NASA TECHNICAL MEMORANDUM

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HEAO-C OBSERVATORY DESCRIPTION

By Carroll Dailey and Thomas A. Parnell
HEAO Office

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NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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HEAO-C OBSERVATORY DESCRIPTION

I. INTRODUCTION

The purpose of this report is to provide an abbreviated description of the High Energy Astronomy Observatory (HEAO) Program, including its missions, observatories, and instrumentation, with emphasis on HEAO-C. Besides providing general information for those interested in the HEAO Program, this document is intended as a guide to those planning to submit proposals for investigations under the HEAO-C Guest Observer Program. It is not, however, expected that this information will be sufficient to prepare a detailed proposal. Contacts with individual HEAO-C principal investigators or other key HEAO Program personnel (presented in the Appendix) will normally be required to discuss specific details and arrangements for desired investigations.

The HEAO Program consists of three observatories carrying experiments in X-ray and gamma ray astronomy and cosmic ray research. The HEAO Program is under the cognizance of the Office of Space Science at NASA Headquarters, and the project management is being carried out by Marshall Space Flight Center in Huntsville, Alabama. Integration of the HEAO observatories and experiments was performed by TRW Systems, Inc., Redondo Beach, California. The scientific participation in HEAO-C is listed in Table 2.

II. HEAO PROGRAM

HEAO is an acronym for High Energy Astronomy Observatory. The HEAO Project consists of three HEAO missions. The characteristics of these missions are summarized in Table 1. All are launched by Atlas Centaur launch vehicles.

The HEAO Project objectives are to collect high quality, high resolution data on X-ray and gamma-ray sources and cosmic-ray flux over the entire celestial sphere. Data will include radiation energy spectra and precise locations of the high electromagnetic energy radiating sources of stars and galaxies, as well as elemental and isotopic abundances and energy spectra of cosmic rays. The three HEAO missions are:

HEAO-1: X-ray scanning mission with four scientific instruments to survey and map the X-ray sky. Launched August 12, 1977, completed extended mission on January 9, 1979.

TABLE 1. HEAO OBSERVATORY CHARACTERISTICS

	HEAO-1	HEAO-2	HEAO-C
Normal Operational Mode	Scan and Pointing	Pointing	Scan
Observatory Spin Rate (±10 percent)	0.03	—	0.05
Spin Axis Directional Accuracy, deg	±1.0	—	±1.0
Pointing Accuracy, arc min	±60 - 90	±1.0	—
Approximate Target Pointing Frequency	5/week (after first 3 months)	1/orbit (avg)	—
Data Rate, kbs	6.4	6.4	6.4
Housekeeping	1.0	1.0	1.0
Experiments	5.4[a]	5.4	5.4
Orbital Altitude, n.mi.	240	290	269
Orbital Inclination, deg	22.75	23.50	43.6
Attitude Determination Accuracy, arc min	±6.0 ±0.1 deg/axis	±1.0 arc min/axis	±0.12 deg/axis
Mission Duration, months	17	12[b]	6[b]
Launch Date	August 1977	November 1978	September 1979

a. A-1 special high data rate mode — 128 kbs.
b. Currently approved duration.

HEAO-2: X-ray pointing mission with high resolution telescope to accurately locate and collect detailed radiation data from selected sources over long periods of time. Scientific instruments include four focal plane instruments and one nonfocal plane instrument. Launched November 13, 1978.

HEAO-C: Gamma-ray and cosmic-ray scanning mission with three scientific instruments to map the sky in higher energy regions of the electromagnetic spectrum and of the cosmic ray flux. The approved mission life of HEAO-C is six months.

The HEAO-C will perform an all-sky survey from a 43.6-degree inclination, nominally circular 269 n.mi. orbit. The scientific objectives of the mission are met by arranging the experiments in the observatory so that the scanning direction is perpendicular to the axis of rotation. The movement of this axis as the Earth orbits the Sun provides complete coverage of the celestial sphere in six months.

III. HEAO-C OBSERVATORY

The HEAO-C Observatory (Fig. 1) consists of a mission-common spacecraft equipment module interfacing with a mission-peculiar experiment module. The majority of the spacecraft components are common to all three HEAO missions. Specific mission requirements are met by adding or removing modular electronic equipment.

The spacecraft equipment module structure has a rigid central cylinder which contains the reaction control system propellant task assembly. A closed octagonal honeycomb structure, to which electronic components are attached, surrounds the central cylinder. These components which are readily accessible during integration and test are distributed to maintain thermal equilibrium and mass balance.

The experiment module (EM) structure is hexagonal. Two sides are wider than the others to provide for large apertures through which experiments can obtain lateral views of the celestial sphere. With the exception of C-3, each experiment on HEAO-C is thermally isolated with its own thermostatically controlled heaters. Each has a separate experiment accommodation assembly (EAA) which provides power, command, and data interfaces with the spacecraft without affecting the other experiments.

The dual-frequency communication system has overlapping hemispherical antenna coverage with a signal-to-noise ratio sufficient to ensure full communications capability under any foreseeable condition during the HEAO missions.

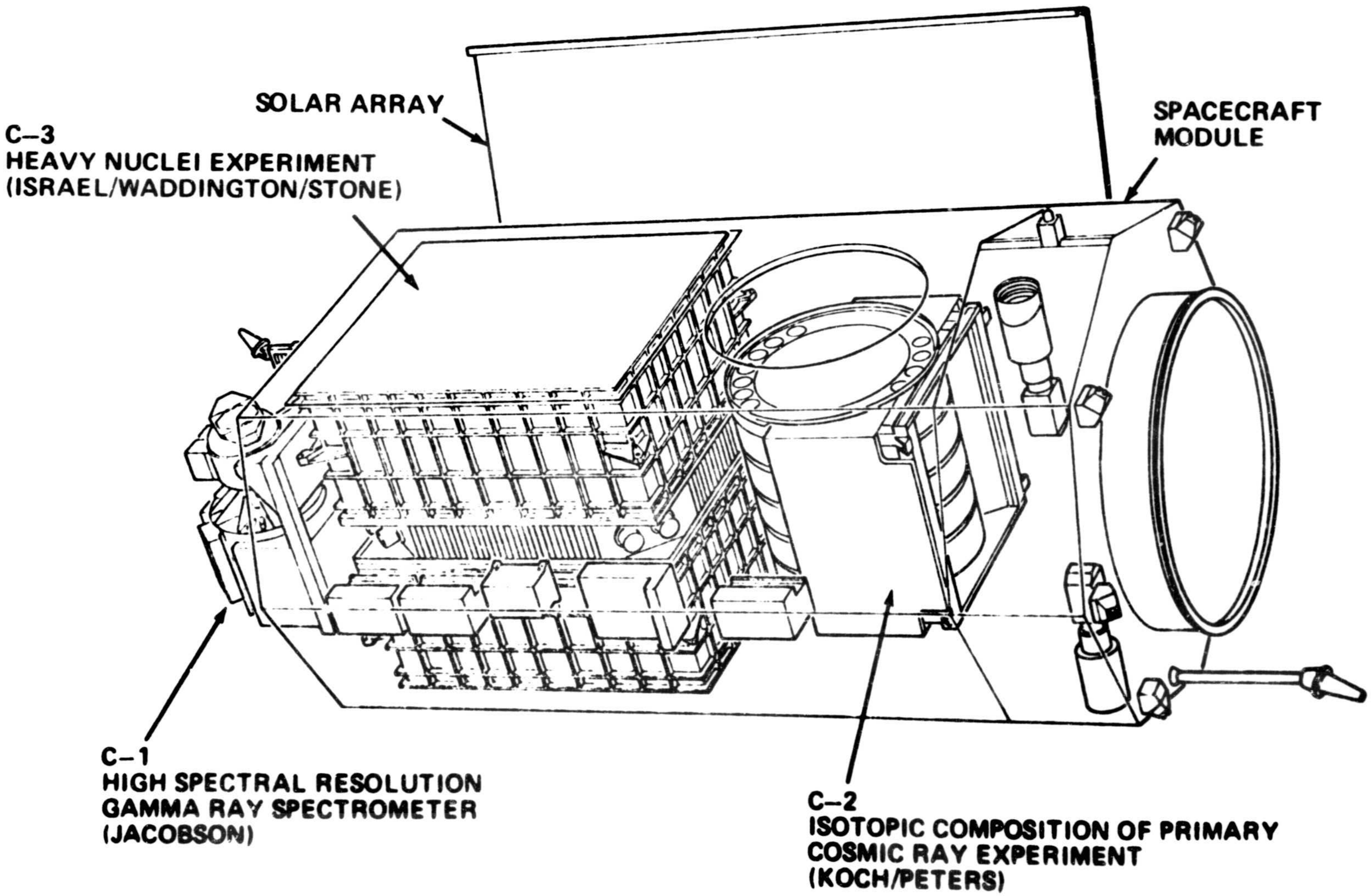

Figure 1. HEAO-C Observatory.

The on-board tape recorder provides sufficient storage capacity to accumulate data for more than two orbits without dumping if ground stations are not available when needed. HEAO-C carries three tape recorders to provide redundancy.

An onboard digital processor common to all three observatories provides extensive, automatic, onboard attitude control. HEAO-1 had sun acquisition, scanning and point modes, and HEAO-2 has sun acquisition and celestial point modes. HEAO-C has the same modes as HEAO-1 except that it has no pointing. In the event of a critical power loss, a low voltage sensor automatically commands the observatory into a contingency mode in which simple, hard-wired logic control laws maintain attitude based on sun sensor data only. This ensures observatory survival until the specific source of difficulty can be determined by ground control.

Orbital altitude has been considered in relation to mission life, radiation environment, launch vehicle capability, and specified orbit inclination. The initial orbital altitude provides a 0.98 probability of 15 months orbit maintenance above 200 n.mi. for HEAO-C.

IV. HEAO-C SCIENCE OBJECTIVES

The HEAO-C Observatory contains three experiments. Experiment C1 is a high resolution gamma ray instrument utilizing cooled intrinsic germanium detectors. C2 is a cosmic ray isotope experiment containing five Cherenkov counters, and taking advantage of the Earth's magnetic field for analysis of isotopic abundances. C3 is a large area cosmic ray experiment depending upon parallel plate ion chambers and a Cherenkov counter to measure the atomic number of cosmic ray nuclei from $Z \approx 13$ through uranium. Experimenters associated with HEAO-C are listed in Table 2.

The overall science objective of HEAO-C is to study the processes of nucleosynthesis in space as revealed by the properties of the cosmic ray and gamma ray flux. Specifically, the scientific objectives of the mission are to:

1) Measure the elemental abundances of the cosmic ray nuclei above atomic number $(Z) = 3$.

2) Measure the isotopic composition of the cosmic rays between $4 \leq Z \leq 26$.

3) Measure the energy spectra of the nuclei from ≈ 0.3 GeV/nucleon to 10 GeV/nucleon.

4) Search for nuclear gamma ray lines with high resolution from 0.06 to 10 MeV from supernovae remnants, the galactic center, neutron star surfaces and other possible sources.

TABLE 2. HEAO-C SCIENTIFIC PARTICIPATION

C-1 — High Resolution Gamma Ray Spectrometer Experiment	
Principal Investigator	
Dr. A. S. Jacobson	Jet Propulsion Laboratory
Co-Investigators	
Dr. A. E. Metzger	Jet Propulsion Laboratory
Dr. L. E. Peterson	Univ. of California, San Diego
Dr. J. R. Arnold	Univ. of California, San Diego
C-2 — Isotopic Composition of Cosmic Rays	
Principal Investigator	
Dr. Lydie Koch	Centre D'Etudes Nucleaires, De Saclay
Dr. Bernard Peters	Danish Space Research Institute, Lyngby
C-3 — Heavy Nuclei Experiment	
Principal Investigators	
Dr. Martin Israel	Washington University
Dr. Edward Stone	California Institute of Technology
Dr. Cecil Waddington	University of Minnesota
Co-Investigators	
Dr. R. Binns	McDonnell Douglas Research Laboratory

5) Obtain high resolution gamma ray spectra and time variations from known X-ray sources over the 0.06 to 10 MeV energy range.

6) Observe time structure of gamma ray bursts and search for other transient gamma ray sources.

From an analysis of the above measurements, the following results may be anticipated:

1) Characterize the sources of the cosmic radiation including the definition of the processes of nucleosynthesis producing the cosmic rays.

2) Determine if the cosmic rays are accelerated near the source.

3) Define characteristics of cosmic ray propagation such as the lifetime of the flux and the path length through interstellar material.

4) Improve the understanding of nuclear matter by identifying super heavy ($96 < Z$) nuclei or setting upper limits on their flux.

5) Through a measurement of gamma ray lines in supernovae remnants, gather direct evidence on the nucleosynthesis process.

6) Discover new evidence in gamma ray spectra concerning the composition and distribution of uncondensed matter in the galaxy.

A. C1 – High Resolution Gamma Ray Spectrometer

The C1 instrument consists of four cooled intrinsic germanium detectors for high resolution gamma ray measurements, collimated by an active (cesium iodide scintillator) anti-coincidence detector. The germanium detectors sit in wells in the CsI detector so that the free field of view of the germanium detectors is 27 degrees full width half maximum and a minimum thickness of 34 gm/cm^2 shields the germanium detectors. A thin plastic scintillator anti-coincidence detector covers the top of the CsI wells to reject charged particles. All scintillators are viewed by 1-1/2 in. photomultiplier tubes. The germanium detectors are connected via a cold finger to a passive refrigerator cooled by solid methane to ≈100 K. A secondary refrigerant (solid ammonia at 160 K) is also used. Lifetime is limited by depletion of the cryogens to less than one year.

The electronic system includes a 8192-channel pulse height analyzer for the germanium detectors and a 256-channel analyzer for the CsI shield. Logic is included to perform the anti-coincidence function for the shields and identify pair events in the shields. Circuitry is also included for analyzing the time structure of gamma ray burst events in the shields.

The list below shows the objectives of this experiment. Figure 2 is a simplified diagram of the instrument. Following the list of objectives is a list of instrument characteristics.

1. Scientific Objectives

1) Measure gamma ray lines from 0.06 to 10 MeV.

   a) From nucleosynthesis processes in supernovae.

   b) From positron annihilation in the galaxy.

   c) From reported galactic center source.

   d) From nuclear reactions in the low energy cosmic ray flux.

   e) From reactions on neutron star surfaces.

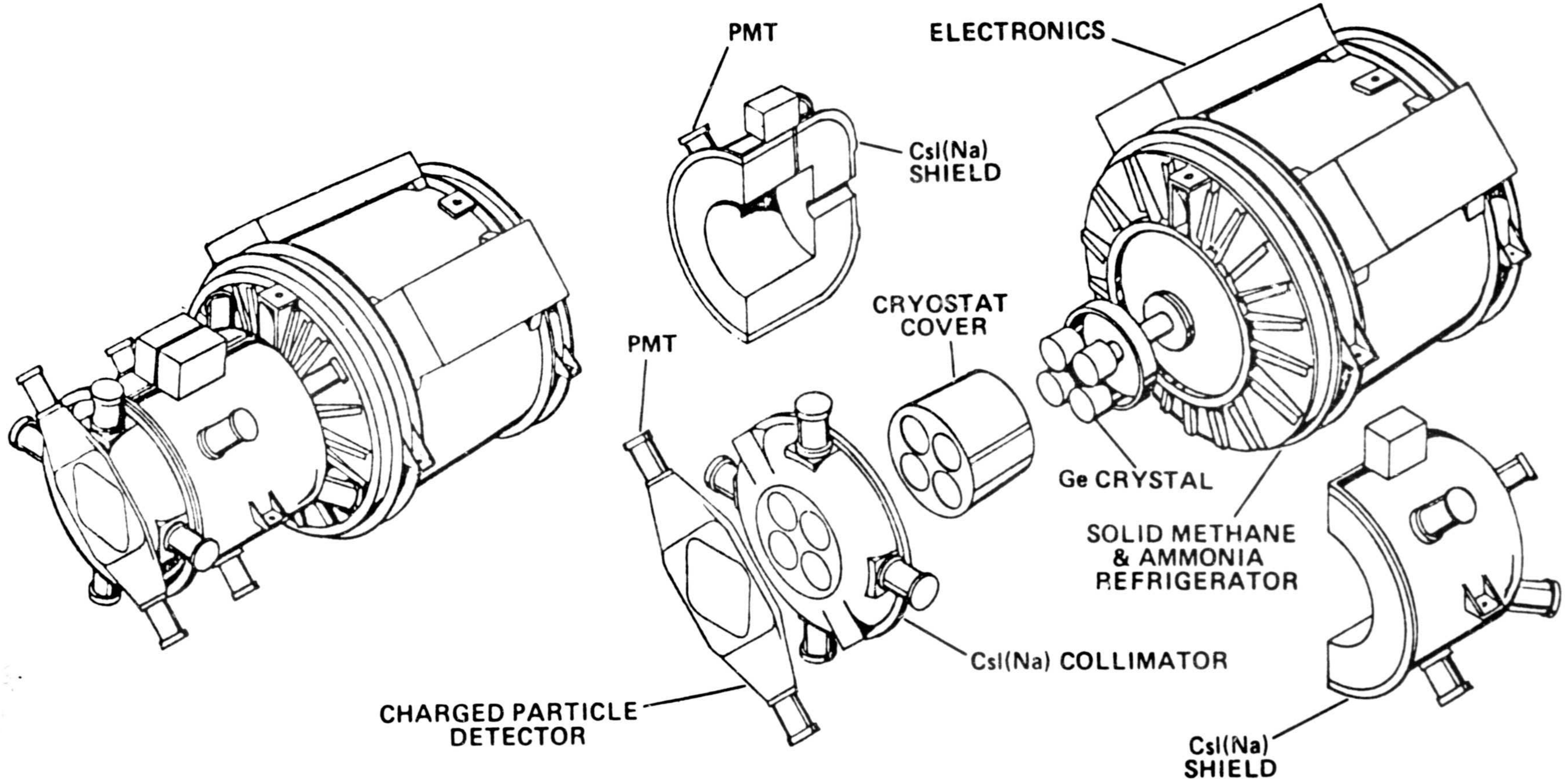

Figure 2. HEAO C-2 Experiment.

2) Obtain spectra and time variations from known X-ray sources.

3) Observe gamma ray bursts.

4) Search for other transient sources.

2. Experiment Characteristics

1) Energy range: 0.06 MeV to 10 MeV

2) Spectral resolution: $\leq$2.5 keV at 1.33 MeV

3) Line sensitivity: 10^{-4} to 10^{-5} photons/cm^2-sec, depending on energy (6 months observation) (about 30 hr on a source) (reduced if Doppler broadened)

4) Geometry factor: 11.1 cm^2-Steradian

5) Field of view: 27° FWHM (0.17 Steradian) for GeLi detectors

6) Minimum shield thickness: 34 gm/cm^2 - 1.5 MFP at 1 MeV

7) Time resolution: <0.1 msec for GeLi, ~10 sec for CsI spectral accumulation time (except for ratemeters)

8) Four intrinsically pure Ge detectors: Area = 16 cm^2 each; Volume = >60 cc each; Efficiency = $\geq$60% relative to 3 × 3 in. NaI at 1.33 MeV for all detectors summed

9) Weight: 237 kg

10) Power: 46.1 W

11) Telemetry: 2.2 KBPS (background rate ≈ 1/3 of saturation)

B. C2 — Isotopic Composition of Cosmic Rays

The C2 instrument consists of five Cherenkov detectors and four hodoscope (track determining) trays of detectors consisting of neon flash tubes. The instrument is bi-directional, measuring cosmic rays arriving from either side of the spacecraft. Two Cherenkov counters at either end of the instrument, consisting of lead glass (index of refraction 1.64) are used to determine the charge (Z) of the cosmic ray nuclei. The remainder of the Cherenkov counters have lower indices of refraction and are used to measure the velocity of the nuclei with high accuracy over the range of values to be encountered in the HEAO-C orbit. The lead glass detector yields the particle's charge because it is close to Cherenkov saturation when the detector with the next lowest Chrenkov threshold (teflon, n = 1.32) responds to the particle. The Cherenkov radiators are discs 60 cm in diameter and are in cylindrical boxes coated on the interior with a diffuse white reflector. Twelve photomultiplier tubes view each detector.

Each flash tube tray of the hodoscope consists of two perpendicular layers of 120 tubes, 5 mm each in diameter. The tubes, filled with neon and other gases, are located between conducting planes that are pulsed with high voltage upon the passage of a particle of interest (as determined from the Cherenkov counters). The addresses of the neon flash tubes that fire are read out electrically.

The isotopic composition measurement utilizes the Earth's magnetic field. The velocity spectrum of each element will be sorted according to the geomagnetic region in which the data is taken. The shape of the spectra near the geomagnetic cut-off velocity will then be used to determine the isotopic composition of the individual element.

The electronic system contains logarithmic preamplifiers to cover the wide dynamic range of Cherenkov counter outputs, and utilizes two pulse height analyzers for each counter, one each for half the tubes on a Cherenkov counter. A flash tube delay circuit controls the time of application of high voltage to the hodoscope trays (based upon the Cherenkov counter pulse heights) to control the number of flash tubes fired by secondary electrons from high Z particles. A time-of-flight system is used to determine the direction of travel of cosmic rays through the instrument. The list below gives the detailed objectives of the measurement. Figure 3 is a simplified diagram. A list of instrument parameters also follows.

1. Scientific Objectives

1) Measure the isotopic composition of cosmic rays between $4 \leq Z \leq 26$ in the momentum range $1 \leq p \leq 15$ GeV/c nucleon to 10 percent precision for most abundant elements.

2) Measure the elemental abundances of cosmic rays up to charge $Z \approx 50$.

3) Isotopic ratios of cosmic rays should reflect strong differences when compared with universal abundances due to their origin in particular nucleogenic processes. The observed ratios should clearly identify these processes.

4) Isotopic ratios of the secondary nuclei (Li, Be, B) should show whether post-injection acceleration of cosmic rays is operating since the production ratios are energy sensitive.

5) The relative abundances of Be^{10} and other radioactive isotopes offer a direct measure of the "age" of cosmic rays.

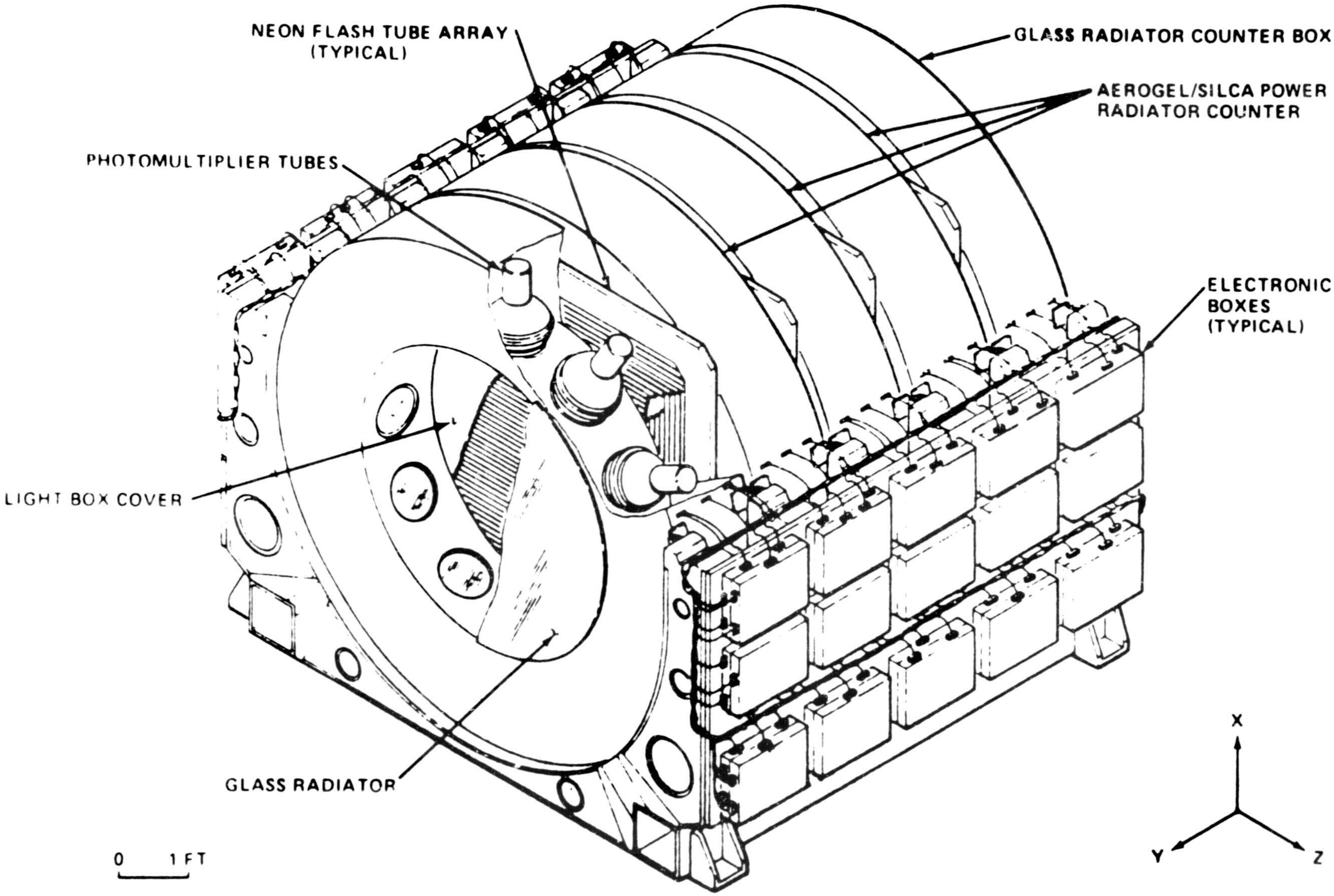

Figure 3. HEAO C-2 Experiment.

2. Experiment Characteristics

1) Geometric factor ≈ 1000 cm^2-Steradian

2) Estimated precision for most isotopic ratios: 10 percent (for abundant elements)

Cherenkov Detectors		Threshold for A/Z = 2
Lead Glass	C1 and C5	(n = 1.64) 0.725 GeV/c Nucleon
Aerogel	C2	(n = 1.055) 2.8 GeV/c Nucleon
Teflon	C3	(n = 1.33) 1.1 GeV/c Nucleon
Aerogel	C4	(n = 1.015) 4.4 GeV/c Nucleon

3) Angular resolution of hodoscope: ≈0.2 degree

4) Weight: 354 kg

5) Bit rate: 1.5 KBPS

6) Power: 51.3 W.

C. C3 — Heavy Nuclei Experiment

The C3 detector system consists of large area pulse ionization chambers, a Cherenkov counter, and ionization counter hodoscopes. The instrument is bi-directional, accepting cosmic ray nuclei from two sides of the spacecraft. The instrument has two pressure vessels, each containing a common gas volume for the parallel plate ion chambers and for the hodoscope assemblies. The gas is a mixture of 90 percent argon and 10 percent methane at 16 psia. Three dual-gap parallel plate pulse ion chambers of 6.9 cm thickness are in each gas volume. A common high voltage supply holds the cathodes at -1000±25 V. When a cosmic ray nucleus transits the detector system, ionizing the gas, a charge pulse is collected on each of the three anodes. A charge-sensitive pre-amplifier and pulse height analyzer attached to each anode provides three independent samples of the ionization energy loss of the nucleus.

Two hodoscope assemblies, one above and one below the ion chambers, define the trajectories of the cosmic rays. The hodoscope assemblies are two dual-gap ionization chambers in which the collecting electrodes are parallel wires spaced 1 cm apart. The collecting wires in each layer are perpendicular. The trajectory is obtained by recording which collecting electrodes see the cosmic ray.

One Cherenkov counter is placed between the two ion chamber boxes. The Cherenkov counter consists of a plastic radiator (pilot 425) in a box coated with highly reflective diffuse white paint. The Cherenkov counter is viewed by eight photomultiplier tubes. An amplifier and pulse height analyzer are associated with each pair of photomultipliers.

An event is recorded when a particle transits one ion chamber assembly including the hodoscopes, and deposits energy equivalent to that of a $Z = 17$ particle.

As the spacecraft orbits the Earth, it moves through regions of low geomagnetic cutoff (< 1 Gv) to high cutoff (16 Gv). At low cutoffs the combination of Cherenkov and ionization measurements determine the charge and velocity of each nucleus. At high cutoffs the Cherenkov and ionization counters supply independent charge measurements and the rigidity spectrum is derived by comparing fluxes at various cutoffs.

The list below contains the scientific objectives of this measurement. Figure 4 is a diagram of the instrument. A list of instrument parameters follows.

1. Scientific Objectives

1) Measure the charge spectrum of cosmic ray nuclei $17 \leq Z \leq 120$.

2) Measure the energy spectra of these nuclei from ≈ 0.3 GeV/Nucleon to about 2 GeV/Nucleon and integral rigidity spectra up to 15 GV/c using geomagnetic cutoffs.

3) Search for anisotropy of iron nuclei with $E > 100$ GeV/Nucleon.

a) Characterize the cosmic ray sources including definition of synthesis process.

b) Define characteristics of the propagation such as path length and lifetime (the latter objective possibly enhanced by "clocks" such as Cm and Np).

c) Improve the understanding of nuclear matter by identifying super heavy elements ($Z > 96$) or setting upper limits on their flux.

2. Instrument Performance Parameters

1) Overall geometrical factor: ≈ 5.9 m^2-Steradian

2) Instrument charge resolution: 0.2 to 0.4 charge units depending on particle trajectory, charge, and energy.

3. Experiment Characteristics

1) Cherenkov counter charge resolution: 0.2 to 0.4 charge units RMS.

2) Energy resolution: ≈ 6 percent below 1.5 GeV/Nucleon. Determined by statistics to 15 GV/c.

3) Hodoscope accuracy: 1.3°.

4) Particles accumulated in 6 months: $Z > 50 \approx 10^3$

5) Weight: 703 kg

6) Power: 24 W

7) Telemetry: 1.7 KBPS.

V. GUEST INVESTIGATOR PROGRAM

After a HEAO Observatory is in orbit and is determined to be providing good science data, an announcement of opportunity to participate (Space Science Notice) is issued to the scientific community by OSS. The announcement describes the scientific objectives and instrument characteristics of the specific mission and gives details concerning the proposal preparation, the review process, and categories of participation offered.

Proposals are reviewed by a review committee at OSS for science objectives, approach/observing time required, schedule and costs proposed. Preliminary selections are made and the proposals are then further screened to meet budgetary constraints.

Selected proposals requiring NASA funding are forwarded to the Project Office for contract implementation. Selected proposals, not funded by NASA, are approved by letter from OSS.

Guest Investigators deal directly with the Instrument Principal Investigators for observations and data and publish scientific reports as the product of their efforts.

The Principal Investigator organizations are provided supplementary funds through the Project Office to support the Guest Investigator activities.

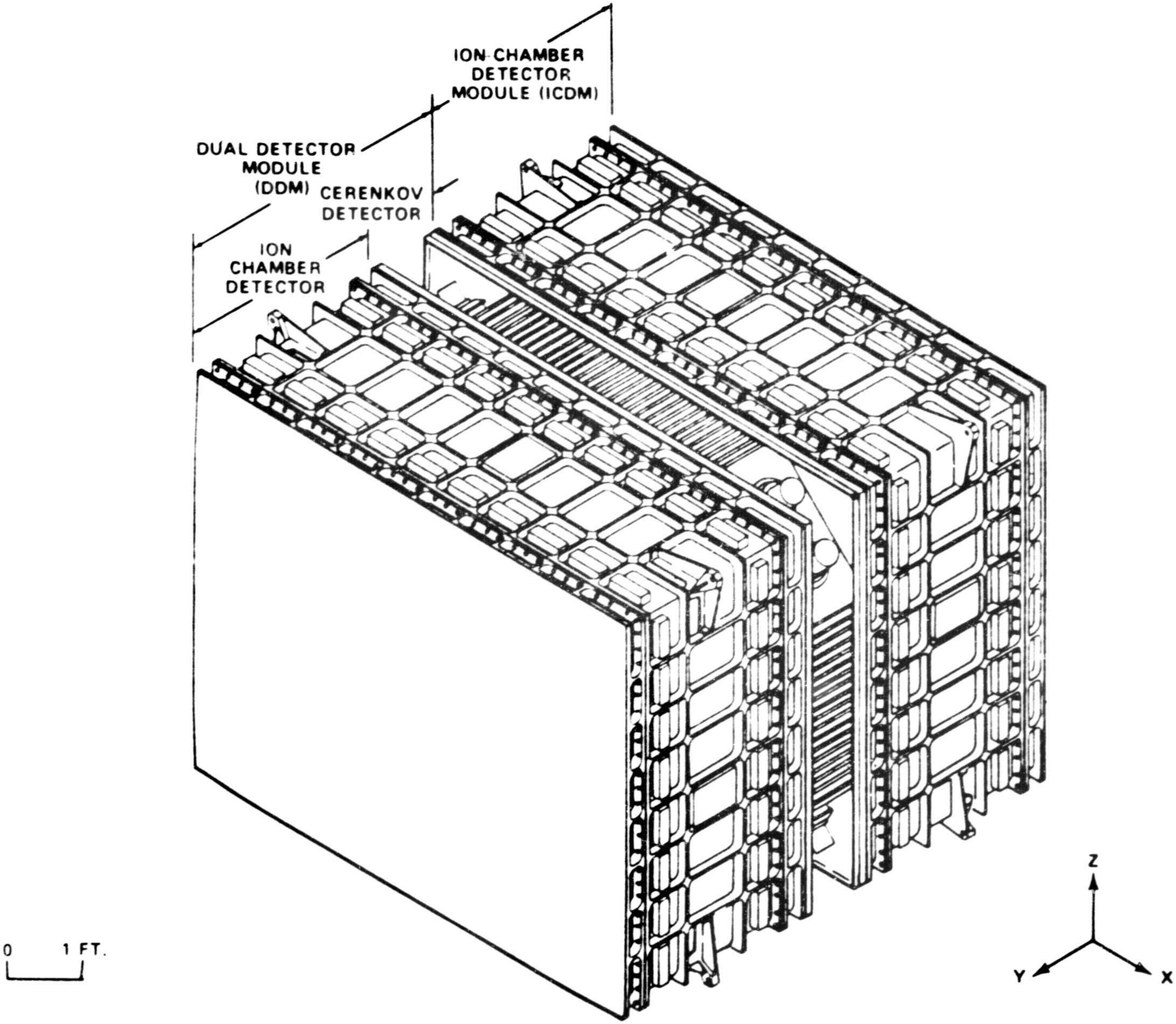

Figure 4. HEAO C-3 Experiment.

VI. MISSION EXTENSION PROGRAM

If the HEAO-C observatory shows a potential of providing good science data beyond the baseline mission, OSS can choose to extend the mission up to the projected useful life of the observatory in order to realize the maximum scientific return. Current planning contemplates total life of HEAO-C at approximately one and one-half years, although depletion of cryogens on C-1 is expected to result in a shorter lifetime for this experiment. The scientific support to the mission operations and the scientific data reduction and analysis of the additional data from the extended mission are provided accordingly.

Additional funding is provided through the Project Office to the Principal Investigator organizations for extended mission activities as described above and, where appropriate, for scientific data reduction and analysis activities beyond these mission extensions.

VII. MISSION OPERATIONS AND DATA MANAGEMENT

The Operations Control Center (OCC) for HEAO is at GSFC. A mission operations team consisting of representatives from the scientific groups, TRW, and NASA will plan and direct the observatory operations.

The Flight Control Team at the OCC has a Flight Director from MSFC who directs all operations there. His team consists of GSFC flight control personnel, data net personnel from GSFC, observatory personnel from TRW, and a scientific liaison team from the experiment groups. The OCC team is planned for a 5 day week, one shift operation after checkout and activation of the observatory, which will require approximately 2 weeks.

During the two work shifts a day when the full OCC team is not present and on weekends, the OCC will be manned by a reduced crew to carry out normal observatory operations. The functions to be performed by the OCC flight control team include:

1) Perform and schedule telemetry ground station passes.

2) Generate and transmit commands to the observatory

3) Monitor and evaluate the state of health of the observatory and resolve anomalous behavior

4) Manage observatory subsystems and experiment configuration

5) Integrate experiment operational requirements into the observatory operation plan and execute requirements such as purging gas counters and pointing the observatory.

Data are transmitted to the ground and commands are generated to the spacecraft during passes within range of the stations of the Space Tracking and Data Net (STDN). Commands received by the observatory may be executed in real time or stored on-board to be executed at a preset time. The commands stored on-board are for instrument cutoff in the South Atlantic Anomaly and pointing operations.

At GSFC two facilities are involved in processing experiment data. The Data Reduction Laboratory (DRL) is a facility attached to the OCC. Its purpose is to examine a selected subset of the experiment data to monitor experiment health and to facilitate operations such as the initiation of normal operations, experiment gas purges, etc. Normal scientific data processing will not be performed at the DRL, but rather with data processing facilities at the institution of the scientific investigators.

The Data Reduction Center (DRC) will handle the preprocessing of the bulk of the data before the data are sent to the investigators' facilities. Its function includes stripping out individual experiment data from the main data stream and calculating post facto ephemeris and spacecraft attitude information to be supplied to the experimenters.

During a STDN station pass, the real time data from the observatory at 6.4 kbs are forwarded, unmodified, to the OCC at GSFC. Some of these data are processed and displayed at the OCC and may be used in the DRL for assessing experiment health. The observatory tape dumps received at the tracking stations are abstracted and the abstracted data are forwarded to the OCC within a few minutes. This abstracted data include spacecraft and experiment housekeeping data.

Each day one or more orbits of data will be designated "quick look" data and the complete data from this orbit will be transmitted from a STDN site to the OCC, delayed only by the transmission time. The scientific data from each experiment will be stripped out at the DRC and transmitted to the individual experimenters' facilities for scientific data analysis. Receipt of the quick look data by the investigators will be within 24 hr of the STDN tape dump.

The bulk of the data will be mailed from the STDN sites to the OCC. After being preprocessed at the OCC, the data from the individual experiments will be forwarded to the investigators' facilities for scientific processing. It is planned that the investigators will receive the data within approximately 6 weeks of the observatory tape dump at the tracking stations.

APPENDIX

HEAO-C GUEST OBSERVER PROGRAM CONTACTS

	Mail Code	Telephone No.
Mr. Richard E. Halpern OSS HEAO Program Manager	SA	202/755-3616
Dr. Albert G. Opp OSS HEAO Program Scientist	SA	202/755-2685
Dr. F. A. Speer MSFC HEAO Project Manager	HA01	205/453-2070
Dr. Thomas Parnell HEAO-C Project Scientist	ES62	205/453-5133
Dr. C. R. O'Dell MSFC Associate Director for Science	DS30	205/453-3033
Mr. Carroll C. Dailey Project Level Scientific Coordination	HA01	205/453-1680
Mr. Joseph B. Jones, Jr. Project Responsibility for Contractual Actions	HA28	205/453-4932

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APPROVAL

HEAO-C OBSERVATORY DESCRIPTION

By Carroll Dailey and Thomas A. Parnell

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

F. Speer

F. A. SPEER
Manager, Space Science Projects Office

Charles A. Lundquist

CHARLES A. LUNDQUIST
Director, Space Sciences Laboratory