arme Verhalten der Detektoren, die hohe Stabilität der Analogelektronik sowie die fehlerfreie Funktion der Digitalelektronik, und sie zeigen an, daß wir wie gewünscht die Eigenschaften des interplanetaren Raumes zu einer Zeit minimaler Sonnenaktivität untersuchen können.

6. SCHLUSSBEMERKUNGEN

Das Experiment wurde im Rahmen des Projekts HELIOS im Auftrage des Bundesministers für Forschung und Technologie durch die Gesellschaft für Weltraumforschung gefördert. Die Entwicklung und raumflugtaugliche Fertigung erfolgte hauptsächlich bei der Firma Dornier System GmbH. Das Institut für Datenverarbeitungsanlagen der Technischen Universität Braunschweig entwickelte den Kernspeicher und große Teile der Digitalelektronik. Das 1. Physikalische Institut der Universität Hamburg, die Physikalisch-Technische Bundesanstalt in Braunschweig und die University of Maryland, College Park, USA, gaben uns die Möglichkeit, die verschiedenen Exemplare des Instruments an Teilchenbeschleunigern zu eichen.
Allen beteiligten Institutionen, Firmen und Mitarbeitern sagen wir an dieser Stelle unseren aufrichtigen Dank.

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The HELIOS A/B Cosmic Ray Instrument (E 7)

J. H. TRAINOR, D. E. STILWELL, R. M. JOYCE, B. J.TEEGARDEN and H. O. WHITE, Jr.
NASA Goddard Space Flight Center, Greenbelt, Md,USA

This paper describes the design and performance of a cosmicray particle experiment for the Helios A/B space missions. This experiment had to be very lightweight, low power and electronically sophisticated in order to meet the spacecraft and scientific requirements, and very similar to those on the Pioneer 10 and 11 missions to Jupiter. Both sets of missions use several solid-state detector telescopes to measure protons from ~ 100 KeV to ~ 800 MeV per nucleon. Additionally, the Helios experiment includes a proportional counter to monitor the solar X-ray activity. The experiment has functioned quite well for 5 months in space, and large quantities of data are now being received.

Dieser Bericht beschreibt Entwurf und Leistung eines Experimentes zur Messung der kosmischen Strahlung bei der HELIOS A/B Mission. Dieses Experiment mußte sehr leicht sein, geringen Energiebedarf und eine fortschrittliche Elektronik aufweisen, um die Anforderungen zu erfüllen; es ist ähnlich dem Meßgerät bei den PIONEER 10/11-Missionen zum Jupiter. In beiden Fällen werden mehrere Festkörper-Detektor-Teleskope verwendet, um Protonen von 100 keV bis 800 MeV Energiebereich zu messen. Zusätzlich besitzt das HELIOS-Experiment einen Proportionalzähler zur Registrierung der solaren Röntgenstrahlung. Das Experiment hat 5 Monate im Weltraum gut gearbeitet und große Datenmengen werden z. Zt. empfangen.

1. INTRODUCTION

The purpose of Helios experiment E-7 is to carry investigation of the energy spectra, charge composition and flow patterns of both solar and galatic cosmic rays. Three separate dE/dX vs. E telescopes, in combination, enable the following particle species and energy ranges to be measured: electrons, 50 KeV to ~ 8 MeV; protons, 100 KeV to ~ 800 MeV; alpha particles, to 600 MeV per nucleon; heavier elements up to Neon to ~ 200 MeV per nucleon. In addition, the Helios experiment includes a proportional counter to monitor solar X-rays in the range 2-8 KeV. FIG. 1 shows a picture of the experiment.

2. DETECTORS

FIG. 2 shows a cross-sectional view of each of the three telescopes. The High-Energy Telescope (HET) at the left uses two thin silicon diode detectors, A and B, to define an acceptance cone for incoming particles and to provide two separate measurements of rate of energy loss (dE/dX). The C_2 element consists of a stack of four identical detectors summed together. If a particle stops in C_2 (as determined by no C_3 event), then C_2 measures its total energy. If it penetrates, then both C_2 and C_3 provide dE/dX or total E measurements.
The Low-Energy Telescopes (LET-I and -II) operate in a

FIG. 1: **The Helios E-7 experiment with the various detector assemblies and the experiment heat shield**

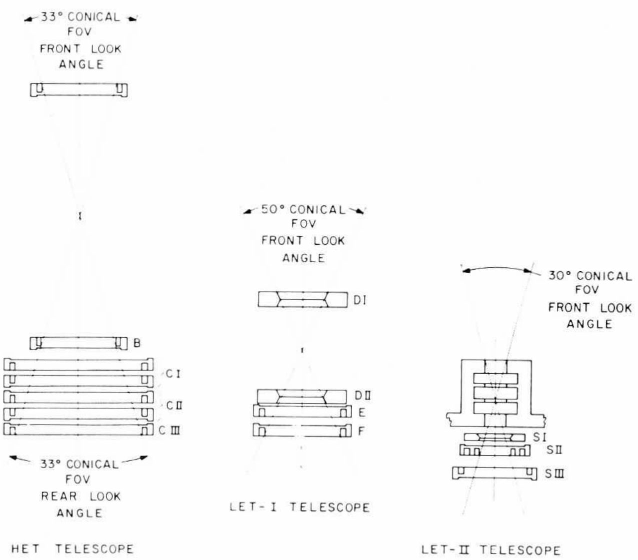

FIG. 2: **HET, LET-I and LET-II Telescope Assemblies**

similar fashion, but LET-II uses significantly smaller, thinner detectors for lower energy particles and a smaller geometry factor. Both LET-I and LET-II reject penetrating particles by using the rear elements (F and S_3) in anti-coincidence. LET-I uses D_1 and D_2 to define an acceptance cone for incoming particles and for a double dE/dX measurement, while LET-II uses a mechanical collimator instead. Particle events from HET and LET-I may be selected for pulse-height analysis. TABLE I summarizes the characteristics of each of these telescopes and their component detectors:

Pioneeer carried one of each of these telescopes, while Helios carries an additional LET-II – one directed 20° above the ecliptic and the other 20° below the ecliptic. The solar disc is thus 5° outside the field of view. Helios also includes a proportional counter with two active detector volumes within a common gas volume. Separate Be foil windows admit photons and particles to be counted. An narrow collimator in front of one window is ~ 0.28° wide in the ecliptic and ± 10° above and below the ecliptic. This permits sectored count-rate data across the solar disc. In front of the other

TABLE I: **TELESCOPE CHARACTERISTICS**

Telescope	HET	LET-I	LET-II
Geometrical Factor (cm^2-ster)	.015	.22	.155
Detectors (thickness x area)	A,B: 2.5 mm x 3 cm^2 C's: 2.5 mm x 8.5 cm^2	D_1, D_2: 100 μ x 1 cm^2 E, F: 2.5 mm x 3 cm^2	S_1: 50 μ x 50 mm^2 S_2: 2.5 mm x 50 mm^2 Sa: 2.5 mm x 50 mm^2 S_3: 2.5 mm x 200 mm^2

window a second collimator, 60° wide, is covered with 2 mil aluminized mylar foil to eliminate low-energy X-rays. This counter is sensitive only to penetrating charged particles, and is used for monitoring solar electrons and for background correction.

3. LINEAR ELECTRONICS

Pulses from each detector are amplified and shaped in a preamp/post-amplifier, and carried to one or more pulse-height discriminators which produce logic pulses of uniform amplitude and width for each input pulse exceeding the threshold. These logical pulses are used to form the many coincidence-anticoincidence conditions corresponding to various particle energies and types. Both single detector rates and coincidence rates are counted in 24-bit binary counters. Eighty-three such rates are monitored in Helios E-7. Examples of several such rates, their logical formation and their physical meaning are given in TABLE II. Certain coincidence conditions may initiate pulse-height analysis (PHA) of selected events. The pulse amplitudes of three selected detector outputs are then digitized by three 10-bit ADC's. A detailed description of these electronics has already been published [Stilwell, **et al.,** 1975].

4. DATA SYSTEM

All rate data is counted in "Mars bugs", a custom PMOS LSI chip developed at the Goddard Space Flight Center [White, et al., 1971]. A single chip contains a 24-bit binary [White, **et al.,** 1971]. A single chip contains a 24-bit binary counter, a quasi-log compressor to convert the 24-bit binary number to a 5-bit characteristic and a 7-bit mantissa, and a 12-bit storage buffer to hold the data for readout. PHA data is also counted and stored in PMOS integrated circuits. All spacecraft interface, command processing logic, control of the accumulation intervals, and formatting of Rate and PHA data into the available telemetry space is accomplished in this data system using low power T^2L circuits. Discreet components were used where necessary to comply with S/C interface impedances and levels.

The telemetry formatting was designed to keep the rate data cycle time down to a few minutes for as many bit rates, distribution modes and formats as possible which were most likely to be used during a nominal mission. PHA data is interleaved with rate data, and the experiment can process up to 5 events/sec on Helios at the highest available bit rates. PHA telemetry is always equally divided between HET and LET. Because of the wide variation in bit rate (4096/sec to 8/sec on Helios), a complete data cycle for all rates becomes quite long, up to ~ 2.5 hours on Helios at the slowest possible combination of bit rate and format.

It is most important that the experiment acquire spin-sectored data. A sectored rate synchronizer generates suitable control signals to insure that the sectored rate

TABLE II: **EXAMPLES OF DATA MODES**

Rate	Coincidence	Particle/Energy
R 1	$(A_2K_1+A_1C_1)B\overline{C_3}$	Protons, Z>2: 20-56 MeV/nuc
		Electrons: 2-8 MeV
R 2	$A_1\overline{A_2}B\,C_3$	Protons: > 230 MeV
	$A_1BK_2\,\overline{C_3}$	Z>2: 20-56 MeV/nuc
R 3	$A_2B\,C_3$	Alphas: >56 MeV/nuc
	$A_2BK_2\,\overline{C_1}$	Alphas: 20-30 MeV/nuc
R 4	$A_2BK_2\,C_1\,\overline{C_2}$	Alphas: 30-45 MeV/nuc
	A_1	
R 5	$A_2BK_2\,C_1\,C_2\,\overline{C_3}$	Alphas: 45-56 MeV/nuc
	A_2	
R 6	$A_1\overline{A_2}B\,\overline{C_1}$	Electrons: 2-4 MeV
	$A_1\overline{A_2}B\,C_1\,\overline{C_2}$	Electrons: 4-6 MeV
R 7	$A_1\overline{A_2}B\,C_1\,C_2\,\overline{C_1}$	Electrons: 6-8 MeV
	$A_2BK_1\,\overline{C_1}$	Protons, Alphas: 20-30 MeV/nuc
R 8	$A_2BK_1\,C_1\,\overline{C_2}$	Protons, Alphas: 30-45 MeV/nuc
	$A_2BK_1\,C_1\,C_2\,\overline{C_3}$	Protons, Alphas: 45-56 MeV/nuc
R 15	$\underset{1}{S_1}\;\overline{S_2}\,\overline{S_{2a}}\,\overline{S_3}$	Protons: .15-2.1 MeV
	$\underset{2}{S_1}\;\overline{S_2}\,\overline{S_{2a}}\,\overline{S_3}$	Protons: .72-2.1 MeV
	$\underset{3}{S_1}\;\overline{S_2}\,\overline{S_{2a}}\,\overline{S_3}$	Protons: 1.2-2.1 MeV
	$\underset{4}{S_1}\;\overline{S_2}\,\overline{S_{2a}}\,\overline{S_3}$	Alphas: .6-2.1 MeV/nuc
R 16	$S_1\,\underset{1}{S_2}\;\overline{S_{2a}}\,\overline{S_3}$	Protons: 3.1-21 MeV
	$S_1\,\underset{2}{S_2}\;\overline{S_{2a}}\,\overline{S_3}$	Protons: 5.7-21 MeV
	$S_1\,\underset{3}{S_2}\;\overline{S_{2a}}\,\overline{S_3}$	Protons: 15.1-21.2 MeV
	$S_1\,\underset{4}{S_2}\;\overline{S_{2a}}\,\overline{S_3}$	Alphas: 6-21 MeV/nuc

accumulators are live for an exact integral number of spacecraft revolutions. The number of revolutions is determined by the bit rate in use and varies between 53 revs/readout to 2231 revs/readout on Helios (spin rate ~ 60 RPM). Sectors are 45° wide on both spacecraft. The Helios instrument also contains a separate X-ray sectoring system which counts solar X-rays in eight very narrow sectors centered on the solar disc. Since it would have been quite difficult to accurately align the X-ray sensor on the spacecraft, the X-ray sector synchronizer provides for a variable electronic delay between the "see sun" pulse from the solar aspect sensor and the beginning of X-ray live time. This can be adjusted by ± 3.2° about the nominal orientation in 31 steps by ground command. The output of the narrow-angle X-ray detector is then multiplexed sequentially to eight accumulators, each receiving counts for about 10.5' of arc. These window widths can be doubled to 21' of arc by command when the spacecraft is closer to the sun.
Commandable features include: (a) disabling the sector synchronizers in the event of failure, (b) turning on internally-generated test pulses to stimulate the electronics for pre-flight and in-flight checkout, (c) disabling the 1700-volt power supply for the X-ray counter, and (d) enabling a self-check system for the commandable X-ray offset.

5. CONCLUSIONS

This experiment is an example of an extremely lightweight, low power electronic design for severe environmental conditions. The experiment includes more than 9,000 discrete electronics components per flight unit and more than 44,000 transistors – largely in medium- and large-scale integrated circuits.
Experiment performance has been excellent. FIG. 3 shows the LET-I PHA data. This is a plot of the average dE/dX value ($[D_1+D_2]/2$) versus the E value with a consistency check applied to the D_1 and D_2 values. The chemical elements are readily identified, and isotopic separation even for the Magnesium line is possible.

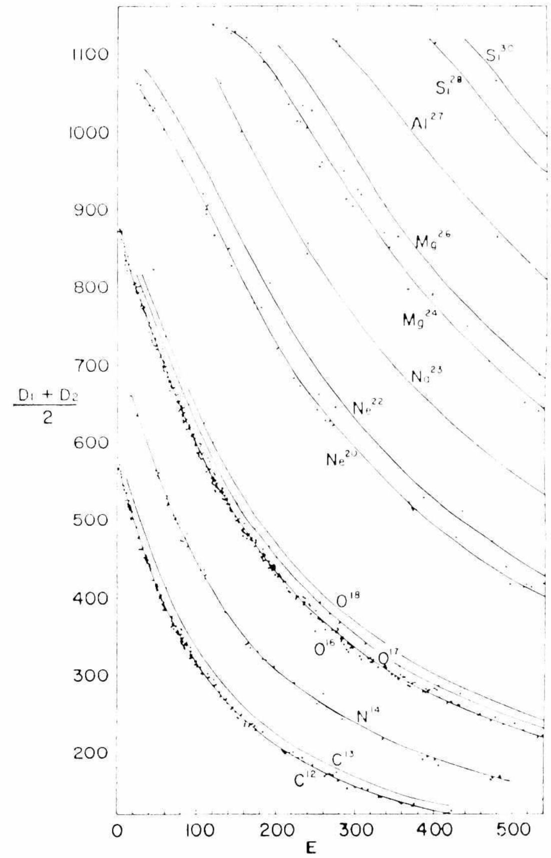

FIG. 3: **dE/dX vs. E results from the Pioneer LET-I telescope during the August 1972 solar event. Clear isotopic resolution for elements up to Mg. is possible**

Acknowledgements

Much of the design and fabrication was accomplished at Spacetac, Inc., Bedford, Mass. At GSFC the detector telescopes were carefully assembled and tested by W. D. Davis; final system assembly, testing and calibration was performed by M. Beazley. Mechanical design was provided by H. Trexel. To all we extend our thanks for their assistance and patience.

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