ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

EARTH ORBITAL SCIENCE

Space in the Seventies

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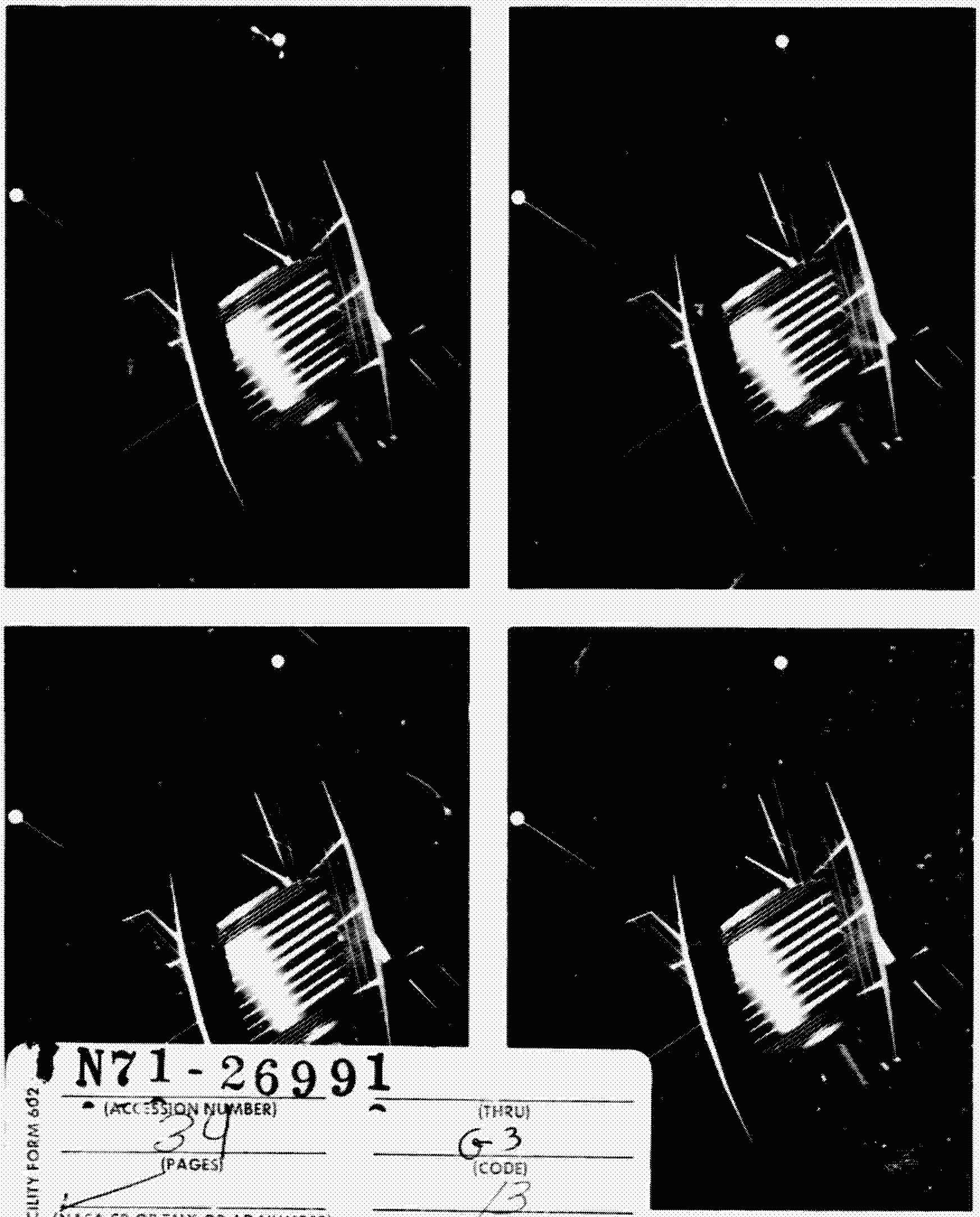
COLOR ILLUSTRATIONS



National Aeronautics and Space Administration

EARTH
ORBITAL
SCIENCE

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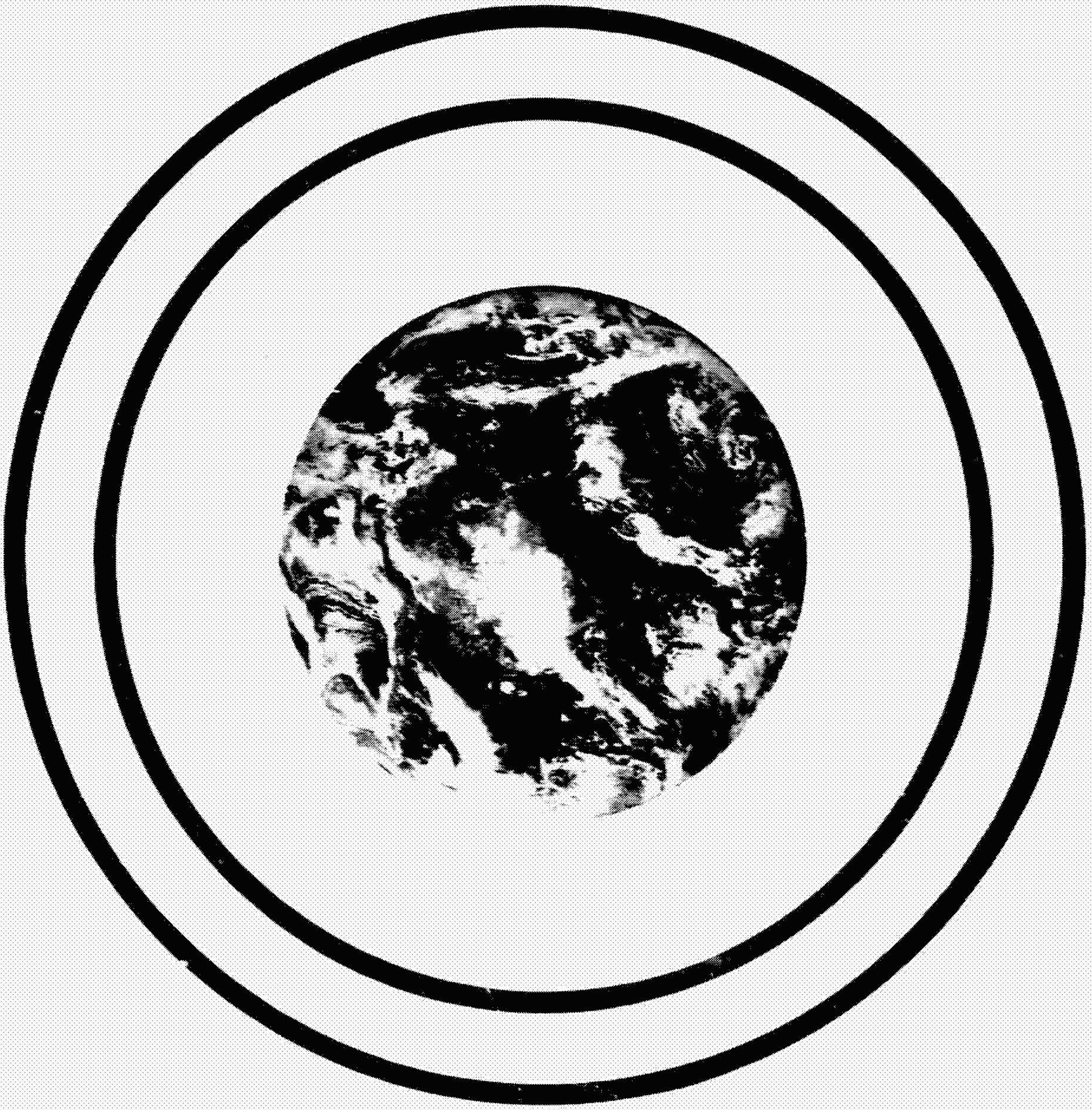

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INTRODUCTION

From 100 miles up, the universe looks much different than it does from the Earth's surface. However, the things seen from satellite orbit depend strongly upon the "eyes" used. To an astronaut in orbit, the sky is a black dome sprinkled with hard points of light and dominated by the Sun and Moon. The Earth below unrolls as a panorama filling almost half the sky. In reality, the astronaut sees more than an Earth-bound scientist but he sees little that is really different. But when ultraviolet detectors, radiation counters, and magnetometers replace human eyes in orbit, the Earth's magnetic envelope and radiation belts become visible; the Sun, the stars, and the other galaxies are seen in light that never penetrates the curtain of the atmosphere.

It was, of course, the presence of this atmospheric curtain that stimulated scientists first to climb mountains with their instruments, then place them on balloons, and more recently install them in rockets and satellites. Radiation detectors carried aloft by balloons proved that cosmic rays came from outer space rather than the Earth itself. Satellite discoveries of the radiation belts, the solar wind, the magnetosphere (the magnetic envelope around the Earth that wards off the bulk of the space radiation), the X-ray stars, and many other space phenomena have radically changed our view of the solar system and of the universe as a whole. Yet, after more than a decade of scientific satellites, what can Earth orbital science do for an encore? What remains undiscovered? If we knew. space science would be cut and dried. Scientists no longer dare say, as many did toward the end of the last century, that the task of Science was complete except for adding a few decimal places here and there. In fact, Earth orbital science has just begun to exploit the potential of satellite instrument carriers. We are just beginning to understand in detail what transpires above the atmospheric blanket that, until 1957, clouded and distorted our view of the universe. The main task of the next decade, therefore, is learning the how and why of the phenomena we have discovered.

Some General Objectives of Earth Orbital Science. *Since one cannot plan unexpected discoveries, the* objectives of Earth orbital science are necessarily rather general:

- Understand better the nature of the space environment and the hazards it may pose to men and machines.
- Identify the forces that shape the Earth's environment.
- Understand better the origin and evolution of the cosmic environment.
- Carry out experiments that cannot be done on Earth; that is, use space as a new laboratory environment.

An Overall Strategy. The strategy of Earth orbital science is two-pronged: one thrust for "space physics," another for "space astronomy." The first deals primarily with the near-Earth environment; the second with the Sun and other *stars beyond. As the historical summaries (below)* show, the strategies in both areas have evolved in

Step Increases in Proficiency— Space Physics	Examples
In situ measurements at orbital altitudes	Explorer 1, 1958
Topside sounding of the ionosphere	Alouette 1, 1962
In situ measurements in cislunar space	Explorer 18, 1963
Large satellites carrying many related experiments	Orbiting Geophysical Observatory 1, 1954
Small, modular, highly automated satellites for synoptic, in situ measurements	Small Scientific Satellite, 1971*
Low altitude, in situ measurements from self-propelled satellites	Atmosphere Explorer C, 1973*
Group flights of two or more satellites to measure correlative phenomena	Proposed

Step Increases in Proficiency— Space Astronomy	Examples
Instrument platforms providing glimpses of Earth, Sun, and stars at ultraviolet and radio wavelengths	Sounding rockets, Explorer satellites, over many years
Pointable instrument platforms for above purposes	OAO 2, 1968* RAE 1, 1968*
Unstabilized instrument platforms giving brief views of Earth, Sun, and stars at X-ray and gamma-ray wavelengths	Small Astronomy Satellite, 1970*
Pointable instrument platforms for above purposes	High Energy Astronomical Observatory, 1974*
Unstabilized and stabilized instrument platforms carrying infrared instrumentation	Proposed

*** Satellite programs covered in this booklet.**

the direction of ever-more-sophisticated spacecraft carrying instruments with wider ranges and better accuracies.

Turning these strategies into action, NASA has begun the design, construction, and testing of the spacecraft listed in Table 1.

In the field of space physics, an entirely new kind of spacecraft, the Atmosphere Explorer C, will be able to penetrate the fringes of the atmosphere without being slowed and quickly removed from orbit by air drag. A small, on-board engine makes up for frictional losses. In addition, the same engine can change the orbit in stepwise fashion, giving a single satellite the perspective of several different satellites in fixed orbits. With the bigger launch vehicles now available another innovation becomes feasible. NASA hopes eventually to orbit small groups of satellites in close flight patterns to detect the so-called correlative phenomena in space, such as the strange "gravity waves" caused by electromagnetic, gravitational, and thermodynamic forces working in concert.

NASA strategy in space astronomy calls not only for additional Orbiting Astronomical Observatories (OAOs), Orbiting Solar Observatories (OSOs), and Radio Astronomy Explorers (RAEs) to expand surveys of the celestial sphere in the ultraviolet and radio regions of the spectrum, but also for new instruments to extend our knowledge at very short wavelengths. The Small Astronomy Satellite (SAS) and High Energy Astronomical Observatory (HEAO) will search the sky looking for X-ray, gamma-ray, and cosmic-ray sources of energy. Some of these sources have already been seen fleetingly by sounding rockets and spinning satellites. Because they may hold the key to understanding how stars and galaxies get their energies, scientists wish to take longer looks from better stabilized spacecraft.

Every time we look at the universe with a new instrument we see a new facet of a cosmos that is ever more complex and mysterious. Our hope is that somewhere in the solution of the great puzzle that nature has presented us we will discover the physical laws that control the cosmos as well as the key to our own fate.

TABLE 1. NASA's Planned Program in Earth Orbital Science*

	71	72	73	74	75	76
Space Physics						
Interplanetary Monitoring Platform (IMP)		H	J			
Small Scientific Satellite (SSS)	A					
Atmosphere Explorer (AE)			C	D	E	
Space Astronomy						
Small Astronomy Satellite (SAS)	B	C				
Orbiting Astronomical Observatory (OAO)	C					
Radio Astronomy Explorer (RAE)		B				
High Energy Astronomical Observatory (HEAO)				A		
Orbiting Solar Observatory (OSO)	H		I	J		K

* The letters designate spacecraft flight models. After a successful launch, a number is assigned; for example OSO H would become OSO 7.

Part One
RESEARCH IN SPACE PHYSICS

The scientific discipline of space physics is usually divided into three parts: (1) Atmospheric physics; (2) Ionospheric physics; and (3) Particles and Fields. It is tempting to divide the volume immediately above the Earth's surface in a similar fashion—like an onion—with the atmosphere on the bottom, next, the ionosphere, and, finally, the radiation belts and magnetosphere. However, this division is highly artificial because the electrically charged atoms and molecules in the ionosphere coexist with their neutral counterparts in the atmosphere. (Fig. 1) Further, all three regions are dominated by a single force—the Sun—and there is considerable interchange of energy and particles between the three regions.

Although sounding rockets began to probe these regions frequently in 1946, when a large supply of captured German V–2 rockets were equipped with scientific instruments rather than high explosive warheads, the brief glimpses of high altitude phenomena only whetted the scientist's appetites. The several score scientific satellites launched since 1957 have described the gross features of the Earth's environment, but they have also revealed the great complexity of the dynamic, Sun-stirred regions surrounding the Earth. Some of the important unsolved problems in space physics follow.

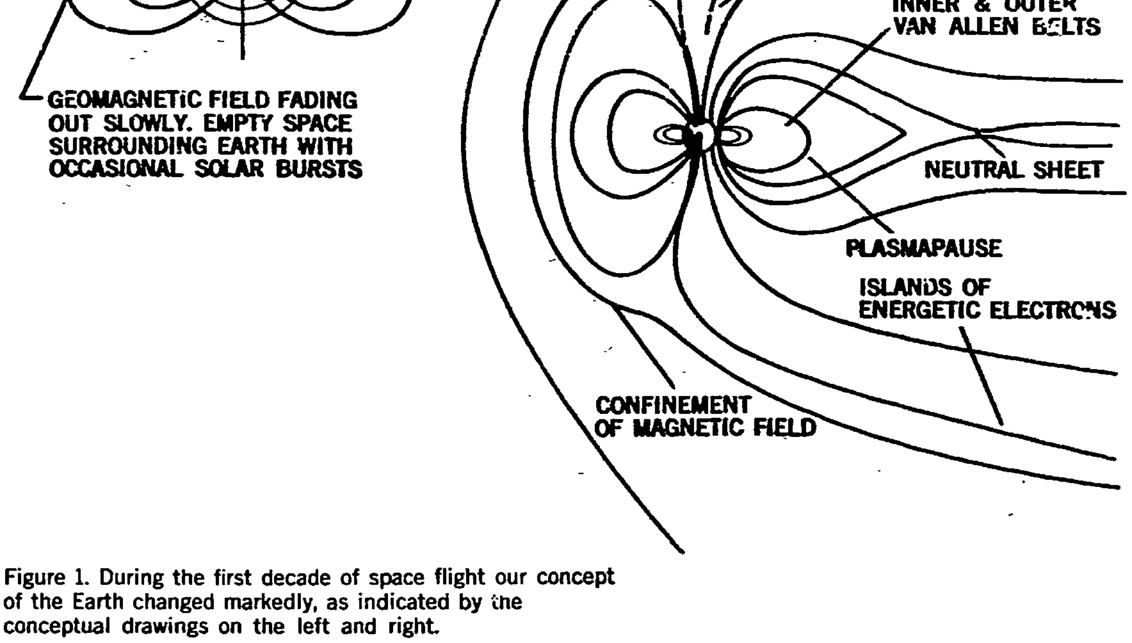


Figure 1. During the first decade of space flight our concept of the Earth changed markedly, as indicated by the conceptual drawings on the left and right.

Some Unsolved Problems of Space Physics

ATMOSPHERIC STRUCTURE AND COMPOSITION:

- What causes the changes in the upper and lower regions of the atmosphere and how are the two regions related?
- We now know fairly well the global distribution of atmospheric composition, density, and temperature as functions of season, the solar cycle, and geomagnetic activity; but we do not know why these factors vary as they do.
- Much of the Sun's energy is absorbed in the transition region between 75 and 95 miles up. What processes occur within this region and how do they affect the regions on either side? (This kind of information is needed for the design of space shuttles and advanced aircraft.)

THE IONOSPHERE

- What are the details of the photochemistry of ion production and loss? In other words, how is the ionosphere created and changed?
- What dynamic processes control ion mobility and transport?
- What is the nature of the Sudden Ionospheric Disturbance (SID)? And other ionospheric disturbances? (This information will be useful in predicting terrestrial communication capabilities.)

PARTICLES AND FIELDS

- Where do the particles trapped in the radiation belts come from? How are they trapped? How do they escape?
- How, in detail, does the solar wind interact with the Earth's magnetosphere? (Fig. 2)
- What is the exact nature of the shock front created when the solar wind collides with the magnetosphere? Why is it located where it is?

INTERRELATIONS AMONG THE REGIONS

- How are the strangely beautiful auroras created?
- How does solar activity cause magnetic storms?
- How does the solar wind vary with time?

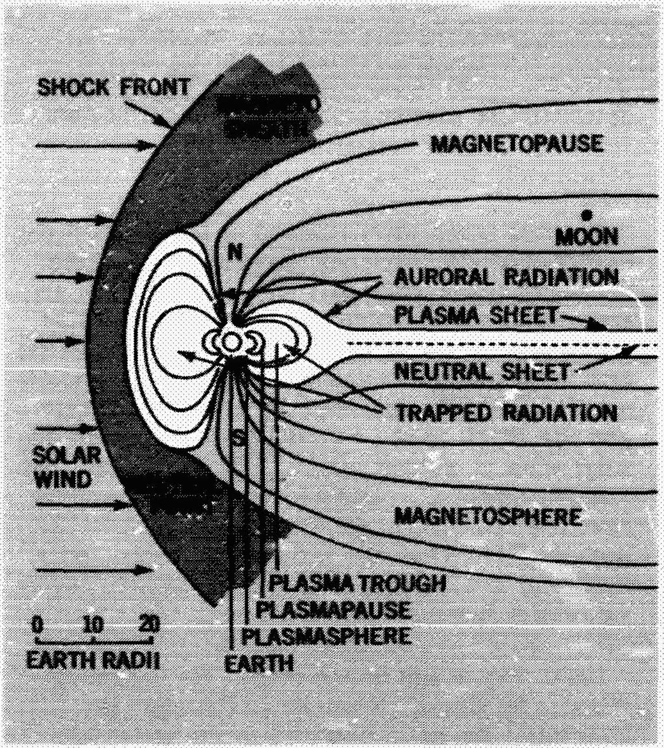


Figure 2. A detailed view of the Earth's magnetosphere and the shock front created when the solar wind hits it.

THE INTERPLANETARY MONITORING PLATFORMS (IMPs)

The IMP series began at NASA's Goddard Space Flight Center in the early 1960s. It has been one of NASA's most successful families of spacecraft. The previous launches in the series have been:

IMP Designation	Official Name	Launch Date
IMP A	Explorer 18	Nov. 27, 1963
IMP B	Explorer 21	Oct. 4, 1964
IMP C	Explorer 28	May 29, 1965
IMP D	Explorer 33	July 1, 1966
IMP E (lunar orbit)	Explorer 35	July 19, 1967
IMP F	Explorer 34	May 24, 1967
IMP G	Explorer 41	June 21, 1969

All of the IMPs are relatively small, spin-stabilized, solar-cell-powered satellites launched by Delta rockets into either highly eccentric Earth orbits or, in the case of the so-called Anchored IMPs, lunar orbit. Many IMP orbits repeatedly pierce the Earth's magnetosphere so that the satellite instruments can sample conditions within and outside the confines of the magnetosphere. Part of the time they measure the interplanetary medium, and part of the time, the environment captured by the Earth's gravitational and magnetic fields. The IMP instrument cargoes usually include magnetometers, radiation detectors, and plasma probes. Essentially, they are "particles and fields" specialists in NASA's inventory of scientific spacecraft.

The first seven IMPs mapped in broad detail the Earth's magnetosphere and the space between the Earth and Moon (cislunar space). Cosmic rays generated by the Sun and the galaxy at large have also been recorded. These spacecraft have provided the first accurate measurements of the interplanetary magnetic field, the boundary of the magnetosphere, and the shock front or "bow wave" caused as the solar wind is warded off by the Earth's protective magnetosphere. Over one hundred scientific papers have been based on data telemetered back to Earth from the IMPs. Thus, the forthcoming IMPs—models H, I, and J—extend a long line of proven, highly successful spacecraft.

IMP-I (Fig. 3) will be the first of the upcoming IMPs to fly, despite the order of the alphabet. With IMP-I the basic objective of the series has shifted from the broad mapping of space phenomena to attempting to understand the details of the processes that create the phenomena. The earlier IMPs, for example, thoroughly studied the particles trapped within the magnetosphere: the new IMPs will investigate the ways in which these particles are accelerated and their sources of energy. This represents a basic change in IMP experimental philosophy.

Within the IMP series, one finds a steady increase in spacecraft capabilities; that is, their growing capacity to provide power, data-handling support, and telemetry services to scientific instruments. To illustrate, IMP A weighed 138 pounds and its solar cells generated an average of 38 watts; IMP-I will weigh in at 613 pounds, with a power capacity of about 166 watts. One of the most important features of IMP-I—from the scientists' viewpoint—is the Digital Data Processor installed on the satellite. In reality, the scientist has a little computer at his disposal that efficiently prepares (encodes) his experiment's data for transmission to the Earth. Experiment design and integration into the spacecraft are consequently much easier than before. Tables 2 and 3 summarize the spacecraft and experiment features for IMP-I.

IMP-I is scheduled for launch during the first half of 1971 from Cape Kennedy. The target orbit has a perigee of 150 nautical miles and an apogee of 117,000 nautical miles. The desired inclination is 28.9°. If this orbit is attained, the satellite period will be 4.58 days.

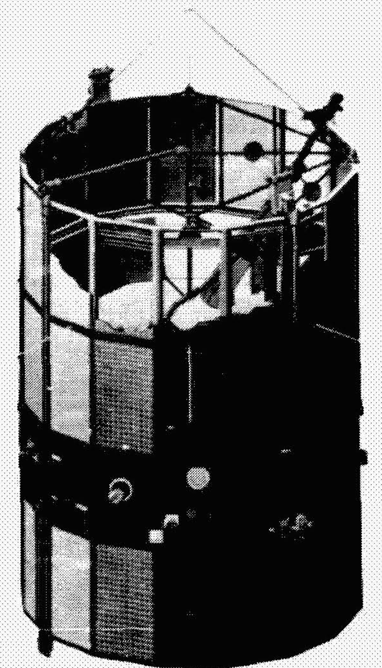


Figure 3. Artist's concept of IMP-I.

THE SMALL SCIENTIFIC SATELLITE (SSS OR S³)

The first S in SSS, for "Small," infers a spacecraft of such a size that it is both inexpensive and launchable by a small rocket. The SSS launch vehicle is the solid-fuel Scout, the smallest satellite launcher in NASA's inventory. The Scout rocket is easily transported and may be launched without the elaborate facilities needed for the bigger rockets, such as those launched from Cape Kennedy. Several additional launch sites therefore become available to the SSS. Thus, the first S really stands for launch site flexibility as well as low cost.

The SSS is also standardized in the sense that it is a general-purpose instrument platform with interchangeable parts. The interchangeable parts on an SSS are actually modules; that is, subassemblies that can be plugged in or removed as the situation demands—like the small drawers of electronic equipment in some television sets. The SSS modules are standardized in such a way that various modules can be plugged into the basic satellite structure to modify the spacecraft for different missions. In this way, the SSS series is made flexible in application; it can be applied to particles-and-fields research, ionosphere studies, solar wind measurements, and so on. Flexibility can be maintained while still retaining the advantages of low cost and reliability gained from using flight-proven modules over and over again.

The SSS idea germinated at Goddard Space Flight Center in the middle 1960s. Originally, SSS was conceived as a logical follow-on to the Energetic Particles Explorer (EPE) series of satellites launched between 1961 and 1964. (After launch, EPEs A, B, C, and D were designated Explorers 12, 15, 16, and 26.) The basic objective of the EPEs was the survey of the radiation belts. Although SSS-A retains the basic objective of the EPEs, the program approach will result in a spacecraft with much broader applications.

SSS-A is a 26-sided polyhedron with a skirt of eight solar panels around the bottom. (Fig. 4) Other solar cells are mounted on the spacecraft body. The magnetometer boom atop the spacecraft, with the spherical instrument housing, gives SSS a superficial resemblance to the EPE series, but

TABLE 2. Design Features and Vital Statistics, IMP-I

Spacecraft Functions	Design Features
Communications	Pulse-code-modulated (PCM) telemetry at 137.170 MHz; 8 watts of power. Analog telemetry at 136.170 MHz; 4 watts of power; for Iowa experiment and tracking.
Power supply	166 watts average beginning of life, 128 watts after one year in space environment. n-on-p solar cells and silver-cadmium battery.
Thermal control	Passive thermal control using black and white paints on exposed parts of spacecraft.
Attitude control	Spin-stabilized. A small monopropellant rocket, using Freon-14, orients the spin axis perpendicular to the plane of the ecliptic and maintains a 5 rpm spin during boom deployment.
Guidance and control	Sun and Earth sensors measure Sun angle, spin rate, and spin axis orientation. 189 commands possible from Earth-based controller.
Data handling	Digital Data Processor (see text) can handle 3200 bits/sec of PCM telemetry or 800 bits/sec with "convolutional" coding. 15,000-bit memory.
Structure	Sixteen-sided drum, 71.7 inches high, 53.4 inches across flats. Weight: about 625 pounds.
Launch vehicle	Delta
Tracking and data acquisition network	Space Tracking and Data Acquisition Network (STADAN).

TABLE 3. Scientific Instrumentation, IMP-I

Instrument	Scientific Objectives	Principal Investigator
Three solid-state cosmic-ray telescopes	Measure cosmic-ray energies, composition, and angular distribution, 0.05 to 500 Mev per nucleon up to atomic number 30.	F.B. McDonald (Goddard Space Flight Center)
Two solid-state cosmic-ray telescopes	Similar to above; 0.5 to 1200 Mev. Emphasis on high charge resolution.	J.A. Simpson (University of Chicago)
Low-energy proton and electron differential-energy analyzer (LEPEDEA)	Measure differential energy spectra, angular and spatial distributions, and time variations of electrons and protons; 5 to 50,000 ev.	L.A. Frank (University of Iowa)
Solid-state detectors and Geiger counter telescopes	Measure the energy spectrum of solar electrons; 20 to 400 kev. Study electron fluxes in outer radiation belt.	K. Anderson (University of California, Berkeley)
Five solid-state detectors	Monitor solar protons; 210 kev to over 60 Mev; and solar electrons over 10 kev.	C. Bostrom (Applied Physics Laboratory)
Collimated electron detector, background detector, and gamma-ray spectrometer	Measure cosmic-ray electrons; 50 kev to 2 Mev.	T. L. Cline (Goddard Space Flight Center)
Plasma probe	Measure the temperatures of hydrogen and helium ions in the solar plasma; 200 to 8000 ev.	K.W. Ogilvie (Goddard Space Flight Center)
Hemispherical plasma analyzer	Study electrons and positive ions in the solar wind, magnetosheath, and magnetotail.	S.J. Bame (Los Alamos Scientific Laboratory, Los Alamos)
Three orthogonal pairs of antennas	Monitor the electric field vector.	T.L. Aggson (Goddard Space Flight Center)
Three antenna systems	Study the origin and characteristics of radio noise in the magnetosphere, the transition region, and the solar wind.	D. Gurnett (University of Iowa)
Three-axis fluxgate magnetometer	Measure the Earth's magnetic field with high precision.	N.F. Ness (Goddard Space Flight Center)
Two complementary radiometers	Study the radio spectra of the galaxy, the Sun, and Jupiter.	W.C. Erickson (University of Maryland)

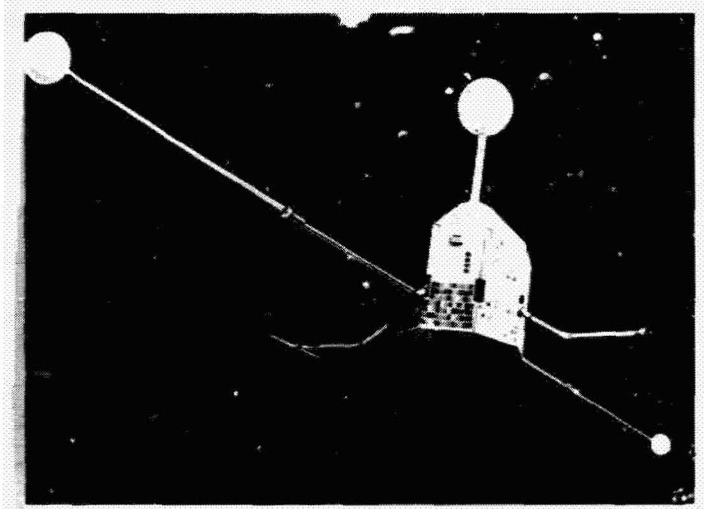


Figure 4. Artist's concept of SSS–A.

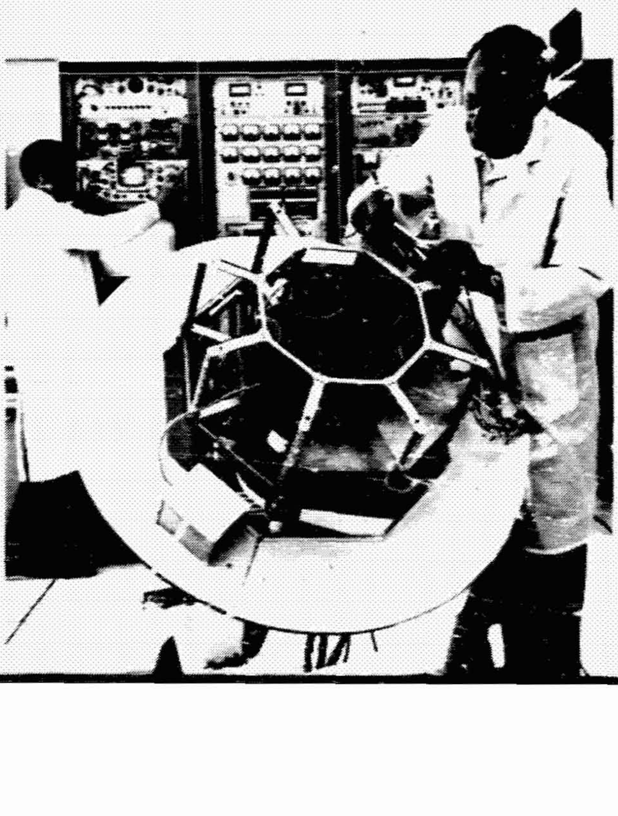
without the EPEs solar paddles. The scientific experiments and much of the spacecraft equipment are packaged in standard trapezoidal-shaped modules that plug into the eight-sided central section. Other spacecraft particulars are given in Table 4.

The scientific objectives of the first SSS, SSS-A, include the investigation of the Earth's equatorial ring current, the evolution of magnetic storms, time variations of the charged particles trapped in the radiation belt, and the relationship between trapped particles, the Earth's magnetic storms, and the auroras. The instrumentation of SSS-A will be much like that on the EPE and IMP series. The SSS, however, is a close-in spacecraft, orbiting within the magnetosphere almost all of the time, in contrast to the EPEs and IMPs that swung out tens of thousands of miles in highly elliptical orbits. The SSS-A instruments are identified in Table 5.

SSS-A was originally scheduled for launch in Sept. 1970, but, after midnight on December 10, 1969, a fire at Goddard Space Flight Center damaged the partially built spacecraft. Some spacecraft parts and equipment were salvaged, and, with the combination of spare parts and newly fabricated parts, a new spacecraft was assembled. The fire damage set the program back about six months. The SSS-A launch is now planned for early 1971.

Because the SSS-A mission involves the equatorial ring current, it is desirable to inject the spacecraft into an equatorial orbit. This cannot be done with the Scout rocket and SSS payload from American launch sites. However, the Scout rocket, which was also the launch vehicle for the Italian San Marco satellites, can be launched from the San Marco Range. This Range originates on a Texas-Tower-like platform built close to the equator in the Indian Ocean. The planned orbit has an apogee of 13,800 nautical miles and a perigee of 150 nautical miles. The inclination to the Earth's geographical equator is to be about 2.9°. (Note that the geomagnetic and geographical equators do not coincide; neither do the poles.)

Figure 5 and 6. SSS-A after fire at Goddard Space Flight Center (left). Rebuilt satellite (below).



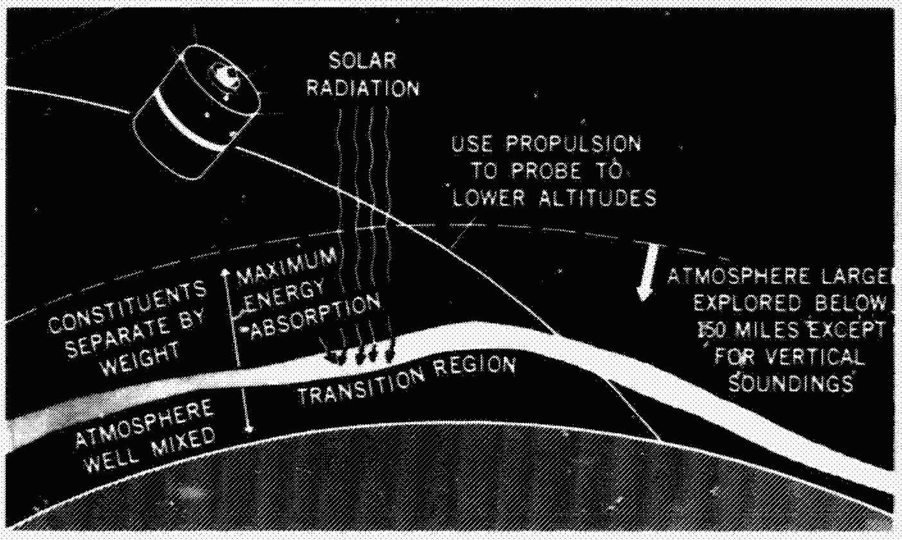


Figure 7. The mission of the Atmosphere Explorer takes it deep into the Earth's transition region.

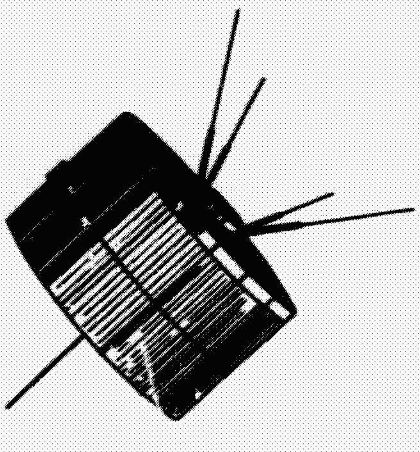


Figure 8. Artist's concept of AE-C.

SATELLITES IN THE TRANSITION REGION, THE ATMOSPHERE EXPLORERS (AEs)

The Earth's atmosphere below 50 miles has been well explored by aircraft, balloons, and sounding rockets. Above 100 miles, where air resistance is slight, satellites can orbit for months or years, relaying back to Earth information on the composition, density, and temperature at the outer fringe of our planet's gaseous envelope. Unfortunately, one of the most important parts of the atmosphere, the transition region (Fig. 7) 75 to 95 miles up, where most of the Sun-induced photochemistry occurs, has seen few instrument carriers. The air here is too dense for satellites, which would quickly decelerate and fall back to Earth. Of course, sounding rockets can penetrate this region, but such flights provide only spotty coverage. The Atmosphere Explorers C, D, and E were designed to fill this gap in our knowledge.

The two preceding satellites in the AE series—AEs A and B (Explorers 17 and 32)—were injected into relatively high orbits well above the transition region. Explorer 17, for example, discovered the belt of neutral helium atoms existing between 150 and 600 miles. Except for the kinds of instruments carried, the new AEs bear little resemblance to AEs A and B. The first two AEs were spherical in shape, whereas the new models are cylindrical with a rocket nozzle protruding from one end. (Fig. 8.) It is this engine that makes the new AEs unique among scientific satellites. On occasion, at the perigee end of its elliptical orbit, when the AE plunges into the denser regions of the upper atmosphere, this small hydrazine engine will fire to compensate for the air drag encountered. AEs C, D, and E are also about twice the weight of A and B. At 1000 pounds (100 pounds for instruments), the new AEs are the largest of NASA's Explorer-class satellites.

Another interesting feature of the new AEs is the use of heat sinks to absorb and distribute the aerodynamic or friction-caused heat picked up during the brief forays into the sensible atmosphere. Heat sinks are masses of material with high heat capacity, such as beryllium, that temporarily absorb much of the aerodynamic heat pulse. With heat sinks and a propulsion system to make up drag losses, the AEs represent significant advances in satellite technology. Other AE features are listed in Table 6.

The instruments selected for AE-C are described in Table 7. The fundamental AE-C objectives are to investigate the photochemical processes in the transition region, where the Sun's ultraviolet dissociates many molecules, and the cause-and-effect relations at higher altitudes. As AE-C's complement of instruments indicates, one must look not only at the particle population in this region but also the solar ultraviolet light, which actually causes the reactions. Because the satellite will dip far enough into the atmosphere for air drag to be a measurable quantity, an

TABLE 4. Design Features and Vital Statistics, SSS-A

Spacecraft Functions	Design Features
Communications	Pulse-code-modulation (PCM) telemetry at 136.830 MHz. Two-level transmitter; ½ or 5 watts. Command receiver at 148.980 MHz
Power supply	Solar cells plus silver-cadmium battery. 800 2x2 cm n-p cells and 1116 2x3 cm n-p cells on top, side, and skirt facets. 25–30 watts at beginning of life.
Attitude control	Spin-stabilized satellite with magnetic torquing.
Thermal control	Passive thermal control using various thermal coatings. Spacecraft bottom protected with superinsulation.
Guidance and control	Sun and Earth sensors. SCADS (Scanning Celestial Attitude Detection System) determines attitude from guide stars to within 0.1°. From the ground, 80 PCM commands plus backup tone commands.
Data handling	Modular, general-purpose data handling system. Incorporates a buffer memory, central processor, and enables the reprogramming of the telemetry format in-flight. Tape recorder.
Structure	26-faceted polygon with 8-facet skirt around bottom. Four radial instrument booms and central magnetometer boom on top along spin axis. Weight: about 115 pounds. Polyhedron approximates a sphere 27 inches in diameter.
Launch vehicle	Scout
Tracking and data acquisition network	San Marco Range during launch. Space Tracking and Data Acquisition Network (STADAN) thereafter.

TABLE 5. Scientific Instrumentation, SSS-A

Instrument	Scientific Objectives	Principal Investigator
Channel multipliers, scintillators, solid-state detectors in an electrostatic analyzer	Measure the relationships between trapped particles, the geomagnetic field, and the auroras	D.J. Williams (Goddard Space Flight Center)
Two-axis fluxgate magnetometers and two search-coil magnetometers	Correlation of magnetic fields with charged particle measurements made in above experiment	L.J. Cahill (University of New Hampshire)
A.C. and D.C. electric field detectors (actually spheres on ends of booms)	Measure particle-wave interactions	D.A. Gurnett (University of Iowa) and N.C. Maynard (Goddard Space Flight Center)

accelerometer has been included in the payload. Of course, this instrument will also record velocity changes caused by the small onboard hydrazine engine. These data, combined with precision tracking of the spacecraft from the ground, will be useful to aerodynamicists designing space shuttle craft that must fly back and forth through the transition region as they carry cargo to orbital vehicles and stations.

AE-C and AE-D are scheduled for flight in 1973 and 1974, respectively. Plans call for putting AE-C into an elliptical orbit inclined midway between the Earth's equatorial plane and a plane through the poles. AE-D will be placed in polar orbit; while the third of the new AEs, AE-E, is destined for an equatorial orbit. In this way, the transition region will be mapped at most latitudes when the perigees of these three orbits carry the AEs into different parts of the upper atmosphere. To attain these inclinations, different launch sites are required:

AE-C	Mid-inclination	Cape Kennedy
AE-D	Polar inclination	Western Test Range
AE-E	Equatorial inclination	An equatorial site

TABLE 6. Design Features and Vital Statistics, AE-C *

Spacecraft Functions	Design Features
Communications	Pulse-code-modulation (PCM) telemetry. 8640 bits sec. Transmitter frequencies: 136 and 2250 MHz. PCM command frequency: 148 MHz.
Power supply	n-p solar cells on top and sides of spacecraft. Nickel-cadmium battery. Provides 100 watts.
Attitude control	Spin and despin modes, 0–10 rpm. Spin axis perpendicular to orbital plane. Momentum wheels, magnetic torquers, and nutation dampers control attitude and spin.
Propulsion	Hydrazine engine produces about 5 pounds of thrust. Propellant tank will carry 400 pounds of fuel.
Guidance and control	Horizon scanners and solar aspect sensors.
Data handling	Encoders. Two tape recorders.
Structure	Cylinder 54 inches in diameter and 40 inches high. (Fig. 8) Weight: about 1000 pounds, including propellant and instruments.
Launch vehicle	Delta
Tracking and data acquisition network	Space Tracking and Data Acquisition Network (STADAN).

* Some of these data, particularly weights, may change as design and fabrication progress.

TABLE 7. Scientific Instrumentation, AE-C

Instrument	Scientific Objectives	Investigators
Neutral mass spectrometer (closed source)	Measurement of the concentrations of neutral atoms: H, He, N, O, Ar; molecules N_2, O_2; and the local temperature.	D.T. Pelz (Goddard Space Flight Center)
Neutral mass spectrometer (open source)	Measurement of the densities of neutral constituents. 1–50 amu.	A.O. Nier (University of Minnesota)
Langmuir probe	Measurement of electron density and temperature.	L.H. Brace (Goddard Space Flight Center)
Photometer (extreme ultraviolet range)	Measurement of ultraviolet light emitted by the upper atmosphere airglow in several bands between 180 and 1100 Angstrom units.	D.F. Heath (Goddard Space Flight Center)
Spectrometer (extreme ultraviolet)	Recording of the continuous spectrum in the extreme ultraviolet from 170–1700 A.	H.E. Hinteregger (Air Force Cambridge Research Laboratories)
Ion spectrometer	Measurement of ionic composition in upper atmosphere, 1–64 amu.	J.H. Hoffman (University of Texas)
Neutral temperature probe	Measurement of the temperature of the neutral atmosphere.	N.W. Spencer (Goddard Space Flight Center)
Ion trap	Measurement of ionic density, composition and temperature.	W.B. Hanson (University of Texas)
Photoelectron spectrometer	Measurement of the density and energy distribution of photoelectrons in the upper atmosphere.	J.P. Doering (Johns Hopkins University)
Accelerometer	Measurement of atmosphere-induced decelerations and the neutral air density.	K.S. Champion (Air Force Cambridge Research Laboratories)

COOPERATIVE PROGRAMS IN SPACE SCIENCE

The upper atmosphere and the space between the Earth and the Moon is such a fertile region for space research that several foreign countries have built their own satellites. However, the costs of launch vehicles. launch ranges, and world-wide tracking and data acquisition networks are high. Therefore, many countries prefer to enter into cooperative agreements with the United States, under which the United States provides those elements of technology missing in their space programs. It is a two-way street, though, because American scientists often get opportunities to fly instruments on these foreign spacecraft. Further, the foreign efforts permit the United States to make better use of its scientific resources. The NASA cooperative satellite effort launched its first satellites in 1962, when Great Britain's Ariel 1 and Canada's Alouette 1 were orbited successfully. So successful have these cooperative programs been that the number of countries involved has expanded. In fact, the satellites now being prepared for flight are so numerous that a table is in order to describe them (Table 8). It should also be noted that the United States has many cooperative agreements with foreign countries involving sounding rocket research.

NASA also supports other agencies of the United States government, such as the Air Forc and Navy, in their space research programs. Table 8 also includes these programs.

TABLE 8. Launch Schedule For NASA Cooperative Programs—Scientific Satellites

Satellite Designation	Country or U.S. Agency	NASA Involvement*			Launch Date	Scientific Objectives
		Vehicle	Range	Network		
Aeros	Germany	Scout	WTR	none	1972	Measure the relationship between the state of the upper atmosphere and absorption of solar ultraviolet radiation.
AFCRL	Air Force	Scout	WI	STADAN	1971	Study magnetic storms through measurement of fields and particles in inner magnetosphere.
ANS	Netherlands	Scout	WTR	STADAN	1974	Study stellar spectra in the range 1500-3300A, and X-rays in ranges 0.2-4 kev and 2-40 kev.
Barium ion cloud†	Germany	Scout	WI	Optical tracking	1971	Using a released barium ion cloud, study physical properties of magnetosphere at several Earth radii.
ISIS-B, C	Canada	Delta	WTR	STADAN	1971, 1972	Measure distribution of electrons and ions in ionosphere, the particles that interact with them.
San Marco -C	Italy	Scout	San Marco	STADAN and others	1971	Measure equatorial atmospheric parameters between 100 and 500 miles.
Solrad-10	Navy	Scout	WI	STADAN	1971	Monitor solar X-ray and ultraviolet emissions and solar flares. Monitor stellar X-rays.
UK-4	Great Britain	Scout	WTR	STADAN	1971	Investigate interactions among plasma, charged particle streams, and electromagnetic waves in the upper atmosphere.
UK-5	Great Britain	Scout	WI	STADAN	1973	Investigate galactic and extragalactic X-ray sources. Measure positions, spectra, intensities, and time variations from 0.3 to over 300 kev.

* WI—Wallops Island Range, Virginia.
WTR—Western Test Range, California.

† Not an orbital vehicle, but larger than most sounding rockets. Will fly higher and carry a greater payload than most sounding rockets.

Part Two
RESEARCH IN SPACE ASTRONOMY

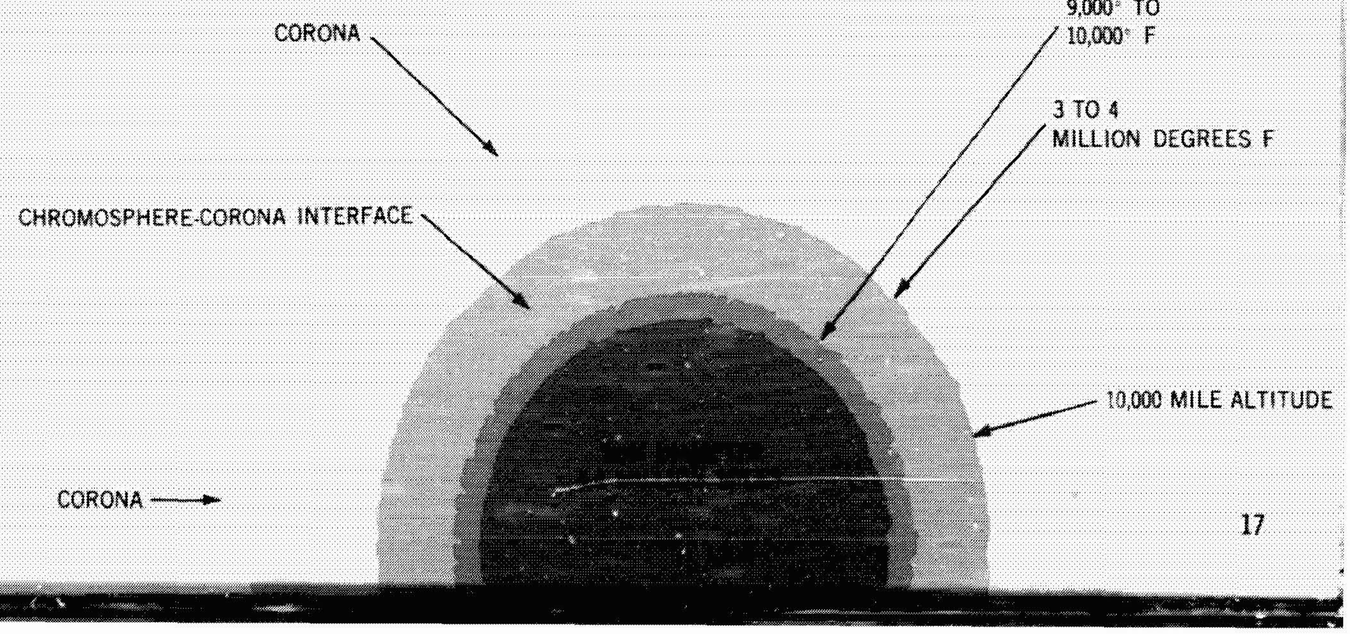
Space astronomy began—not with satellites—but rather with high altitude balloons and sounding rockets. The early sounding rockets are dwarfed by today's Saturn rockets, but these early rockets were able to carry several pounds of ultraviolet and X-ray detectors above the bulk of the Earth's atmosphere. The flights began in the early 1950s; many were executed by the Naval Research Laboratory from which many key scientific personnel were drawn when NASA was created in 1958. Scanning the celestial sphere (the Sun in particular) during the few moments available at the tops of their trajectories, these sounding rockets revealed unexpected sources of ultraviolet light and X-rays. Their views of what the sky really looks like were all too brief for they fell quickly back to Earth. What they saw, however, was enough to make astronomers realize that there was a great deal more to the universe than visible light revealed.

When satellites began more lengthy sojourns above the atmosphere in 1957, emphasis was on space physics at first. The first satellite devoted to space astronomy was Solrad-1, a tiny "piggyback" satellite orbited by the Navy in 1960 to monitor solar ultraviolet light and X-rays. NASA's Explorer 11, in 1961, represented an early attempt to search the sky for gamma ray sources.

Space astronomy concentrated first on the Sun. The first Orbiting Solar Observatory, OSO-1, launched in 1962, marked the beginning of a long highly successful program in solar research. The important innovation on OSO-1 was the "sail" portion of the spacecraft that always pointed at the Sun. Accurate instrument pointing has been crucial to space astronomy, and OSO-1 was the first to lock onto a star—the Sun—with instruments that saw outside the visible portion of the spectrum. The history of space astronomy has been primarily a story of our ever-increasing ability to find specific stars and point instruments at them—steadily, for long periods of time.

Astronomical instruments vary depending upon the wavelengths measured and whether or not one wishes to focus this electromagnetic radiation into an image of a star or, in the case of the Sun, a selected portion of the Sun's disk. To

Figure 9. Our current model of the Sun's outer regions, as modified by the early OSO flights.



illustrate the effect of wavelength, consider the Radio Astronomy Explorer (RAE) satellite. In order to detect and determine the origin of low-frequency radio waves in space, the RAE antennas had to be 1500 feet long. Even then, sharp images of radio stars, analogous to those bright points we know in visible light, are still impossible. At the short wavelength of the spectrum, images are hard to form for a different reason. X-rays cannot be focussed by conventional telescopic lenses. Telescopes that form images of stars at these short wavelengths must be based upon the property of reflection rather than refraction. Such telescopes are often quite large. Thus, a second major problem of space astronomy has been the sheer size of some of the instruments.

The following pages will demonstrate that great progress has been made in solving the problems of instrument size and pointing. Because the Sun was the first target of space astronomy, NASA's new OSOs will head the list of projects. Then, more or less in the order in which technical problems were solved, the new OAOs and RAEs will be covered. Two new astronomical spacecraft complete the list: the Small Astronomy Satellite (SAS) and the High Energy Astronomical Observatory (HEAO).*

SCRUTINIZING OUR NEAREST STAR

The Sun is so close and such a powerful radiator of energy that one wonders why adequate observations cannot be made from terrestrial observatories. Of course, the atmosphere is the culprit, blocking most wavelengths except the visible band and some portions of the radio spectrum. Even where the atmosphere is relatively transparent, its turbulence compromises scientific observations. Consequently, until instruments on rockets and satellites took a look, solar physicists were essentially color blind—at least in terms of the ultraviolet, some of the infrared, and most of the rest of the electromagnetic spectrum.

The OSOs have found the Sun to be most "expressive" at the short wavelengths. X-rays and ultraviolet light are indicative of solar processes more energetic than those that emit visible light. For example, solar flares seem to announce their development by emitting X-rays and ultraviolet light before they can be seen visually.

Solar flare prediction is valuable to us 93,000,000 miles away from the Sun because magnetic storms and solar radiation affect not only our astronauts out in space but also terrestrial communications and possibly our weather and other phenomena. The Sun is also an astrophysical laboratory—the only star we can see in detail. By studying it we have learned a great deal about the evolution of all stars. There is still much we do not know, however, as the following list shows:

Some Unsolved Problems of Solar Physics

- What is the relationship between the Sun's magnetic field and solar activity? Can solar flares be forecast by analyzing changes in the Sun's field?
- How are solar cosmic rays generated? How are the charged particles accelerated to such high energies? Are solar flares the principal sources of solar cosmic rays?
- Why do flares, prominences, and other signs of solar activity follow the classical sunspot cycle?
- How is energy transferred in the Sun's atmosphere?
- Does the solar constant—that is, the amount of energy reaching the Earth—vary with the sunspot cycle?

THE ORBITING SOLAR OBSERVATORIES, OSOs, H, I, J, and K

The primary objective of OSO-H is the acquisition of high resolution spectrograms from the solar corona in white light during one complete solar rotation. A secondary objective is the recording of the spectrum of solar and cosmic X-rays beyond the first solar rotation.

As a spacecraft family, the OSOs are unique in that their top portions (the sails) point perpetually at the Sun, while the bottom wheels spin gyroscope-like to stabilize the spacecraft (Fig. 10). Of course, a motor on the spacecraft turns the sail at just the right speed so that the sail and its instruments always look at the Sun. Gas jets at the rims of the wheel and sail portions control the satellite's attitude. The sunward side of the sail is obviously the best place to mount solar cells for electrical power generation. Other design features are presented in Table 9.

The success of the OSO program can be inferred from the number of successful satellites that have been orbited:

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* The Apollo Telescope Mount (ATM), a manned mission, is covered in another booklet in this series

Preflight designation	Postflight designation	Launch date	Remarks
OSO A	OSO 1	March 7, 1962	
OSO B-2	OSO 2	February 16, 1965	OSO B-1 was accidentally destroyed at Cape Kennedy
OSO C	none	August 25, 1965	Launch vehicle failure
OSO E	OSO 3	March 8, 1967	
OSO D	OSO 4	October 18, 1967	
OSO F	OSO 5	January 22, 1969	
OSO G	OSO 6	August 9, 1969	

The six OSOs already injected into orbit are all similar. Their weights vary somewhat and there have been steady improvements in the scientific payload capacity, the data handling capabilities, and especially in the ability of the spacecraft to point accurately and steadily at the Sun. The OSO's sail is a platform which permits certain instruments mounted on it to scan the solar surface zigzag fashion in what is called a "raster." In other words, platform-mounted instruments can build up a picture of the Sun (say, in ultraviolet light) just as a TV camera constructs a picture in visible light.

OSO-H, the next satellite in the series to be launched, is roughly twice as heavy as the earlier OSOs. The wheel diameter has grown from 44 inches to 67 inches; power production has been more than doubled; the number of command decoders has been increased from four to seven, making the spacecraft more responsive to commands from the experimenters and ground controllers. What stimulated these major changes? The experiments selected and assigned to OSO-H simply outgrew the standard OSO spacecraft. OSO-H instruments were selected over three years before the planned flight in order to give the

Figure 10. Illustration of OSO showing the major spacecraft components visible from the outside.

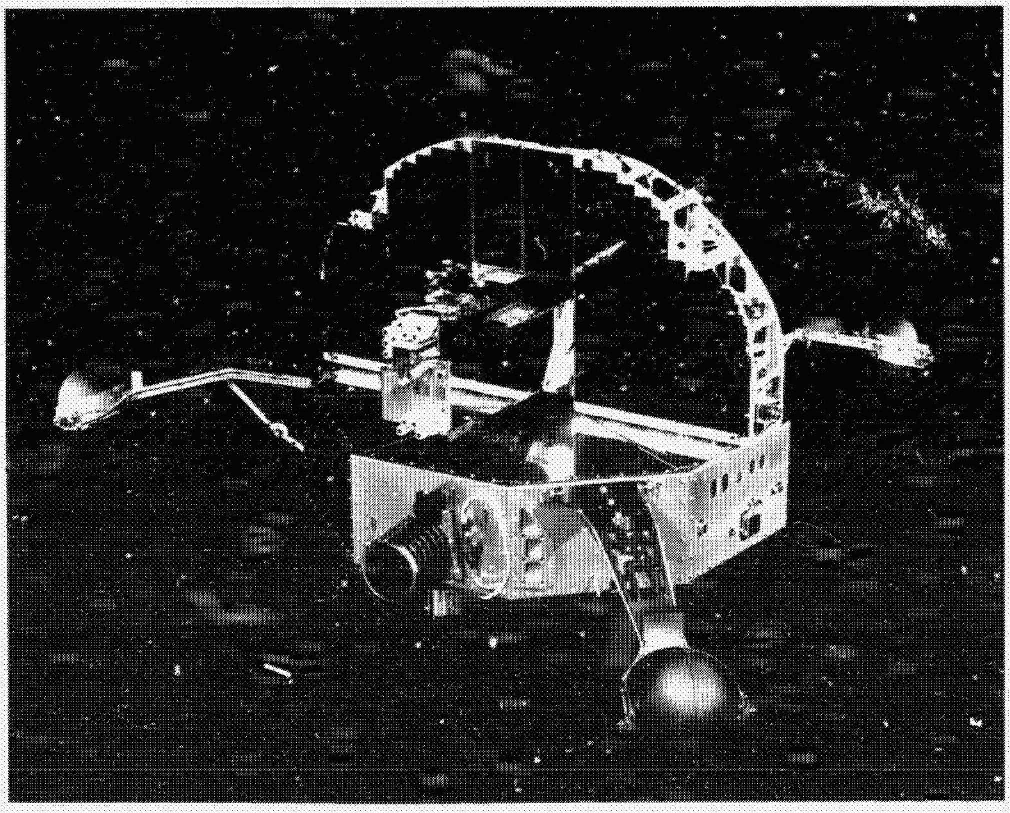


TABLE 9. Design Features and Vital Statistics, OSO-H*

Spacecraft Functions	Design Features
Communications	Pulse-code-modulated (PCM) telemetry.
Power supply	n-p solar cells on sail provide up to 100 watts.
Attitude control	Spin-stabilized by wheel section. Gas jets and inertia wheels control attitude and spin rate. Nutation damper.
Thermal control	Passive paints and coatings.
Guidance and control	New aspect system, consisting of star-mapper and gyroscopes, determines roll attitude and permits nighttime pointing. Scanning platform has 60x60 raster. 490 commands possible.
Data handling	Tape recorder
Structure	Nine-sided wheel plus rectangular sail. Wheel: 57 inches in diameter. Space craft: 67 inches high. Weight: about 1329 pounds.
Launch vehicle	Delta
Tracking and data acquisition network	STADAN

* Some of these data, particularly weights, may change as design and fabrication progress.

experimenters ample time to design and test their apparatus. As the instrument payload grew during the design process, the spacecraft responded in the same way. To illustrate; the OSO-H wheel will accommodate about 300 pounds of instruments as compared to the roughly 250 pounds in the earlier models; the sail payload will jump from 90 to about 200 pounds.

OSO-H even looks different from the previous OSOs. The sail is squareish rather than semicircular. The gas jets are no longer on the tips of the three radial arms that once made the satellite look a little like an octopus. The engineering features are mainly the same, and OSO-H possesses most of the family's field marks.

OSOs I, J, and K have not been designed. The industrial contractor has not yet been selected. These OSOs will continue the trend toward larger size and more sophistication begun with OSO-H. The expected weights of OSOs I, J, and K are in the neighborhood of 1800 pounds, making them almost three times the size of the early OSOs. We will, in effect, have a whole new OSO family.

The increasing sophistication of the OSOs came in response to the desires of the scientists who wanted to fly better instruments on a spacecraft that could point them more accurately and more steadily at their targets. Specific instruments have already been selected for OSOs H and I (Tables 10 and 11). It is apparent from these lists that ultraviolet and X-ray instruments predominate in the pointable sail.

SURVEYING THE GALAXY

The stars are so far away that we cannot see surface details. For this reason, stellar astronomy is concerned mainly with the population and spectral classifications of stellar objects rather than individual stars per se. Stellar astronomy is like census taking while solar physics is akin to compiling a dossier on an individual. Of course, some specific stars with especially interesting characteristics are also studied in detail, and some classes of stellar objects, such as the pulsars, hold special interest.

The words "stellar objects" were used above rather than "stars." Perhaps the most important discovery of modern astronomy has been that those hard points of visible light we call stars are also sources of X-ray, gamma-ray, and radio energy. In other words, there is much more to

Table 10. Scientific Instrumentation, OSO-H

Instrument	Scientific Objectives	Principal Investigator
White-light and extreme ultraviolet coronograph (in sail)	Study high velocity matter travelling out from the Sun. Study polar streamers and dust in solar atmosphere.	R. Tousey (Naval Research Laboratory)
X-ray and extreme ultraviolet spectroheliograph (in sail)	Deduce distribution of matter and temperature in corona above active regions. Obtain spectroheliograms between 1.75 and 400 A.	W.M. Neupert (Goddard Space Flight Center)
Two multicompartment X-ray proportional counters (in wheel)	Survey whole sky for cosmic X-rays between 1 and 60 kev.	G. W. Clark (M.I.T.)
Gamma-ray scintillation spectrometer (in wheel)	Monitor solar gamma rays between 0.3 and 10 Mev.	E.L. Chupp (University of New Hampshire)
X-ray scintillator telescope (in wheel)	Observe spectrum of cosmic X-ray sources between 10 and 300 kev.	L.E. Peterson (University of California, San Diego)
Scintillator-proportional counter X-ray telescope (in wheel)	Study hard X-ray bursts from Sun in range 2 to 300 kev.	L.E. Peterson (University of California, San Diego)

TABLE 11. Scientific Instrumentation, OSO-I

Instrument	Scientific Objectives	Principal Investigator
High-resolution ultraviolet spectrometer (in sail)	Measure line profiles and their variations with time and position. Make spectroheliographs of some lines.	E.C. Bruner, Jr. (University of Colorado)
Cassegrain telescope and spectrometer (in sail)	Study the chromosphere fine structure by means of simultaneous high-resolution observations of selected spectral lines	P. Lemaire (University of Paris)
Bragg X-ray spectrometer and polarimeter (in wheel)	Monitor solar X-rays in the range 2 to 8 kev. Measure polarization of stellar X-rays from 5 to 25 kev. Obtain complete X-ray spectrum of Sun during flares.	R. Novick (Columbia University)
Mapping X-ray heliometer using proportional counters (in wheel)	Measure location, spectrum, and intensities of X-rays in range 2 to 30 kev.	J.L. Culhane (Lockheed Missiles and Space Company)
Proportional X-ray counter telescope (in wheel)	Study the galactic latitude dependence of X-ray background radiation.	W.L. Kraushaar (University of Wisconsin)
X-ray spectrometer using proportional counters (in wheel)	Obtain spectra of X-ray sources and diffuse background in the range 2–40 kev.	E.A. Boldt (Goddard Space Flight Center)
X-ray scintillator telescope (in wheel)	Measure energy spectra of all known celestial X-ray sources in range 0.01 to 1 Mev above a certain threshold.	K.H. Frost (Goddard Space Flight Center)
Ultraviolet photometers (in wheel)	Determine concentration of helium and hydrogen in Earth's atmosphere by measuring the solar ultraviolet radiation.	C.S. Weller (Naval Research Laboratory)

the universe than astronomers once believed; there are, for example, quasars, radio stars, X-ray stars, and the pulsars mentioned above. Some of these stellar objects do emit visible light, but most can be detected only through the eyes of instruments in orbit or the big terrestrial radio dishes. These previously unseen objects may help us to understand better stellar evolution and the origin of the universe. It is also likely, as surveys of the sky are made from orbit at very long and very short wavelengths, that our instruments will detect brand-new, even more mysterious species of "stellar objects." Astronomy is far from being cut and dried.

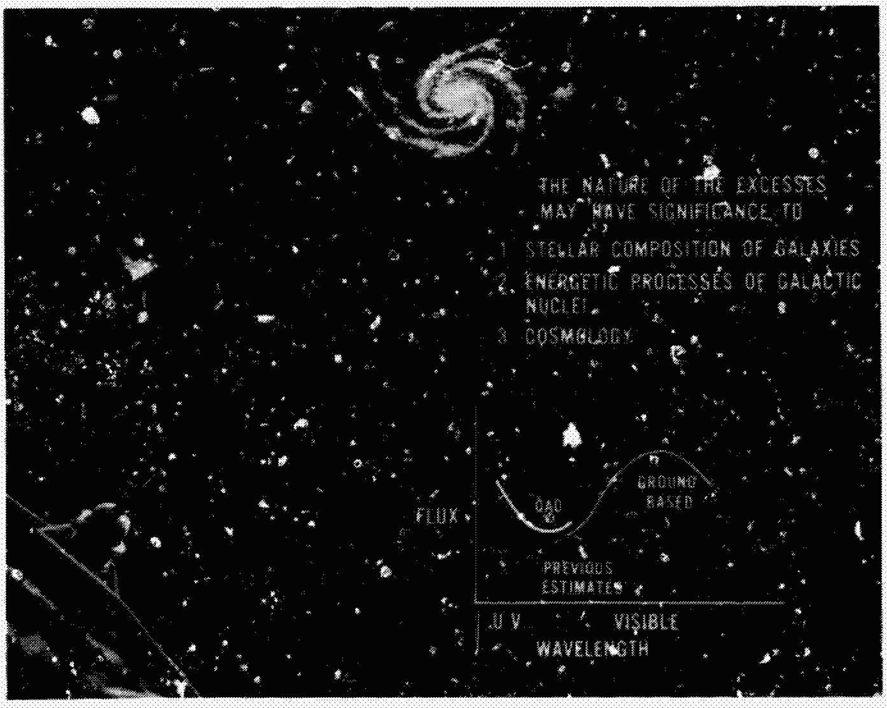
Some Unsolved Problems of Stellar Astronomy

- Why do stars that are apparently alike in other ways emit radically different amounts of energy in certain parts of the spectrum?
- OAO surveys show that many stars are much brighter in the ultraviolet than expected. Why? (See Fig. 11.)
- What are the major constituents of interstellar dust and gas? Graphite has recently been detected between the stars. What is its origin?
- Where and what are the major sources of X-rays and gamma rays? Essentially, the answer to this question means that maps must first be drawn at these wavelengths; then, one must determine what physical mechanisms generate the radiation. This same question is equally applicable to infrared radiation and that portion of the radio spectrum (0.5 to 10 MHz) that does not reach the Earth's surface due to the presence of the ionosphere.
- How much radio energy do the quasars and pulsars emit in the range unaccessible to terrestrial radio telescopes; that is, 0.5 to 10 MHz?
- OAO surveys have indicated that many galaxies are brighter in the ultraviolet than expected. Does this trend hold for all galaxies? If so, the astronomical distance scale may have to be revised, making the universe a bigger place than we thought.
- Early in 1970, OAO-2 discovered that the new comet, Tago-Sato-Kosaka, is surrounded by a cloud of hydrogen as large as our Sun. Is this true of all comets?

THE REMOTELY CONTROLLED OBSERVATORY, OAO

Looking at the Orbiting Astronomical Observatory simply as a machine, it is an engineering accomplishment of the first order. Responding to commands radioed up from the Earth, it can find and point itself and its contained instruments at a single, specific star from among the millions accessible to its star trackers. Although obedient

Figure 11. OAO observations in the ultraviolet indicate that galaxies are much brighter at these wavelengths than expected (see graph).



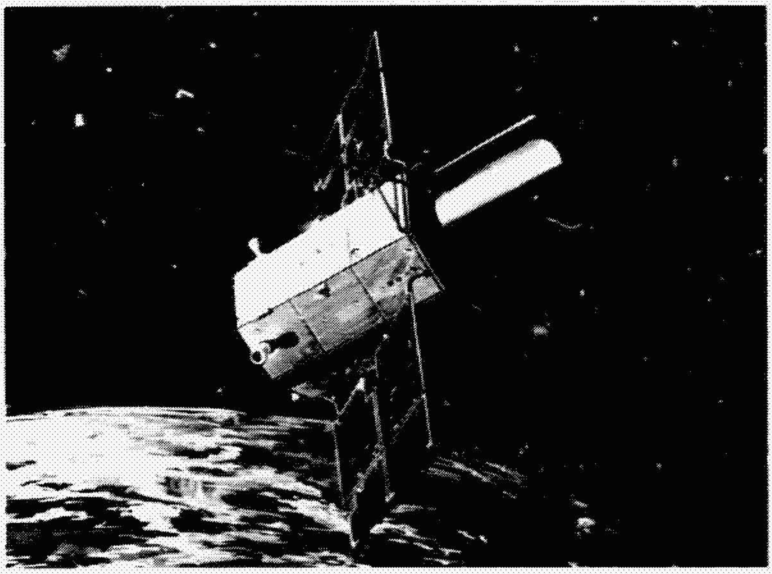


Figure 12. Artist's concept of OAO 3.

to hundreds different terrestrial commands, the OAO is still highly automated in the sense that once it receives a command it proceeds through most of the computations and attitude adjustments on its own.

The OAOs are the most sophisticated of the three series of observatory-class spacecraft managed by Goddard Space Flight Center. (The others are the Orbiting Solar and Geophysical Observatories; the OSOs and OGOs.) Design work on the OAO started at Goddard in the early 1960s. One of the central engineering problems concerned the accurate pointing of the spacecraft. Six star trackers, two to each of the spacecraft's three axes, tell the OAO its orientation with respect to the stars. By comparing its known orientation with the desired coordinates commanded from the Earth, the spacecraft finds its target by increasing or decreasing the speeds of its gyroscope-like inertia wheels. To illustrate, if an inertia wheel mounted on one spacecraft axis is slowed, the entire spacecraft will begin to turn slowly on this axis, as dictated by the Law of Conservation of Angular Momentum. The OAO obeys the astronomers' orders like a terrestrial observatory telescope, but being high above the Earth's atmosphere it "sees" much more of the universe.

The body of the OAO is an octagonal cylinder about ten feet long and 6.7 feet from side to to side. Two wing-like solar paddles fixed to the sides are kept turned toward the Sun as much as possible as the OAO turns from star to star (Fig. 12). The experiments, which are usually telescopes of various kinds, are mounted in a tube 40 inches in diameter located on the axis of the cylinder. Weighing about 4600 pounds, the OAOs are the largest scientific satellites built by the United States to date. Additional spacecraft details are listed in Table 12.

The first OAO, OAO-1 was orbited successfully by an Atlas-Agena from Cape Kennedy on April 8, 1966. Unfortunately, after about a day and a half in orbit it was put out of action by electrical malfunction. OAO-2 was launched on Dec. 7, 1968, by an Atlas-Centaur. Its results may change our concept of the universe substantially. Although there have been three system malfunctions since launch, the OAO-2 was kept in near-normal operating condition by "driving" or "flying" the spacecraft via commands from the ground. By providing alternate ways of doing things, engineers have been able to keep the spacecraft functioning well beyond its design lifetime.

Compared to most scientific satellites, the OAOs are rather single-minded; that is, they carry only one or two major instruments instead of the dozen or two one would expect on a spacecraft weighing over two tons. The large size of the OAO is a direct result of the very sophisticated pointing and command capabilities. OAO-B was launched November 30, 1970, but failed to achieve orbit. The protective nose fairing would not separate from the Centaur stage of the Atlas Centaur launch vehicle. The additional 2400 lbs. made orbit achievement impossible.

Table 13 lists experiments carried by OAO B and those scheduled for OAO-C.

TABLE 12. Design Features and Vital Statistics, OAOs B and C

Spacecraft Functions	Design Features
Communications	Pulse-code-modulated (PCM) telemetry. Data are transmitted in both real-time and delayed modes. Command receiver.
Power supply	Two large tiltable solar-cell paddles. Nickel-cadmium batteries. Average power capacity: about 500 watts.
Attitude control	Inertia wheels to rotate spacecraft. Also uses gas jets and magnetic control devices. Spacecraft can point to within 1 arc second in coarse-pointing mode and 0.1 arc second with experiment sensors.
Thermal control	Paints and coatings, plus active thermal louver system. Heat pipe experiment on OAO-B.
Guidance and control	Star trackers, gyroscopes, Sun sensors.
Data handling	Ferrite-core memory and many components common to a digital computer.
Structure	Octagonal cylinder about 10 feet long, 6.7 feet across the flats. Central experiment tube surrounded by equipment compartments. Weight: about 4600 pounds.
Launch vehicle	Atlas-Centaur
Tracking and data acquisition network	Space Tracking and Data Acquisition Network (STADAN).

TABLE 13. Scientific Instrumentation, OAOs B and C

Major Instrument	Scientific Objectives	Principal investigator
OAO-B: Goddard Experiment Package (Cassegrain ultraviolet telescope and grating spectrometer)	Obtain moderate resolution ultraviolet spectra of stars; check the law of interplanetary reddening; determine the Lyman-alpha shift for nearby galaxies; measure spectra of emission and reflection nebulas.	Goddard Space Flight Center
OAO-C: Princeton Experiment Package (different configuration of Cassegrain telescope and spectrometer)	Obtain high-dispersion spectra of the absorption lines of interstellar gas.	L. Spitzer (Princeton University)

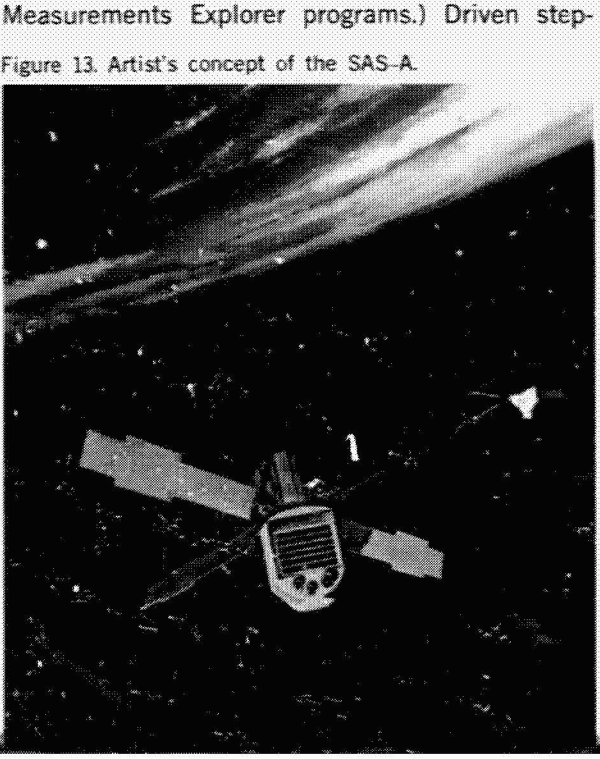
THE SEARCH FOR X-RAY SOURCES, THE SMALL ASTRONOMY SATELLITE (SAS)

Sounding rockets have mapped much of the sky at X-ray wavelengths. Several dozen strong X-ray sources have already been found, mostly along the plane of our galaxy (The Milky Way). But, as emphasized earlier, sounding rockets can provide us only with short, limited views of the celestial sphere. Again, we need an instrument platform that slowly and methodically sweeps the sky over a period of months. One of the OAOs could serve as a suitable instrument platform, but its payload capacity and precision pointing capabilities are not really necessary for a survey mission. All that is really needed is a small spacecraft that can carry 140 pounds or so of instruments into orbit—something with longer life than a sounding rocket. An important point here is that the search for X-ray sources does not require the formation of images at short wavelengths, just the detection of X-rays and knowledge of roughly where they came from. Thus, the satellite and its instruments can be relatively small. The SAS or X-Ray Explorer is NASA's answer to this scientific requirement.

Externally, the SAS is a cylinder 22 inches in diameter and 20 inches from its bottom to its truncated top. Near the bottom, four solar paddles extend spokelike (Fig. 13). The weight of the spacecraft and included experiments is about 320 pounds, making launch possible with the low-cost Scout rocket.

The most interesting part of the SAS is its attitude control and stabilization subsystem. The X-ray instrument in the SAS will be mounted in the top of the satellite and will sweep a sector of the sky each time the satellite rotates on its axis. The spin rate planned is a very slow 1/12th of a revolution per minute. This spin rate is not enough to stabilize the satellite against the gravitational, magnetic, and aerodynamic forces tending to make it tumble. Therefore, an inertia wheel has been added to provide stability along the spin axis. Once the satellite has obtained sufficient X-ray data from one spacecraft orientation, ground controllers can command the satellite to tilt its spin axis slightly to get a different view of the sky. The tilt mechanism is simply a magnetic coil that reacts with the Earth's magnetic field to nudge the spin axis a bit. (Much of the actual technology needed here was developed by NASA and the Johns Hopkins Applied Physics Laboratory during the pursuit of the Atmosphere Explorer and Direct Measurements Explorer programs.) Driven step-by-step by the magnetic coil, the X-ray instrument tilts with the spacecraft and scans the entire celestial sphere. Further information on the spacecraft can be found in Table 14.

Figure 13. Artist's concept of the SAS-A.



The SASs will carry only one type of experiment each. SAS-A will search for X-ray sources; SAS-B will substitute a gamma-ray detector for the X-ray detector. SAS-C will carry four X-ray instruments for studying in detail the sources found by SAS-A. The SAS-A X-ray instrument is being built under the direction of R. Giacconi. The primary scientific objective of SAS-A is a high-sensitivity, high-resolution, all-sky survey for the purpose of producing a catalog of X-ray sources.

At the heart of the instrument are two matrices of X-ray proportional counters (Fig. 14). These counters will count only those X-rays in the 1-to-20 kev range that pass through the two sets of metal collimators installed sandwich-like on both sides of the counter matrix. X-rays hitting the metal sides of the collimator will be absorbed before they actuate the proportional counters. In effect the instrument has "tunnel vision." The instrument is actually a double one; but one side has high sensitivity counters combined with low-resolution collimators, the other side has high-resolution collimators. As the spacecraft slowly spins on its axis, both halves of the instrument will scan the same sections of sky. Continuing the optical analogy, we could say that we have an example of X-ray bifocals.

All three SAS spacecraft are launched aboard Scout rockets from the San Marco Range so that equatorial orbits of about 300 miles altitude can be attained with ease. SAS-A was launched in 1970; SAS-B flies in 1971; and SAS-C in late 1972.

Figure 14. Exploded view of the X-ray detectors mounted in the top of the SAS. Each detector has a different collimator to provide two levels of resolution as the spacecraft spins.

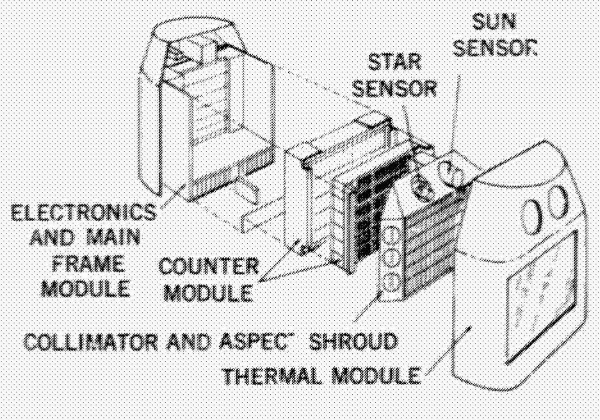


TABLE 14. Design Features and Vital Statistics, SASs A and B

Spacecraft Functions	Design Features
Communications	Pulse-code-modulated (PCM) telemetry at 136.68 MHz. PCM command receiver.
Power supply	Four solar-cell paddles and nickel-cadmium batteries provide an average of 27 watts.
Attitude control	Inertia wheel for stabilization. Magnetic torquers for changing spin-axis orientation.
Thermal control	Passive paints and coatings.
Guidance and control	Solar-aspect sensor and three-axis vector magnetometer to determine attitude.
Data handling	Tape recorder.
Structure	Cylinder, 22 inches long, tapered and truncated at end; height, 20 inches. Weight: about 320 pounds.
Launch vehicle:	Scout
Tracking and data acquisition network	San Marco Range at launch; Space Tracking and Data Acquisition Network (STADAN) thereafter.

THE HIGH ENERGY ASTRONOMICAL OBSERVATORY (HEAO)

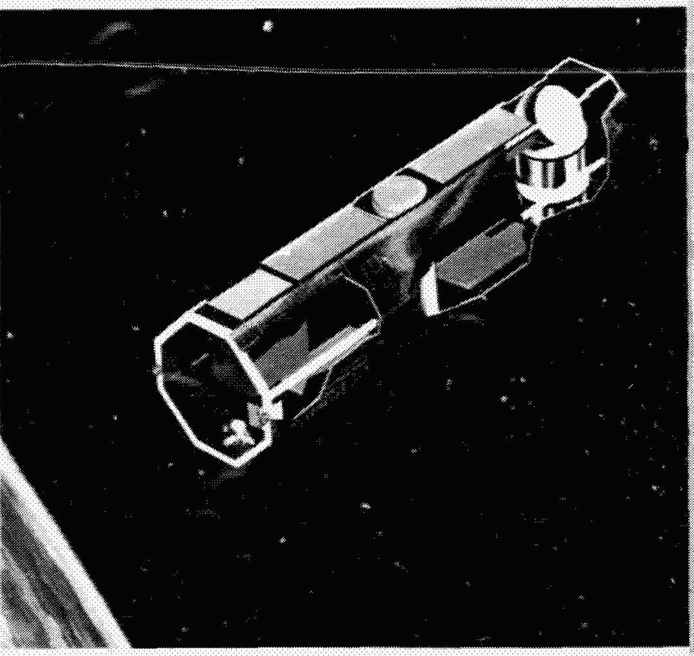
High energy radiations, like earthquake waves, tell us that somewhere powerful forces are at work. X-rays, gamma rays, and cosmic rays are indicative of stellar birth and death pangs, and possibly they even represent reverberations of the so-called Big Bang during which the universe may have been created 10 to 15 billion years ago. Cosmologists and astrophysicists, therefore, would like to know the strengths and locations of celestial sources of high energy radiation.

The greater the energies of gamma rays and cosmic rays, the more rare they are in the universe. Therefore, when one wishes to extend his observations to the higher ranges, he must increase the sensitive surfaces of his detectors to register the lower fluxes.

The implication for space science is that satellite size must also increase as higher energy particles are studied. SAS payload capabilities suffice for low energy X-rays and gamma rays, but a larger satellite —the High Energy Astronomy Observatory or HEAO —is needed to extend measurements to higher energies.

The HEAO program is so new that spacecraft features are under study and experimenters have just been selected. One conceptual design of the spacecraft involves an octagonal cylinder 30 feet long and 8 feet in diameter, weighing about 22,000 pounds (Fig. 15). Like the SAS, the first two HEAOs would be pointable but still spin-stabilized; that is, specific targets could be studied at length. The spacecraft, which will probably be launched by the

Figure 15. Artist's concept of the HEAO.



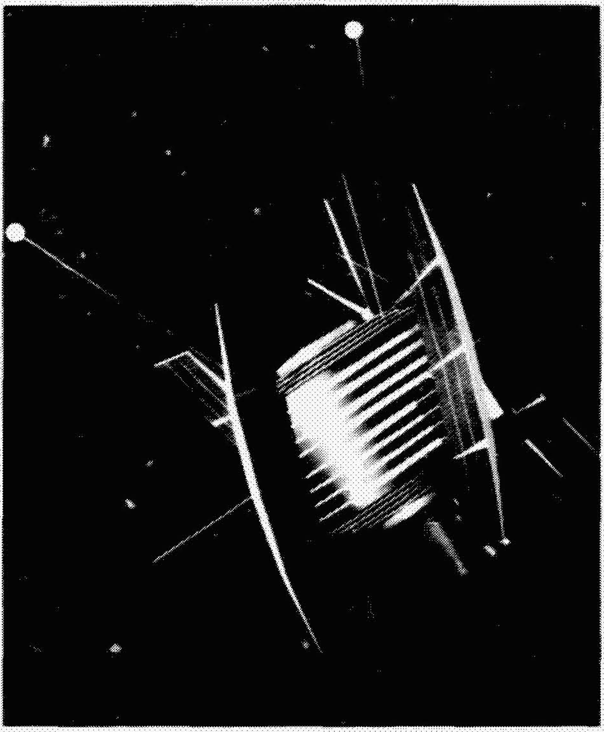


Figure 16. Photograph of a model of RAE-B.

Titan III, is so large that several tons of instruments could be accommodated. The basic purpose of the HEAO is the high-sensitivity, high-resolution survey of the celestial sphere for stellar sources emitting more energetic radiation than that detectable by the SAS instruments.

THE NOISY SKY, THE RADIO ASTRONOMY EXPLORER (RAE)

Ever since Karl Jansky, an engineer with Bell Telephone Laboratories, first recorded cosmic radio noise in 1931, scientists have been trying to interpret the radio din that floods outer space. Radio astronomy prospered after World War II when huge paraboloidal antennas—some over 200 feet across—began to be built all over the world. Radio astronomy has provided many surprises. For example, the enigmatic pulsars were discovered by radio telescopes. Understanding pulsars, quasars, and other radio sources could revolutionize some of our most durable concepts of astronomy. Closer to home, the Sun, Jupiter, and the Earth itself emit much radio noise. Some of Jupiter's noise arrives in bursts that seem to be related somehow to the orbital positions of its satellite Io. These are only a few of the mysteries of radio astronomy awaiting explanations.

Satellites are useful in radio astronomy because they can take radio antennas and receivers high above the Earth's ionosphere—those layers of ionized gases that shield the Earth from cosmic radio waves below frequencies around 15 MHz. The first Radio Astronomy Explorer (RAE-1), which is also known as Explorer 38, was launched on July 4, 1968. It has since provided astronomers with the first comprehensive radio noise spectrum between 200 kHz and 9 MHz. However, outside its 3600-mile orbit lies still another radio shield: the Earth's magnetosphere. This magnetic bottle absorbs and deflects cosmic radio waves below 200 kHz. In order to observe these very long radio waves, RAE-B is destined for lunar orbit which will: (1) take the spacecraft well beyond the magnetosphere most of the time; and (2) remove it from troublesome terrestrial sources of radio noise.

The barrel-shaped body of the basic RAE is dominated by four long antennas, each stretching out 750 feet radially (Fig. 16). Arranged to form an "X", the antennas have a directional reception pattern that is most sensitive along the spin axis of the RAE. As the spacecraft is turned in space, various sources of radio noise can be located and studied. The packaging and deployment of such huge antennas was an engineering challenge. The solution was a beryllium-copper alloy tape that can be kept rolled up into reels seven inches in diameter during launch. After orbit is attained, motors deploy the tapes. As each tape emerges from one of the reels, it curls into a tube due to its prestressing. Tabs on the edges of the tapes are interlocked by the dispenser—somewhat like a zipper. The result is a hollow tube about a half inch in diameter, 750 feet long, and rigid enough in a zero-g environment to make a suitable radio antenna.

Figure 17. The RAE-B mission profile from Earth launch to lunar orbit injection.

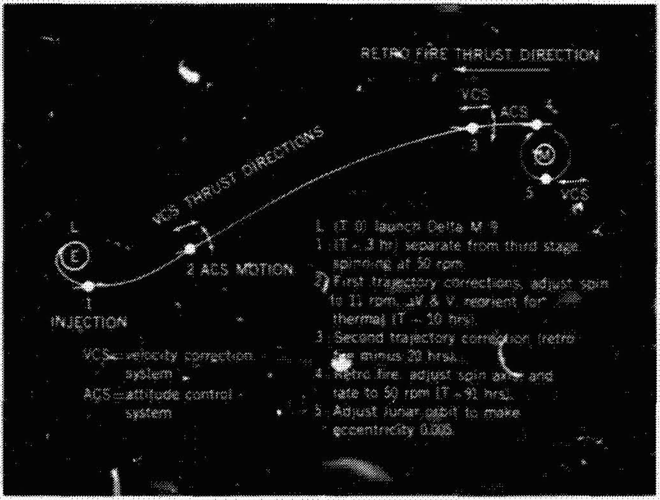


TABLE 15. Design Features and Vital Statistics, RAE-B

Spacecraft Functions	Design Features
Communications	Pulse-frequency-modulated (PCM) telemetry. 6-watt high-power transmitter at about 400 MHz; 3-watt low-power transmitter also at about 400 MHz; 6-watt beacon for tracking at about 136 MHz. Command receiver.
Power supply	Four solar paddles with 5184 2x2 cm and 1728 1x2 cm solar cells provide average power level of about 32 watts. Nickel-cadmium battery.
Attitude control	Gas jets for spin axis orientation. Spin-stabilized at about 2 rpm.
Propulsion	5-pound-thrust hydrazine engine for lunar orbit insertion. Total impulse available: about 44,000 lb-sec.
Thermal control	Passive thermal control with paints and coatings.
Guidance and control	Solar aspect system, horizon sensor system, and special Panoramic Attitude Sensor (PAS).
Data handling	Telemetry encoders. Tape recorder.
Structure	Body of spacecraft is a cylinder 36 inches in diameter and 31 inches high. With solar paddles, diameter is 56.5 inches and height, 56.9 inches. Overall weight: about 725 pounds.
Launch vehicle	Delta
Tracking and data acquisition network	Space Tracking and Data Acquisition Network (STADAN).

RAE-B requires a small rocket motor to decelerate it into lunar orbit, as diagrammed in Fig. 17. As the RAE-B approaches the Moon, the five-pound-thrust hydrazine engine fires, slowing down the spacecraft so that it can be captured by the Moon's gravitational field. The spacecraft is then despun to about 2 rpm; then, the big antennas are unreeled. The RAE is then ready for action.

The major scientific objectives of the RAE-B are:

- Extend radio noise observations below the ionosphere and magnetosphere cutoff frequencies to about 30 kHz, which is the interplanetary cutoff frequency dictated by the Sun's magnetic field.
- Identify and pinpoint sporadic noise sources on the Sun, the Earth, and Jupiter using the lunar disc and its resulting diffraction patterns.

In reality, the entire spacecraft is the instrument; the antennas plus on-board receivers constitute all experiment equipment. The receiving equipment consists of two Ryle-Vonberg radiometers and three swept-frequency burst receivers. The principal investigator is R.G. Stone at Goddard Space Flight Center.

IN RETROSPECT

Earth orbital science is multifaceted. It employs small, low-cost spacecraft as well as large, highly sophisticated observatory-class satellites. Some orbits penetrate deep into the Earth's atmosphere; others carry the spacecraft as far as the Moon. The important scientific realities of orbital space are that: (1) in-situ measurements of the Earth's gaseous envelope can be made in a systematic way; and (2) the universe can be seen in regions of the spectrum that are denied terrestrial observers by the atmosphere, ionosphere, and magnetosphere. The scientific payoff during the first decade of space flight has been high, and this endeavor is only just beginning.

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