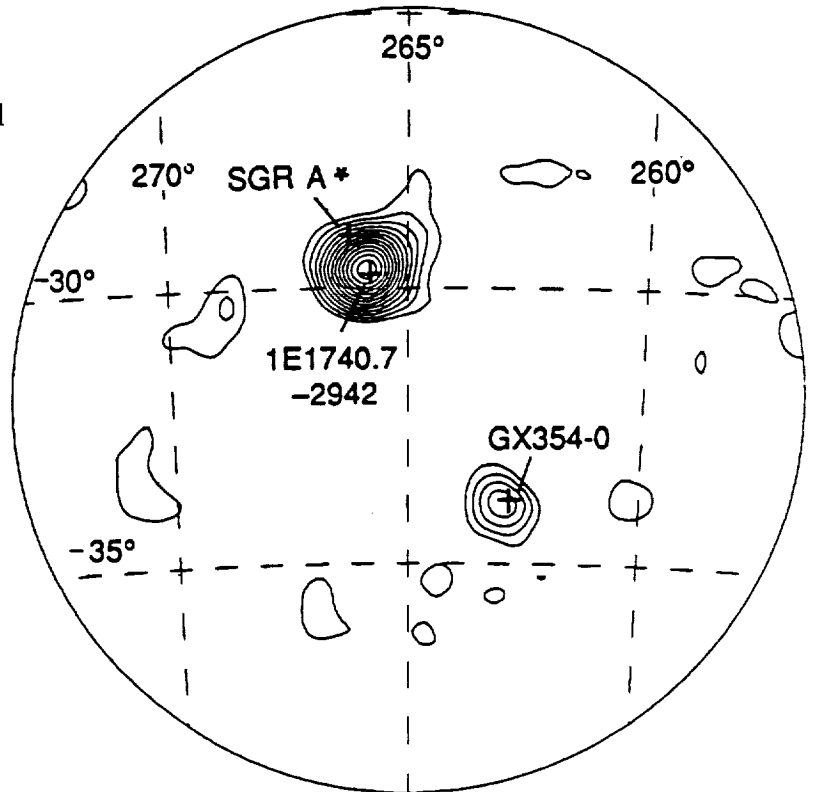
2) First coded-aperture imaging observations of SN1987A. Continuum radiation
extending from 40 keV to ~ 1 MeV, and excess flux in an energy interval containing
the Co^{56} line at 847 keV were detected during observations of November 1987 and
April 1988 (Cook et al., 1988a,c,d). Upper limits were obtained from an observation in
May 1987 (Cook et al., 1987). Figure 10 shows a γ-ray image of SN1987A at energies
from 40 to 1300 keV obtained during April 1988. Imaging capability was important in
demonstrating that LMC X-1, a known source of confusion for supernova observations
at lower energies, did not make a significant contribution to our flux measurements at
energies above 40 keV. The γ-ray spectrum of SN1987A derived by combining data
obtained in November 1987 and April 1988 is shown in Figure 11. Excess flux is
measured at the 2.7σ level in an interval chosen to contain the 847 keV line. While no
significant flux excess was seen in the Co^{56} 1238 keV line interval, the data are
statistically consistent (at 1.3σ) with a 1238 keV line flux of 0.68 times the excess seen
at 847 keV, as would be expected for bare Co^{56}.

Figure 10: Gamma-ray image of
SN1987A at energies from 40 to
1300 keV, obtained during April
1988. The expected location of
the supernova is marked by a
cross, as are the locations of
several known X-ray sources.
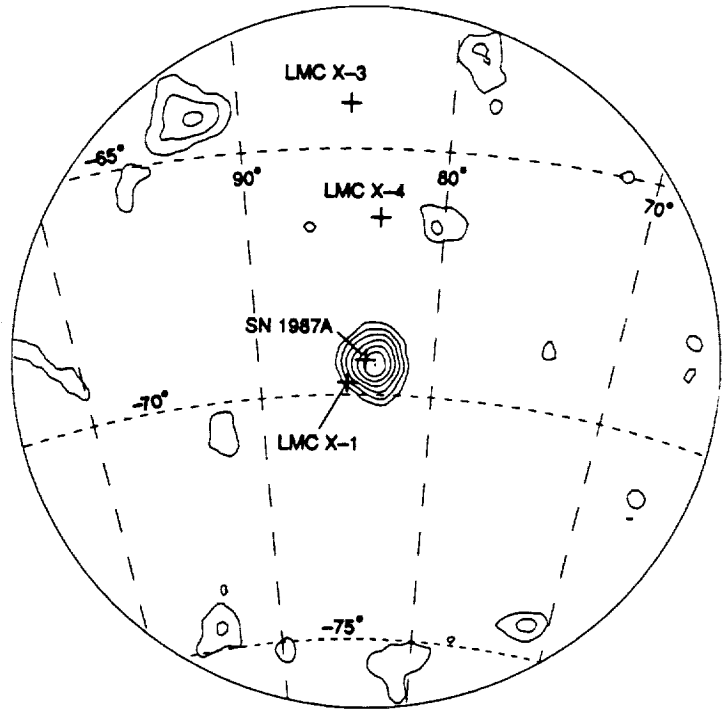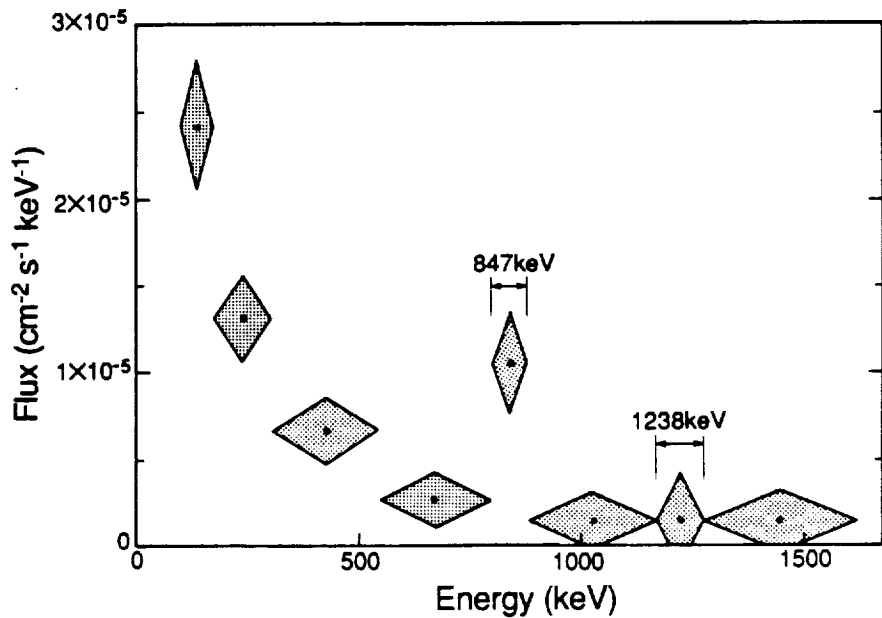(Contours indicate flux level as in
Figure 9.)

Figure 11:
The γ-ray spectrum
measured for SN1987A
(see text).

3) Use of coded-aperture techniques in a pulsar timing observation (Starr et al., 1989).
The pulsed fraction and pulse profile at energies from 50 to 170 keV were measured
for the Crab nebula and pulsar and found to be in good agreement with previous
results. Several analysis methods yielding different systematic and statistical errors
were studied and utilized.

4) Detection of A0535+26 during a giant outburst and measurement of the spectrum up to 100 keV (Cook et al., 1989). A series of images of the Crab/A0535+26 region in successive energy bands is shown in Figure 12. The images illustrate the dramatically different spectra of the two objects, and demonstrate the ability of a coded-aperture telescope to measure the individual spectral characteristics of multiple sources. A timing analysis, in progress, has yielded the first light curves obtained by coded-aperture techniques from a simultaneous observation of two pulsars.
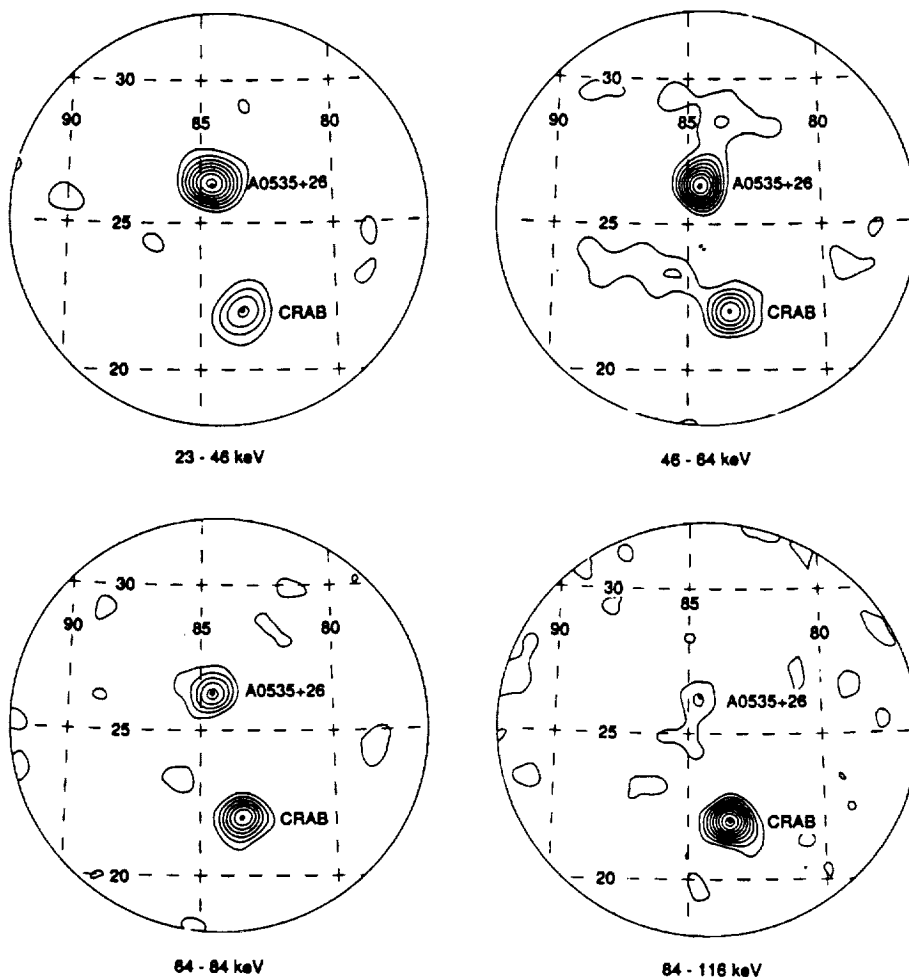

Figure 12: Images of the A0535+26/Crab region in different energy bands, obtained during the giant outburst of A0535+26 in April 1989. (Contours indicate flux level as in Figure 9.)

While the above list of results is respectable for a single balloon instrument, we emphasize that the data analysis of the GRIP observations is still in a very preliminary stage. Because the GRIP instrument has flown 5 times in less than 3 years (5 of the last 6 turnaround periods), limitations in manpower have required that we concentrate largely on the flight program. We anticipate further interesting results, and perhaps even some surprises as more time becomes available for data analysis. In particular, our recent 1989 April flight had two successful galactic center transit observations. If

the galactic center positron annihilation source was on during this flight, we anticipate the possibility of localizing this source to sub-degree accuracy for the first time.

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3. Other Activities

3.1. Lab Facilities

MACSYS Data Acquisition System The SRL is in the process of building a new data acquisition system to replace the very successful, but aging, PACE system which we built ~1975. The new system is called MACSYS, for Multi-channel data ACquisition SYStem. It will consist of as many as 32 channels of analog input when first built, with essentially unlimited expansion capability. Each channel includes a preamplifier, shaping amplifier, and analog to digital converter (ADC). A control computer (Sun Sparcstation 330) receives and records the data and transmits the data to one or more additional computers (smaller Sun workstations such as the 386i and/or the 3/60) which are used for real-time graphics display of the data for monitoring purposes. The system specs include:

ADC linearity, stability	<0.025% of full scale
maximum event rate	~10,000 events per second
maximum recording rate	~200,000 bytes per second

The system design is tentatively complete and the major computer purchases have been made. A sample of a conventional commercial ADC NIM module has been purchased and is being tested. Its speed and accuracy are adequate. We have also begun study of an alternative ADC based on a very high speed integrated circuit which would be similar to the ADCs needed for future balloon and satellite experiments.

3.2. Other

R. A. Mewaldt is serving as a member of NASA's Cosmic and Heliospheric Management Operations Working Group (CHMOWG), the Space Physics Advisory Council (SPAC), and the Committee on Solar and Space Physics (CSSP) of the National Research Council. He is also chairman of the newly formed Balloon-Borne Magnet Facility Advisory Committee.

T. A. Prince has received a Presidential Young Investigator Award from the National Science Foundation. He is serving as a member of the High-Energy Astrophysics Management and Operations working Group (HEAMOWG) and as Chairman of the GRO Users' Committee.

E. C. Stone continues to serve as NASA's Project Scientist for the Voyager Mission. He is also a member of the Commission on Physical Sciences, Mathematics, and Resources of the National Research Council and a member of the Committee on Space Policy of the National Academies of Science and Engineering.

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