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For Release IMMEDIATE

Press Kit

Project International Sun
Earth Explorers
(ISEE)

RELEASE NO: 77-213

Contents

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MOTHER-DAUGHTER SATELLITES SET FOR LAUNCH

Two spacecraft will be launched by a single rocket this month as part of a cooperative program by NASA and The European Space Agency (ESA) to gain a better understanding of how the Sun controls the Earth's near space environment.

Called International Sun Earth Explorers, the mother-and-daughter satellites will be launched about Oct. 19 from Kennedy Space Center, Fla., into looping trajectories around the Earth, ranging in distance from 140,000 kilometers (87,000 miles) to 280 km (174 mi.).

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The mission involves 117 scientific investigators, 35 universities and 10 nations.

Circling our planet for three years or more, the instrument-laden spacecraft are expected to provide detailed data on how solar wind particles control the boundaries between Earth space and interplanetary space. This will lead to a better understanding of a variety of solar-terrestrial phenomena, including weather and climate, energy production and ozone depletion in the atmosphere.

ISEE-A, managed by NASA, and B, managed by ESA (to be designated ISEE-1 and ISEE-2 after orbital insertion), are the first set of spacecraft designed to be used together to investigate Earth's immediate space environment.

Shortly after third stage burnout, when the two spacecraft have attained the required trajectory, they will be separated from each other but will remain in the same orbit. The separation distance between ISEE-1 and ISEE-2 will be varied by the controllers between a few hundred to a few thousand kilometers during the lifetime of the mission.

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For reasons of energy conservation, the smaller spacecraft, ISEE-2, weighing 158 kilograms (348 pounds), will be the maneuverable spacecraft. The orbit of ISEE-1 will not be changed. Initially, however, both spacecraft will undergo attitude maneuvers so that both point to the same place in space.

All maneuvers will be conducted by a NASA/ESA team at NASA's Goddard Space Flight Center, Greenbelt, Md.

The use of two spacecraft, separated by a variable distance, will allow scientists to study the boundaries in near-Earth space and the nature of their fluctuations. These include the plasma pause -- the position at which there is a dramatic drop in the density of the magnetosphere -- the magnetic envelope which surrounds the Earth; the magnetopause, where the magnetic field of the Earth meets that of the solar wind; the bow shock, a sort of bow wave created by the motion of the solar wind past the Earth, and several less obvious features of the Earth's magnetic tail.

Measurements by instruments on a pair of spacecraft will permit ambiguities associated with the motion of these boundaries to be resolved.

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In the past, a large number of phenomena measured by single instruments on spacecraft were not clearly understood. For example, did the sudden increase in energetic particles noted from measurements by one spacecraft come from an eruption on the surface of the Sun, perhaps a solar flare, or did it come from some other source? Perhaps the particles were suddenly released from the Earth's radiation belts or were bounced back from the bow shock front that extends hundreds of thousands of kilometers out from Earth. With two spacecraft at different points on a similar trajectory with similar instrumentation, time and space aspects associated with such problems can be solved.

Even greater scientific returns will be possible when a third spacecraft, ISEE-C, is launched by NASA next summer to what is called the libration point -- about 1.5 million km (932,055 million mi.) from Earth toward the Sun -- where the satellite will remain with only minor onboard gas adjustments. At that point in space, the forces of gravity and the dynamic force exert an equal pull.

ISEE-C (to be called ISEE-3 in heliocentric orbit) will obtain nearly continuous data on the fluctuating solar wind, and on special solar phenomena, such as solar flares, about an hour before the solar particles flow past ISEE-1 and 2 in Earth orbit.

In certain instances, this will give scientists on the ground time to make inputs to onboard instrumentation on the mother-daughter spacecraft to look for correlating phenomena. At the same time, sounding rockets could be fired from any global location on cue from Goddard Center at different launch areas around the world to investigate other aspects of onrushing solar wind. As part of a program called the International Magnetospheric Study (IMS), ground stations, sounding rockets, balloons, aircraft and satellites, including the ISEE spacecraft, will look at the same phenomenon simultaneously from different parts of the Earth, including polar areas and space.

ISEE coordination is designed to fit into the IMS program, which is a world-wide three-year investigation begun in 1976. ISEE-A, B and C are major contributions to the IMS by the U.S. and Europe. Data exchange offices have been established in Meudon, France, and Boulder, Colo. Meanwhile, a sophisticated Satellite Situation Center (SSC) at Goddard will calculate satellite orbits which will be published through the Boulder office. The published SSC orbits are designed for correlation with the various IMS systems to indicate when spacecraft data are likely to be especially fruitful.

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Much of the data returned by ISEE is expected to be of immediate interest in areas of practical application.

For example, a growing mass of evidence suggests that events on the Sun (Sun spots, solar flares, high-speed solar wind streams) may affect our weather. Long-term variations of the Sun's energy output as well as more subtle changes in the solar wind and its magnetic field structure affect our climate. Is the Earth growing warmer or colder? Will certain parts get more or less moisture? Are severe storms and hurricanes in some way linked to solar mechanisms?

Solar and terrestrial exploration can help establish the physical cause and effect relationships between solar stimuli and terrestrial responses. When these relationships are understood, a new tool will be available for weather and climate prediction.

The Earth's ionosphere and ozone layer which protects us from dangerous solar ultraviolet rays are influenced by solar events and conditions in the magnetosphere which these satellites will investigate. The ionosphere must be better understood because of the major impact it has on worldwide communications and precision navigation systems as well as the amount of global ozone.

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Although numerous other spacecraft have been probing the magnetosphere since the early 1960s, the ISEE satellites carry instrumentation 10 times more sensitive than previously flown. Five years ago, the ISEE series couldn't be flown simply because the required technology did not exist. As a result, much fine detail information essential to understanding the range of Sun-Earth phenomena, the entire environmental system of Earth, and the interactions between the two is now available with the ISEE spacecraft for the first time.

The earlier missions have shown that our space environment is very dynamic and exhibits changes more drastic than the weather patterns seen near the ground. It is precisely these changes which need to be studied, using instruments designed to operate in close coordination, to establish the complex interrelationships which control our "space weather."

ISEE-A is a 16-sided cylindrical body measuring approximately 1.73 meters (5 feet 8 inches) across and 1.61 m (5 ft. 4 in.) high. Its main body consists of an 84-centimeter (1 ft. 9 in.) conical center tube, an aluminum honeycomb equipment shelf supported by eight struts. The lower end of the center tube mates with the launch vehicle and the upper end with the ISEE-B.

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Certain exposed areas of the ISEE-A and C spacecraft are coated with a conductive green paint developed at Goddard as passive electrical as well as thermal protection to keep the voltage buildup to no more than one to two volts, even as they pass through the radiation belts.

ISEE-B is a circular cylinder, with a diameter of 1.27 m (4 ft.) and a height of 1.14 m (3 1/2 ft.). Solar cells are mounted on three detachable curved panels. An aluminum honeycomb platform supported by eight struts and center tube are the main load-carrying portions.

NASA is responsible for the A and C spacecraft, Delta launch vehicle, tracking and data acquisition and data processing. ESA is responsible for the ISEE-B spacecraft and its operation.

Goddard will provide orbital computation, attitude determination and spacecraft control support to the ISEE missions during the planned three-year lifetime of the satellites. ESA, in coordination with Goddard, is responsible for preparing, testing and operating the ISEE-B spacecraft and software for maneuver determination and computation.

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There are a total of 117 investigators on all three spacecraft representing 35 university, government and industrial organizations in 10 countries.

ISEE-A is a Goddard Center designed spacecraft built, fabricated and tested at Goddard with all its components either made at Goddard or supplied by industries or universities. ISEE-B is an ESA-European Space Technology Center (ESA-ESTEC) satellite whose design was determined through competitive concepts.

The STAR consortium of 10 countries supervised construction under contract to ESA. STAR consists of industries in Belgium, Denmark, France, Spain, Germany, Italy, Netherlands, Sweden, Switzerland and the United Kingdom. Dornier Systems in Frederickshaven, Germany, heads the contractor team.

Goddard directs the Delta rocket program for NASA's Office of Space Flight and McDonnell Douglas Astronautics Co., Huntington Beach, Calif., is prime contractor.

Estimated cost of the two spacecraft and the scientific instrumentation is about $45 million, exclusive of launch and tracking and data acquisition costs.

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The launch window opens Oct. 12, 1977, and closes Oct. 27, 1977. There is a 20-minute opportunity in the early part of the launch window each day starting between about 10:00 a.m. EDT and 10:30 a.m. EDT, depending on the day. The launch window begins to narrow on Oct. 20 and is reduced to five minutes on Oct. 29.

(END OF GENERAL RELEASE. BACKGROUND INFORMATION FOLLOWS.)

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ISEE-A, -B and -C SCIENTIFIC INSTRUMENTS

ISEE-A

Instrument	Principal Investigator	Affiliation
*Fast Plasma	S. J. Bame	Los Alamos Scientific Laboratory
*Low Energy Proton and Electron	L. A. Frank	University of Iowa
*Fluxgate Magnetometer	C. T. Russell	University of California, Los Angeles
*Plasma Waves	D. A. Gurnett	University of Iowa
*Plasma Density	C. C. Harvey	Paris Observatory
*Energetic Electrons and Protons	D. J. Williams	National Oceanic and Atmospheric Administration
*Electrons and Protons	K. A. Anderson	University of California, Berkeley
D.C. Electric Field	J. P. Heppner	Goddard Space Flight Center
Ion Composition	R. D. Sharp	Lockheed Electronics Co.
VLF Wave Propagation	R. A. Helliwell	Stanford University
Fast Electrons	K. W. Ogilvie	Goddard Space Flight Center
Low Energy Cosmic Ray	D. Hovestadt	Max Planck Institute
Quasi-Static Electric Fields	F. S. Mozer	University of California

*The instruments of A and B that are interrelated.

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ISEE-B

Instrument	Principal Investigator	Affiliation
*Fast Plasma	G. Paschmann	Max Planck Institute
*Low Energy Proton and Electron	L. A. Frank	University of Iowa
*Fluxgate Magnetometer	C. T. Russell	University of California, Los Angeles
*Plasma Waves	D. A. Gurnett	University of Iowa
*Plasma Density	C. C. Harvey	Paris Observatory
*Energetic Electrons and Protons	E. Keppler	Max Planck Institute
*Electrons and Protons	K. A. Anderson	University of California, Berkeley
Solar Wind Ion Measurements	G. Moreno	Laboratorio Plasma Spazio, Frascati, Italy
ISEE-C		
Solar Wind Plasma	S. J. Bame	Los Alamos Scientific Laboratory
Magnetometer	E. J. Smith	Jet Propulsion Laboratory
Low Energy Cosmic Ray	D. Hovestadt	Max Planck Institute
Medium Energy Cosmic Ray	T. von Rosenvinge	Goddard Space Flight Center
High Energy Cosmic Ray	H. H. Heckman	University of California
Plasma Waves	F. L. Scarf	TRW

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ISEE-C (cont'd.)

Instrument	Principal Investigator	Affiliation
Cosmic Ray Electrons	P. Meyer	University of Chicago
Protons	L. D. de Feiter	Space Research Laboratories, Utrecht
X-Rays and Electrons	K. A. Anderson	University of California
Radio Mapping	J. L. Steinberg	Meudon Observatory
Plasma Composition	K. W. Ogilvie	Goddard Space Flight Center
High Energy Cosmic Ray	E. C. Stone	California Institute of Technology
Ground Based Solar Studies	J. M. Wilcox	Stanford University

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MISSION DESCRIPTION

The ISEE-A and B spacecraft are the first set of spacecraft designed to be used together to investigate the physical structures surrounding the Earth. It is hoped that these spacecraft will be able to resolve questions related to the detailed structure of the magnetosphere, magnetopause and shock front that cannot be answered by a single spacecraft. The orbit was selected to nearly maximize the number of bow shock crossings. The separation distance of the two spacecraft is intended to have the spacecraft separation be 100 kilometers (62 miles) at 15 Earth radii as the starting position and let the distance drift to 2 or 3 thousand km (1,240 to 1,865 mi.) before restoring it. The spacecraft are much closer at apogee and very far apart at perigee using this control point.

Solar Wind and Upstream Phenomena

The elemental and isotopic abundances in the solar wind show strong time variations. These could result from diffusion processes in the solar photosphere-corona boundary, from dynamic friction, from wave-particle interactions or from separation processes that depend primarily on ionization and energy.

Energetic solar protons and electrons are observed in the interplanetary medium during solar events. Investigation of these is aimed at discovering how they originate in the Sun and how they are affected by the medium in which they travel. Care is needed to differentiate between source and propagation effects, and in this respect the observations of the heliocentric ISEE-C spacecraft will be very useful.

It is known that the presence of the Earth has a disturbing effect in interplanetary space in front of the bow shock and for quite large distances upstream. By using ISEE-A and B it should be possible to look for the types of particles and waves that are reflected from the bow shock. A study can also be made of the effect of the backstreaming protons and electrons on the solar wind itself.

A great variety of these interplanetary discontinuities exist, traveling with characteristic speeds of the order of hundreds of kilometers per second, making large separations necessary for good observation. Simultaneous "mother" and "daughter" measurements will be able to distinguish shock-accelerated from solar-accelerated protons. ISEE-A and B spacecraft carry electron density measuring equipment which should be able to resolve density variations in shock structures and discontinuities.

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Neutral magnetic and current sheets in the solar wind will be studied as they sweep past ISEE-A and B. The ISEE mission will also be able to distinguish solar co-rotating features from others.

A major part of the ISEE mission is the study of wave-particle interactions. Because of the variability of the solar wind, the characteristic frequencies of the plasma are also highly variable. Using two spacecraft, it should be possible to remove some of the ambiguities.

The complexity and variability of the solar wind velocities, composition and densities together with the presence of particles and waves backstreaming from the bow shock ensures that many known and unknown wave-particle interactions will take place in the near-Earth interplanetary medium. The ISEE twin spacecraft investigation is expected to unravel some of the basic processes.

The Bow Shock

This feature of the Earth's environment has been known to exist since 1963 when it was first seen by IMP-1 but identification of even the dominant mechanisms has not yet been accomplished. A basic problem here is that the bow shock apparently moves back and forth with an amplitude of about one Earth radius and the velocity of this movement seems to vary between 10 and 200 km per second (6 to 125 mi. per second). Both ions and electrons are heated in the shock and the mechanism is thought to be a retardation and heating by some form of electrostatic turbulence.

Detections of regions of this size by a single-point measuring system in the fast-moving bow shock is extremely difficult. Assuming shock speeds of about 100 km/s (62 mi./s), simultaneous measurements at two points about 100 km (62 mi.) apart by instruments with reasonable time resolution should be able to detect the larger scale features.

The bow shock may also be the source of electron spikes seen in the magnetosheath and movement of both ions and electrons towards the Sun upstream of the shock. The mechanism for acceleration and reflection of these particles is not understood at present and in particular the transient nature of the observations is baffling.

Because of space-time ambiguities, the extent and wavelengths of these phenomena have not been determined and so they too are suitable objects for a twin spacecraft study. These spacecraft must spend sufficient time outside the bow shock region for a wide range of solar wind effects to be encountered to evaluate their influence on the upstream phenomena and the bow shock.

The Magnetosheath

Magnetic field fluctuations which occur in different modes and have many different frequencies characterize the Earth's magnetosheath. This complex situation is further complicated because the plasma frame is convecting past the spacecraft at a velocity which is influenced by the solar wind and the position of the spacecraft in the magnetosheath.

The dominant mechanisms by which the turbulences in this region are created have not yet been clearly identified and it is accepted that techniques of correlating field and plasma measurements on a single spacecraft are not adequate for an analysis of this structure. Measurements by ISEE-A and B will be able to identify propagation velocities which should clarify the picture considerably.

The Magnetopause

For many years the nature of the magnetopause boundary has provided a motive for magnetospheric research. Nevertheless, the answers to most of the key questions are still unclear: such problems as the way in which mass and energy are transferred across the boundary, how reconnection works or the mechanism of viscous interaction have not been solved. Is the oscillation of this boundary a simple "breathing" of the magnetosphere or is it the result of the solar wind blowing past?

Theories of reconnection and viscuous interaction are incomplete because the treatment of viscuous interaction needs more detail of the magnetosheath magnetic fields than is available and reconnection studies have not been able to demonstrate that the process works over a sufficient range of interplanetary field angles because of lack of magnetopause information.

Again the problem is associated with the movement of the boundary and with the question of whether the features observed are propagating or not. It is hoped that identification of motions by the ISEE mission will make a large contribution to our understanding of this boundary.

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The Plasma Sheet and the Tail

The ISEE mission is uniquely fitted to study the dynamics of particle acceleration in the tail. Qualitative measurements of the flow of plasma and energetic particles up and down the tail will be made and compared with incoming solar wind parameters as observed by the heliocentric ISEE-C spacecraft.

Single satellite magnetic measurements imply that a thin neutral sheet is embedded in the much thicker plasma sheet. Detection of the neutral sheet is difficult since the field strengths are very weak and there is considerable upward and downward movement of this region, with velocities of between 10 and 100 km/s (6 to 62 mi./s). Twin spacecraft measurements should be able to identify the structural features of the inner plasma sheet by separating out the velocity.

Ring Current and Plasmasphere

The ISEE-A and B spacecraft will be able to provide the first comprehensive observations of the total ring current energy spectrum, pitch angle and spatial distributions during quiet times. They will also allow observation of the drift into this region of the low-energy (tens of keV) protons during the main phase of magnetic storms. It is hoped that the way in which these particles filter around the Earth to form a symmetric ring current will be discovered.

Magnetospheric Substorms

The understanding of the substorm phenomenon is one of the key steps to the understanding of the dynamics of the magnetosphere. However, substorms in themselves are very complex. Violent rearrangements of magnetic fields during the substorm expansion phase associated with strong electric induction fields have drastic effects on plasma flow, charged particles and on the ionosphere.

It seems probable that the energy needed to drive these processes is extracted from the solar wind by some mechanism in the tail, but this mechanism has not been identified. It is not known how or why substorms are triggered. Although particles are accelerated, the region and source of this acceleration have not been discovered. Because geomagnetic substorms involve a large part of the magnetosphere, correlated global measurements will be necessary for any attempt at understanding.

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These measurements must include, as well as ISEE-A and B in the tail, inner magnetospheric observations by GEOS and ATS-6, upstream solar wind measurements by ISEE-C, suitable rocket flights to investigate the ionosphere with other worldwide high-latitude ground-based measurements and assistance from other spacecraft.

INTERNATIONAL MAGNETOSPHERE STUDY SUPPORT

The ISEE project, from its inception, has been designated to support the International Magnetospheric Study (IMS). The IMS is an international cooperative enterprise with a principal scientific objective of achieving a comprehensive, quantitative understanding of key processes associated with energy, mass and momentum transfer from the solar wind to the magnetosphere and atmosphere. IMS is the first attempt to use a systems approach to Sun-Earth study on a large scale.

The system approach in the IMS case is a conscious plan to accumulate data simultaneously so that correlative studies can be made on a worldwide and outer space basis. This requires that spacecraft be located in orbits advantageous to earthbound observations and that prediction of spacecraft positions be available to make sure that ground base data is collected at the appropriate time.

Sounding rocket campaigns will be planned to coincide with spacecraft positions and, in some cases, spacecraft data will be used to determine sounding rocket launch times.

The ISEE-C spacecraft, from its vantage point a million miles in front of the Earth, can measure the parameters of the solar wind unperturbed by the Earth's presence and can do it one hour in advance of that portion of the solar wind's arrival at the Earth's physical boundaries. These data can be compared to the Earth's reaction to this portion of the solar wind as it impinges on the bow shock and the magnetosphere.

In short, ISEE-C measures the solar input function; ISEE-A and B measure its impact on the magnetic field about the Earth; and the ground-based magnetometers measure the resultant changes at the Earth's surface. It is hoped that by obtaining this and similar spacecraft and sounding rocket data over large space and time variations, better models can be established for the behavior of the Earth's fields and radiation belts.

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SCIENTIFIC PAYLOAD DESCRIPTION

Fast Plasma (ISEE-A and B)

Dr. S. J. Bame, Los Alamos Laboratories, Los Alamos, N.M., (ISEE-A) and Dr. G. Paschmann, Max Planck Institute, West Germany (ISEE-B).

Los Alamos Scientific Laboratories supplies the sensor portion of the ISEE-A and B instruments and Max Planck Institute supplies the electronics for both instruments.

Determinations of electron and ion velocity distributions in one-, two- and three-dimensional form will be obtained from both ISEE-A and B spacecraft. These determinations are made using identical 90 degree spherical section electrostatic two-dimensional and three-dimensional analyzers. The A experiment will also include a solar wind ion 150 degree spherical section analyzer.

Low-Energy Protons and Electrons (ISEE-A and B)

L. A. Frank, University of Iowa, Iowa City.

An improved low energy proton and electron differential energy analyzer (LEPEDEA) each on the A and B satellites will be employed. These are in the shape of a quarter sphere and consist of three of these quadrispherical concentric plates. Fourteen channel multipliers are used so that the instrument can measure angular distributions. Seven multipliers are used for protons and seven for electrons. Measurements of both can be made simultaneously.

Fluxgate Magnetometer (ISEE-A and B)

C. T. Russell, University of California, Los Angeles.

Three ring core sensors in an orthogonal triad are enclosed in a flipper mechanism at the end of the magnetometer boom. The electronics unit is on the main body of the spacecraft at the foot of the boom. The magnetometer has two operating ranges of ± 8192 and ±512 in each vector component. The data are digitized and averaged within the instrument to provide increased resolution and to provide Nyquist filtering.

Plasma Waves (ISEE-A and B)

D. A. Gurnett, University of Iowa.

The frequency range to be investigated is 1 Hz to 200 kHz for electric fields and 1 Hz to 10 kHz for magnetic fields. The basic instrumentation provides a complete set of triaxial magnetic field measurements on the A spacecraft and much simpler single axis electric and magnetic field measurements on the B spacecraft. Measurements on the A spacecraft are intended to cover all wave characteristics, such as wave-normal direction, polarization and Poynting flux. The single axis measurements on the B are intended to provide detailed comparisons of the frequency spectrum and field amplitudes at the two spacecraft.

Plasma Density (ISEE-A and B)

C. C. Harvey, Paris Observatory.

The electron density in the vicinity of the A spacecraft will be measured by means of a radio technique to detect resonances of the ambient plasma. These resonances occur at the plasma frequency, the upper hybrid resonance, the cyclotron frequency and its harmonics and their study permits the determination of several plasma parameters and notably the electron density.

Energetic Electrons and Protons (ISEE-A and B)

D. J. Williams, National Oceanic and Atmospheric Administration, Washington, D.C. (ISEE-A) and E. Keppler, Max Planck Institute (ISEE-B).

The principle of the measurements is to separate electrons and protons by a magnet, deflecting each type of particle into one or more solid state detector telescopes where the pulse heights can be analyzed. This will be accomplished by flying solid state detector systems on both A and B spacecraft to measure detailed energy spectra and angular distributions of protons in the energy range 20 keV to 2 MeV and electrons in the energy range 20 keV to 1 MeV. The NOAA Space Environment Laboratory is responsible for A instrument hardware and integration and the Max Planck Institute for Aeronomy is responsible for B instrument hardware and integration.

Electrons and Protons (ISEE-A and B)

K. A. Anderson, University of California, Berkeley.

Two identical solid state detector telescopes are used, one open, and the other covered with parylene foil. The telescopes have a viewing cone with a half angle of 40 degrees, oriented at an angle of about 20 degrees with the spin axis of the spacecraft. Electrons will be measured in two energy bands, 8 to 200 keV and 30 to 200 keV. Protons will also be measured in these energy ranges and in addition between 200 and 380 keV.

Fast Electrons (ISEE-A)

K. W. Ogilvie, Goddard Space Flight Center, Greenbelt, Md.

Two identical instruments are mounted diametrically opposite one another in the spacecraft, each having three electrostatic analyzers. The axes of each set of analyzers are mutually perpendicular and are oppositely directed to those of the other set. Thus the net flux of electrons in a given direction can be determined, and a good approximation to the three dimensional velocity distribution function obtained. Two channelton electron multipliers are used on each of six analyzers. There are three modes of operation: solar wind 7.4 to 494 eV; magnetosheath 10.5 to 2006 eV and magnetotail and solar 106 to 7077 eV.

Low Energy Cosmic Ray (ISEE-A) and Gamma Ray Burst

D. Hovestadt, Max Planck Institute.

The instrument consists of three sensors and associated electronics:

- An Ultra Low Energy nuclear charge (Z), total energy (E) and ionic charge (Q) assembly (ULEZEQ); this sensor consists of two physically separated units.
- An Ultra Low Energy Wide Angle Telescope designated ULEWAT.
- A Gamma Ray Burst detector.

Quasi-static Electric Field (ISEE-A)

F. S. Mozer, University of California.

Fields are obtained from measurements of the potential difference between a pair of spheres, each of which is mounted on the end of a 50-meter wire boom. The measured potential differences are converted to electric field components in the spacecraft frame of reference by dividing each measurement by the sphere separation distance, after which the resulting fields are converted to Earth-fixed, inertial, or other frames of reference by subtraction of the induced electric field resulting from spacecraft motion through the magnetic field.

DC Electric Field (ISEE-A)

J. P. Heppner, Goddard Space Flight Center.

The electric field in the spin plane of the spacecraft is determined by measuring the difference in the floating potential between the conducting tip sections of two colinear wires extended perpendicular to the spin axis.

Calibration checks and plasma impedance measurements can be conducted either instantaneously or periodically by command functions.

Ion Composition (ISEE-A)

R. D. Sharp, Lockheed Electronics Co., Plainfield, N.J.

The energetic ion mass spectrometer is a high-sensitivity high-resolution analyzer designed to measure the ionic composition over the mass-per-unit-charge region from 1 to 138 AMU in the energy-per-unit-charge range from zero to 17 keV. The instrumentation consists of two complete spectrometers. These are required outside the magnetosphere to provide adequate elevation angle coverage.

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VLF Wave Propagation (ISEE-A)

R. A. Helliwell, Stanford University, Palo Alto, Calif.

The main wave injection device is the Stanford VLF transmitter presently in operation at Siple Station in the Antarctic. In recent tests, signals from this transmitter have been successfully injected into the magnetic equatorial plane and have been observed via satellite. For the ISEE mission, the transmitter will be used to inject VLF waves throughout the magnetosphere, producing both VLF emissions and energetic particle pitch angle scattering. In the general case the injected signal, as well as any stimulated VLF emissions will be detected on the A spacecraft broadband VLF receiver provided by Stanford University.

Solar Wind Ions (ISEE-B)

G. Moreno, Laboratorio Plasma Spazio, Frascati, Italy.

This instrument is designed to measure the flow directions and energy spectra of the positive ions in the solar wind. Two modes of operation are provided, one concentrates on high angular resolution and the other on high energy resolution. The main region of interest for this instrument is outward from and including the magnetopause.

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DELTA LAUNCH VEHICLE (2914)

The ISEE-A/B spacecraft will be launched by a three stage Delta 2914 launch vehicle. The launch vehicle has an overall length of approximately 35 meters (115 feet) and a maxumum body diameter of 2.4 m (7.8 ft.). A brief description of the vehicle's major characteristics follows:

First Stage

The first stage is a McDonnell Douglas modified Thor booster incorporating nine strap-on Thiokol solid-fuel rocket motors. The booster is powered by a Rocketdyne engine using liquid oxygen and liquid hydrocarbon propellants. The main engine is gimbal-mounted to provide pitch and yaw control from liftoff to main engine cutoff (MECO).

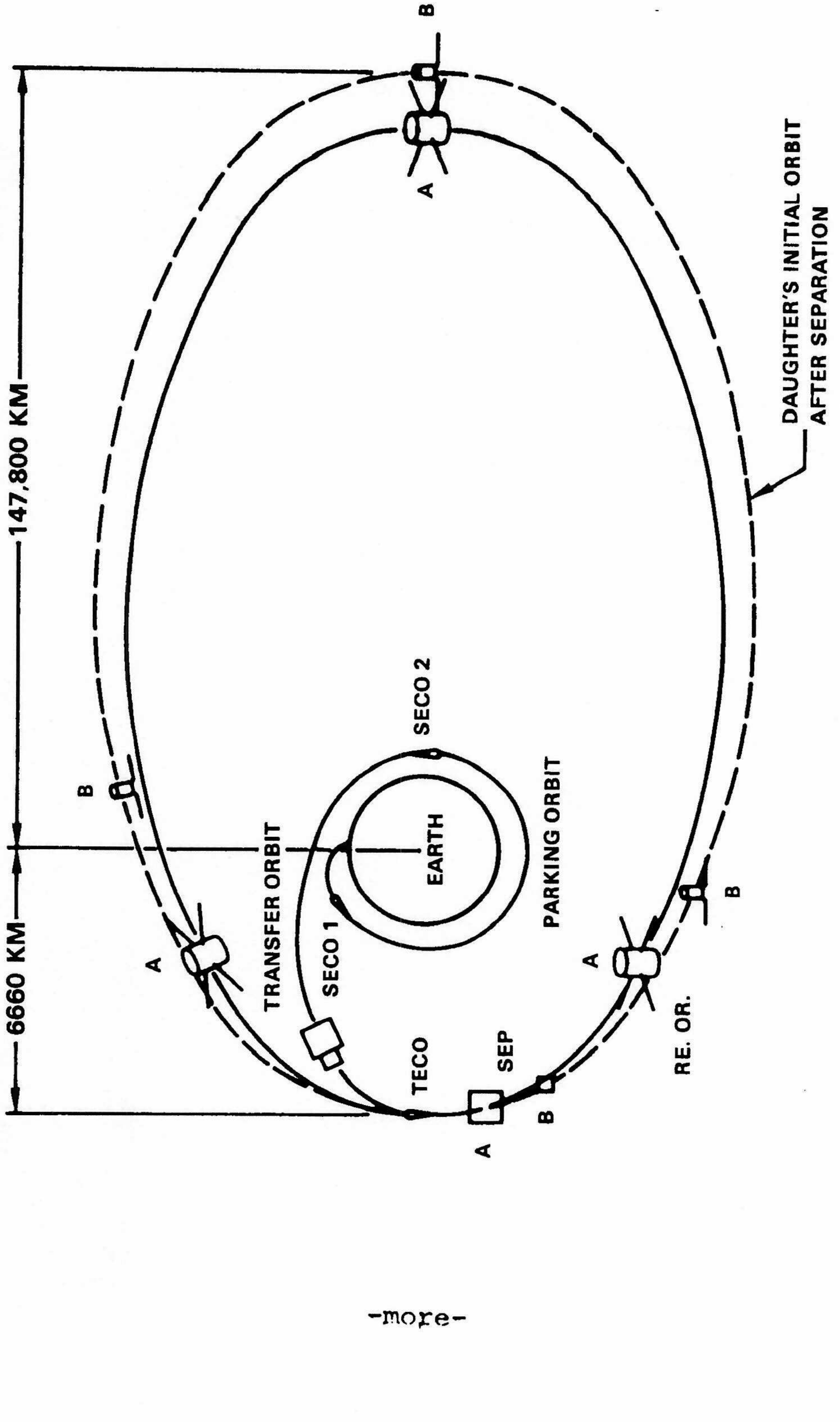
Second Stage

The second stage is powered by a TRW liquid fuel, pressure-fed engine that also is gimbal-mounted to provide pitch and yaw control through the second stage burn. A nitrogen gas system uses eight fixed nozzles for roll control during powered and coast flight, as well as pitch and yaw control during coast and after second stage cutoff (SECO). Two fixed nozzles, fed by the propellant tank helium pressurization system, provide retrothrust after third stage separation.

Third Stage

The third stage is the TE-364-4 spin-stabilized, solid propellant Thiokol motor. It is secured in the spin table mounted to the second stage. The firing of eight solid propellant rockets fixed to the spin table accomplishes spin-up of the third stage spacecraft assembly. The ISEE spacecraft are attached to the third stage motor.

INTERNATIONAL SUN-EARTH EXPLORERS (ISEE-A & B)



INITIAL ORBITS

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LAUNCH OPERATIONS

The Kennedy Space Center's Expendable Vehicles Directorate plays a key role in the preparation and launch of the thrust-augmented Delta rocket carrying the ISEE A/B spacecraft.

Delta 135 will be launched from Pad B, southernmost of the two launch pads at Complex 17, Cape Canaveral Air Force Station.

The Delta first stage and interstage were erected on Pad B on August 30. Four Castor 2 solid strap-on rocket motors were mounted in place around the base of the first stage on August 31 and the remaining five were installed on September 1. The second stage was erected on September 6.

The ISEE B spacecraft arrived at KSC on August 31 and the ISEE A spacecraft was received on September 8. After initial checkout in Hangar S, the two spacecraft were moved to the Spin Test Facility in late September for mating with the Delta third stage in early October. Movement of the spacecraft/third stage assembly to the pad for mating with Delta 135 was scheduled for the first week in October.

Based upon an October 19 launch date, the payload fairing which protects the spacecraft on its flight through the atmosphere is to be put in place about October 16.

ISEE-A&B PROGRAM MANAGEMENT

The memorandum of understanding between the European Space Agency and NASA dated March 17, 1975, divides the project responsibilities and provides for an internatinal management organization. NASA is responsible for the A and C spacecraft, Delta launch vehicle, tracking, data acquisition and data processing. ESA is responsible for the ISEE-B spacecraft and its operation.

NASA's Office of Space Science is responsible for overall direction and evaluation of the NASA portion of the program. The Office of Tracking and Data Acquisition has overall tracking and data processing responsibility.

Goddard Space Flight Center has management responsibility for ISEE-A and is directly responsible for tracking and data acquisition and data processing.

ISEE-A is a Goddard-designed spacecraft with all its components supplied by United States industry. Integration and testing was also done at Goddard.

ISEE-B is an ESA-ESTEC spacecraft with Dornier Systems,Frederickshaven, Germany, heading the contractor team which consists of a consortium of industries in 10 European countries called the STAR Consortium.

Goddard directs the Delta rocket program and McDonnell Douglas Astronautics Co., Huntington Beach, Calif., is prime contractor.

LAUNCH SEQUENCE FOR ISEE-A & B

Event	Time	Altitude Kilometers	miles
Liftoff	0 sec.	0	0
Six Solid Motor Burnout	38 sec.	6	4
Three Solid Motor Ignition	39 sec.	6	4
Three Solid Motor Burnout	1 min. 18 sec.	21	13
Nine Solid Motor Jettison	1 min. 27 sec.	26	16
Main Engine Cutoff (MECO)	3 min. 45 sec.	91	56
First/Second Stage Separation	3 min. 54 sec.	96	60
Second Stage Ignition	3 min. 56 sec.	99	61
Fairing Jettison	4 min. 56 sec.	126	78
Second Stage Cutoff #1 (SECO #1)	8 min. 44 sec.	157	97
Begin Coast Phase Roll (1 rpm)	9 min. 23 sec.	157	97
End Coast Phase Roll	44 min. 23 sec.	275	171
Second Stage Ignition #2	53 min. 31 sec.	285	177
Second Stage Second Cut-Off 2 (SECO 2)	53 min. 52 sec.		
Third Stage/Payload Spin-Up	54 min. 50 sec.		
Jettison Stage II	54 min. 52 sec.		
Third Stage Ignition	55 min. 33 min.		
Third Stage Burnout	56 min. 17 sec.	287	178
Payload Separation, Activate Retro System	57 min. 30 sec.	327	203

-more-

ISEE-A and B TEAM

NASA Headquarters

Dr. Noel S. Hinners	Associate Administrator for Space Science
Dr. S. Ichtiaque Rasool	Deputy Associate Administrator for Space Science (Science)
T. Bland Norris	Director, Astrophysics Programs
Dr. Harold Glaser	Director, Solar Terrestrial Programs
Frank Gaetano	ISEE-A Program Manager
Dr. Erwin R. Schmerling	ISEE-A Program Scientist
John F. Yardley	Associate Administrator for Space Flight
Joseph B. Mahon	Director of Expendable Launch Vehicle Programs
Peter T. Eaton	Manager, Delta Program
Gerald M. Truszynski	Associate Administrator for Tracking and Data Acquisition

European Space Agency

Roy Gibson	Director General
Dr. Ernst Trendelenburg	Director of Scientific and Meteorological Programs
Dr. Edgar Page	Head of Space Science Department, European Space Technology Center (ESTEC)
Maurice Delahais	Head, Scientific Projects ESTEC
Derek Eaton	ISEE-B Project Manager
Dr. Alastair C. Durney	ISEE-B Project Scientist

-more-

Goddard Space Flight Center

Dr. Robert S. Cooper	Director
Robert E. Smylie	Deputy Director
Robert Lindley	Director of Projects
Don Fordyce	Associate Director for Projects
Jeremiah J. Madden	Project Manager
Keith W. Ogilvie	Project Scientist
Dr. Stephen Paddack	Deputy Project Manager, Technical
James O. Redding	Financial Manager
John A. Hrastar	Mission Operations Manager
Martin A. Davis	Scientific Instrument Manager
David W. Grimes	Delta Project Manager
William R. Russell	Deputy Delta Project Manager, Technical
Robert Goss	Chief, Mission Analysis and Integration Branch, Delta Project Office
E. Michael Chewning	Delta Mission Integration Manager
Thomas C. Moore	Mission Operations Manager
Kenneth McDonald	Network Support Manager

Kennedy Space Center

Lee R. Scherer	Director
Gerald D. Griffin	Deputy Director
Dr. Walter J. Kapryan	Director, Space Vehicles Operations
George F. Page	Director, Expendable Vehicles

Kennedy (cont'd)

W. C. Thacker	Chief, Delta Operations Division
Wayne McCall	Chief Engineer, Delta Operations
Edmund M. Chaffin	Spacecraft Coordinator

Contractors

Dornier Systems Friedrichshafen, Germany	ISEE-B Spacecraft (prime)
McDonnell Douglas Astronautics Co. Huntington, Beach, Calif.	Delta Launch Vehicle

ISEE-B was designed and constructed by the European STAR Consortium of companies under contract to the European Space Agency. Dornier Systems as prime contractor is responsible for project management, systems engineering, attitude and orbit control, wire harness, assembly integration and test and launch support.

Other STAR consortium team members are:

Structure	Contraves, Switzerland
Telecommunications and data handling	Thomson-CSF, France Montedel Laben SPA, Italy AEG, Germany L.M. Ericsson, Sweden
Attitude and Orbit Control	British Aircraft Corp., United Kingdom SEP, France Fokker, Netherlands
Solar Array	AEG, Germany
Power Supplies	FIAR, Italy Electronikcentralen, Denmark Fokker, Netherlands Dornier Systems, Germany

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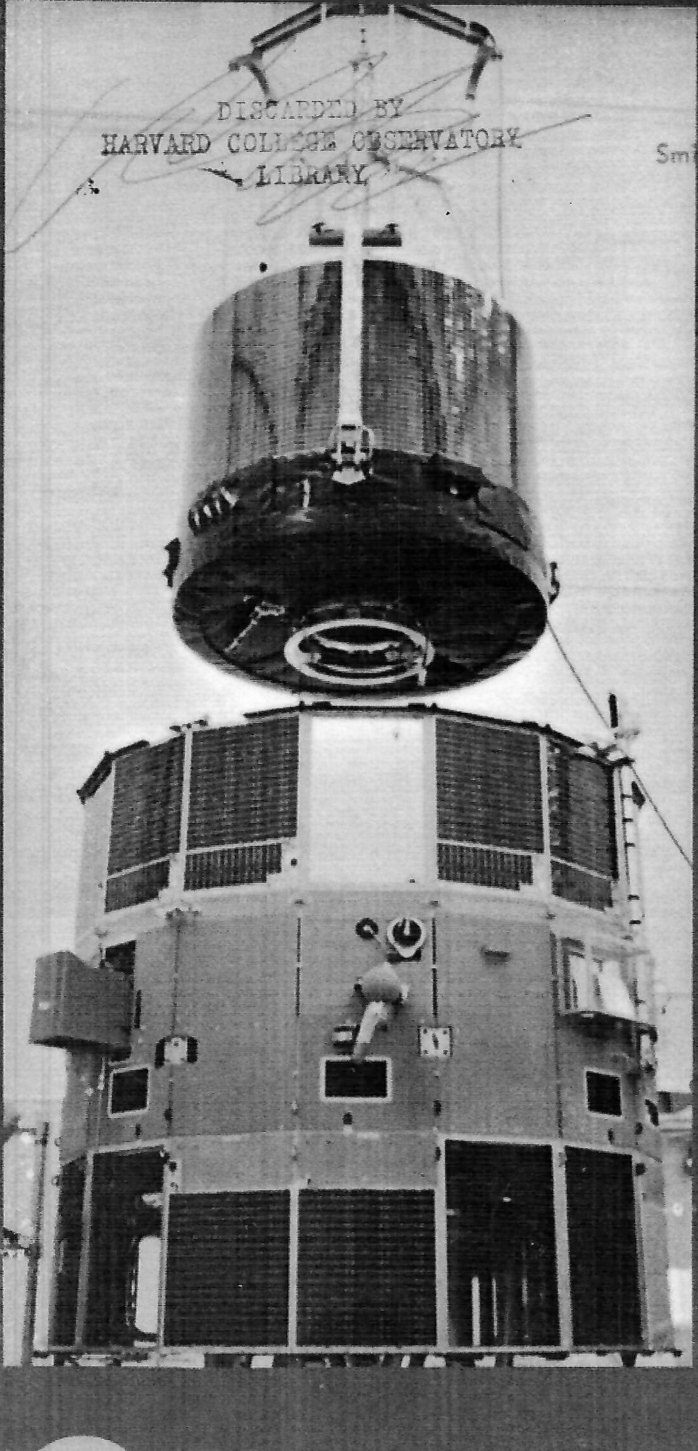
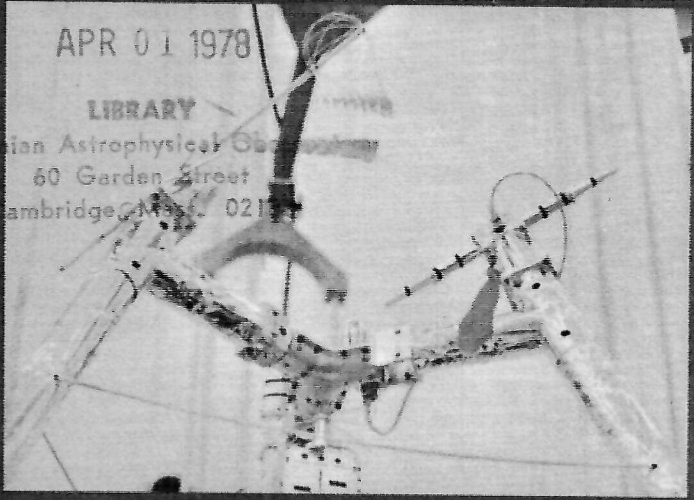
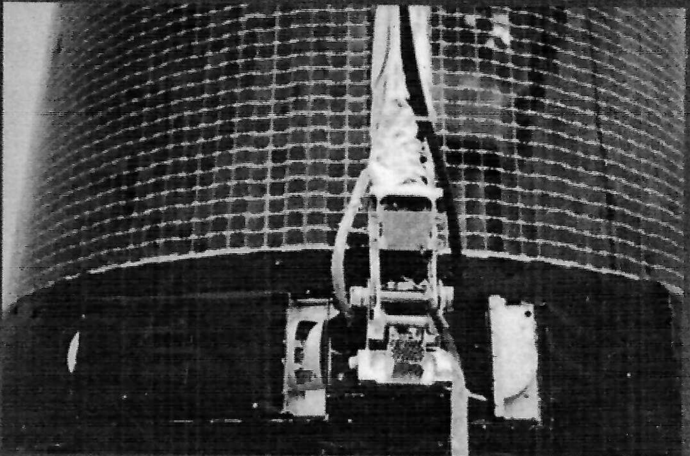
esa bulletin



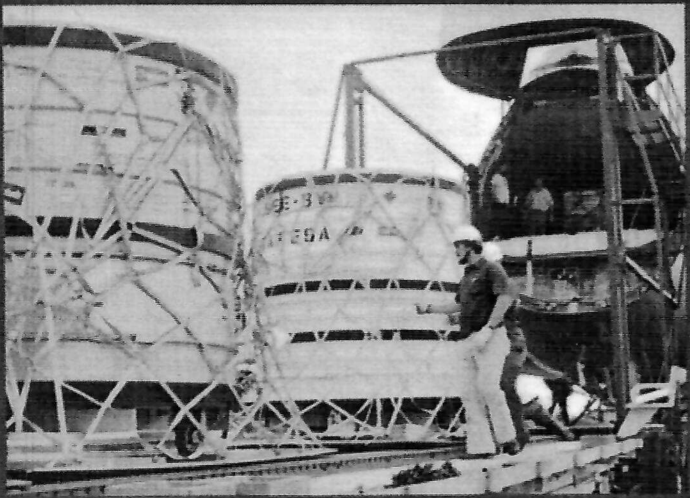


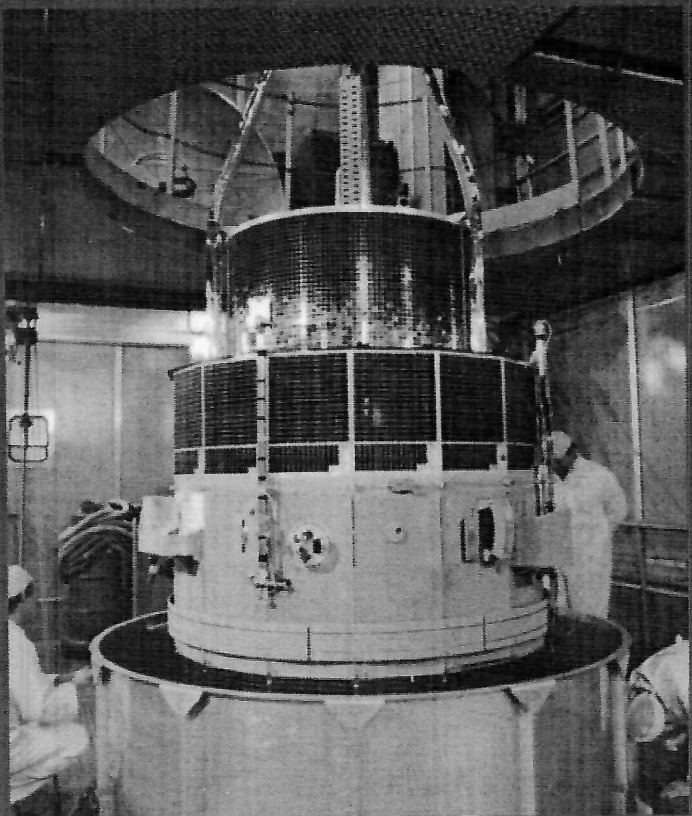


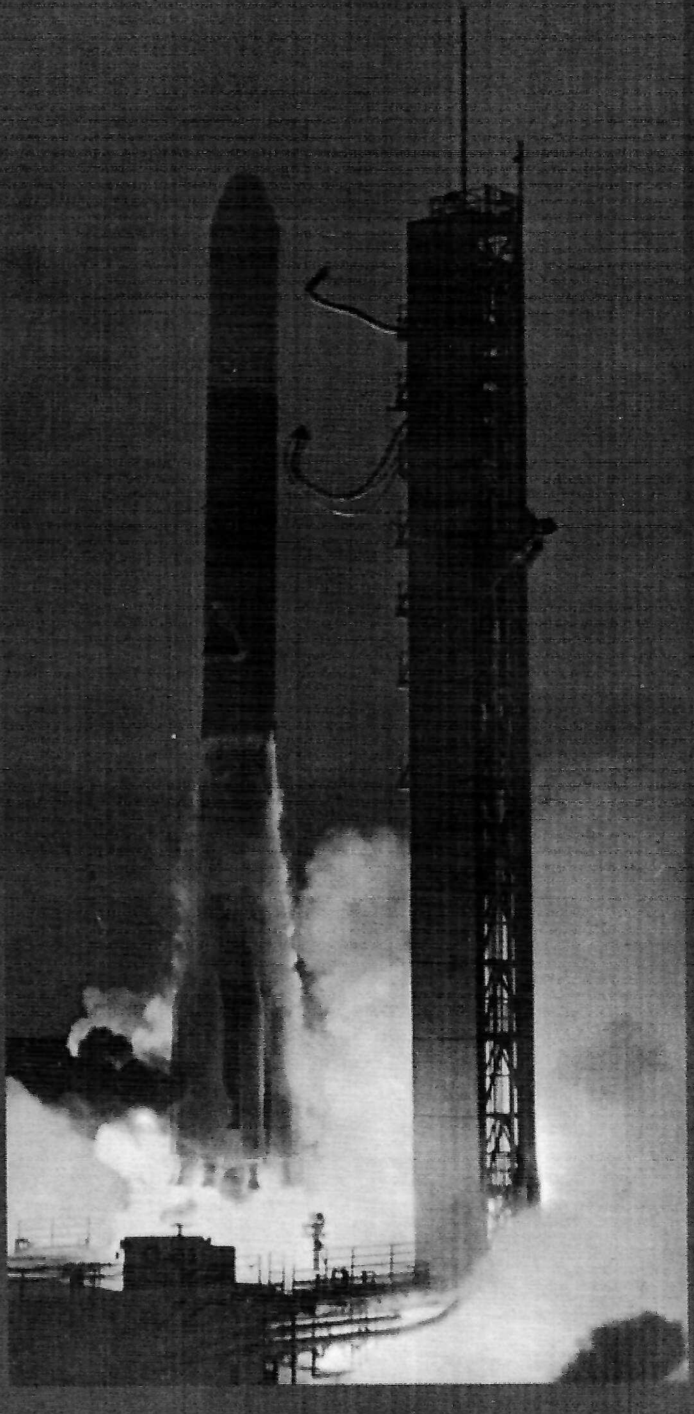
International Sun-Earth Explorer (ISEE) Spacecraft Operational

european space agency
agence spatiale européenne

no. 12
february 1978







MEMBER STATES
Belgium
Denmark
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Spain
Sweden
Switzerland
United Kingdom

ETATS MEMBRES
Allemagne
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Espagne
France
Italie
Pays-Bas
Royaume-Uni
Suède
Suisse

INTERNATIONAL
SUN EARTH
EXPLORER-A/B

Launch Vehicle – Delta 291.

Spacecraft Description – The International Sun Earth Explorer (ISEE-A) was a 16-sided polyhedron measuring approximately 1.73 meters across and 1.61 meters high. Its main body consisted of an 84-centimeter conical center tube. The lower end of the center tube mated with the launch vehicle and the upper end with the ISEE-B.

ISEE-B was a cylinder with a diameter of 1.27 meters and a height of 1.14 meters. Solar cells were mounted on these detachable curved panels.

Project Objectives – Measurements by instruments on the pair of spacecraft permitted ambiguities associated with the motion of near-Earth space boundaries to be resolved.

Spacecraft Payload – Use of two spacecraft, separated by a variable distance, allowed scientists to study the boundaries in near-Earth space and the nature of their fluctuation. These included the plasma pause, the magnetopause, where the magnetic field of the Earth meets that of the solar wind, the bow shock, a sort of bow wave created by the motion of the solar wind past the Earth, and several less obvious features of the Earth's magnetic tail.

Project Results – ISEE-A and -B were successfully launched on October 22, 1977 from the Kennedy Space Center, Florida. ISEE-A's orbit was 138,124 by 280.1 kilometers, inclined at 28.73 degrees and with a period of 57 hours and 26.8 minutes. ISEE-B was in a similar orbit – 138,300 by 279.4 kilometers and 28.6 degrees.

Major Participants – ISEE-A was a NASA Goddard Space Center-designed spacecraft, built, fabricated, and tested at Goddard with all of its components made either at Goddard or supplied by industries or universities. ISEE-B was an ESA – European Space Technology Center – satellite design. The STAR consortium of 10 countries supervised construction under contract to ESA. STAR consisted of industries in Belgium, Denmark, France, Spain, Germany, Italy, the Netherlands, Sweden, Switzerland, and the United Kingdom. Dornier Systems in Germany headed the contractor team.

Goddard directed the Delta rocket program for NASA's Office of Space Flight and McDonnell-Douglas Astronautics Co., Huntington Beach, California, was the prime contractor.

Key Spacecraft Personnel	Affiliation
ISEE/A	
MG J. P. Corrigan	NASA Headquarters
PM R. O. Wales	NASA-GSFC
SC M. J. Aucremanne	NASA Headquarters
PS K. W. Ogilvie	NASA-GSFC
ISEE/B	
PM A. Hawkyard	ESA-ESTEC
PS A. C. Durney	ESA-ESTEC
CO G. E. Kowalski	NASA-GSFC
MG J. R. Holtz	NASA Headquarters
SC E. R. Schmerling	NASA Headquarters

Experiment	Experiment Personnel	Affiliation
ISEE/A		
Fast Plasma + Solar Wind Ion	PI S. J. Bame	Los Alamos Scientific Laboratory
	OI H. Miggenrieder	MPI-Extraterrestrial Physics
	OI K. Schindler	Ruhr University Bochum
	OI J. R. Asbridge	Los Alamos Scientific Laboratory
	OI H. R. Rosenbauer	MPI- Aeronomy
	OI H. Volk	MPI-Nuclear Physics
	OI M. D. Montgomery	Los Alamos Scientific Laboratory
	OI G. Paschmann	MPI-Extraterrestrial Physics
	OI W. C. Feldman	Los Alamos Scientific Laboratory
	OI E. W. Hones, Jr.	Los Alamos Scientific Laboratory
Fast Electrons	PI K. W. Ogilvie	NASA-GSFC
	OI J. D. Scudder	NASA-GSFC
Hot Plasma	PI L. A. Frank	University of Iowa
	OI V. M. Vasyliunas	MPI-Aeronomy
	OI C. F. Kennel	University of California, Los Angeles
Fluxgate Magnetometer	PI C. T. Russell	University of California, Los Angeles
	OI R. L. McPherron	University of California, Los Angeles
	OI P. C. Hedgecock	Imperial College
	OI E. W. Greenstadt	TRW Systems Group
	OI M. G. Kivelson	University of California, Los Angeles

Experiment	Experiment Personnel	Affiliation
Low Energy Cosmic Rays	OI J. J. O'Gallagher	University of Maryland
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	OI M. Scholer	MPI-Extraterrestial Physics
	OI L. A. Fisk	University of New Hampshire
	OI C. Y. Fan	University of Arizona
	OI G. Gloeckler	University of Maryland
Quasi-Static Electric Field	OI M. C. Kelley	University of California, Berkeley
	PI F. S. Mozer	University of California, Berkeley
Plasma Waves	PI D. A. Gurnett	University of Iowa
	OI F. L. Scarf	TRW Systems Group
	OI R. W. Fredericks	TRW Systems Group
	OI E. J. Smith	NASA-JPL
Plasma Density	OI M. Petit	CNET
	OI J. R. McAfee	NOAA-ERL
	OI D. Jones	ESA-ESTEC
	OI J. M. Etcheto	CNET
	PI C. C. Harvey	Paris Observatory
	OI R. J. L. Grard	ESA-ESTEC
	OI R. E. Gendrin	CNET
Energetic Electric and Protons	PI D. J. Williams	NOAA-ERL
	OI C. O. Bostrom	Applied Physics Laboratory
	OI B. Wilken	MPI-Aeronomy
	OI T. A. Fritz	NOAA-ERL
	OI G. H. Wibberenz	University of Kiel
	OI E. Keppler	MPI-Aeronomy
Electrons and Protons	OI C. I. Meng	Applied Physics Laboratory
	PI K. A. Anderson	University of California, Berkeley
	OI F. V. Coroniti	University of California, Los Angeles
	OI J. M. Bosqued	CESR
	OI R. Pellat	Center for Theoretical Physics
	OI G. K. Parks	University of Washington
	OI R. P. Lin	University of California, Berkeley
	OI H. Reme	CESR
DC Electric Fields	PI J. P. Heppner	NASA-GSFC
	OI T. L. Aggson	NASA-GSFC
	OI N. C. Maynard	NASA-GSFC
	OI D. A. Gurnett	University of Iowa
	OI D. P. Cauffman	Lockheed, Palo Alto

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Ion Composition	PI R. D. Sharp	Lockheed, Palo Alto
	OI G. Haerendel	MPI-Extraterrestrial Physics
	OI H. R. Rosenbauer	MPI-Aeronomy
	OI R. G. Johnson	Lockheed, Palo Alto
	OI E. G. Shelley	Lockheed, Palo Alto
	OI J. Geiss	University of Berne
	OI P. X. Eberhardt	University of Berne
	OI H. Balsiger	University of Berne
	OI C. R. Chappell	NASA-MSFC
	OI A. Ghielmetti	University of Berne
	OI D. T. Young	University of Berne
VLF Wave Propagation	PI R. A. Helliwell	Stanford University
	OI T. F. Bell	Stanford University
Gamma-Ray Bursts	OI D. K. Hovestadt	MPI-Extraterrestrial Physics
	OI B. J. Teegarden	NASA-GSFC
	PI T. L. Cline	NASA-GSFC
	OI G. Gloeckler	University of Maryland

Experiment	Experiment Personnel	Affiliation
ISEE/B		
Fast Plasma	OI W. C. Feldman	Los Alamos Scientific Laboratory
	OI E. W. Hones, Jr.	Los Alamos Scientific Laboratory
	OI K. Schindler	Ruhr University Bochum
	PI G. Paschmann	MPI-Extraterrestrial Physics
	OI H. Miggenrieder	MPI-Extraterrestrial Physics
	OI S. J. Bame	Los Alamos Scientific Laboratory
	OI H. Volk	MPI-Nuclear Physics
	OI H. R. Rosenbauer	MPI-Aeronomy
	OI M. D. Montgomery	Los Alamos Scientific Laboratory
	OI J. R. Asbridge	Los Alamos Scientific Laboratory
Solar Wind Ions	PI G. Moreno	CNR, Space Plasma Laboratory
	OI P. Cerulli	CNR, Space Plasma Laboratory
	OI V. Formisano	CNR, Space Plasma Laboratory
	OI A. Egidi	CNR, Space Plasma Laboratory

Experiment	Experiment Personnel	Affiliation
	OI S. C. Cantarano	CNR, Space Plasma Laboratory
	OI S. J. Bame	Los Alamos Scientific Laboratory
	OI G. Paschmann	MPI-Extraterrestrial Physics
Hot Plasma	PI L. A. Frank	University of Iowa
	OI V. M. Vasyliunas	MPI-Aeronomy
	OI C. F. Kennel	University of California, Los Angeles
Fluxgate Magnetometer	PI C. T. Russell	University of California, Los Angeles
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	OI P. C. Hedgecock	Imperial College
	OI E. W. Greenstadt	TRW Systems Group
	OI M. G. Kivelson	University of California, Los Angeles
Plasma Waves	PI D. A. Gurnett	University of Iowa
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	OI F. J. Smith	NASA-JPL
	OI R. W. Fredericks	TRW Systems Group
Radio Propagation	OI R. E. Gendrin	CNET
	OI J. R. McAfee	NOAA-ERL
	OI M. Petit	CNET
	OI D. Jones	ESA-ESTEC
	OI J. M. Etcheto	CNET
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Energetic Electrons and Protons	PI D. J. Williams	NOAA-ERL
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	OI F. V. Coroniti	University of California, Los Angeles
	PI K. A. Anderson	University of California, Berkeley
	OI H. Reme	CESR
	OI R. P. Lin	University of California, Berkeley
	OI G. K. Parks	University of Washington

The International Sun-Earth Explorer (ISEE) Programme*

A.C. Durney

The ISEE Programme is a joint NASA/ESRO undertaking involving the launch of three spacecraft, a prime aim of the mission being to resolve the spatial and temporal ambiguities inherent in magnetospheric measurements from a single platform. Participation in the programme was agreed by the ESRO Council in April 1973, when it approved the inclusion of what was then known as the IME-D satellite in the Organisation's future scientific satellite programme. The former title of International Magnetospheric Explorer has now been amended to International Sun-Earth Explorer (ISEE) and the three spacecraft formerly known as the Mother, Daughter and Heliocentric satellites have been re-named ISEE-A, ISEE-B and ISEE-C respectively. This short article outlines the aims of the overall programme, with particular reference to the role of the A and B spacecraft.

Introduction

The studies that have so far been made of the Earth's magnetosphere have been largely of an exploratory nature, in which a fairly well-substantiated morphological picture has been built up by the discovery of the radiation belts, the magnetopause, the bow shock, the magnetotail, etc., and certain dynamical processes, such as the oscillations of the magnetopause and the acceleration of trapped particles, have been observed. Scientists are, however, in only the very early stages of an understanding of the physical processes involved, and several now look on the Earth's magnetosphere as a kind of "space laboratory" in which the fundamental plasma processes, such as collisionless shocks, instabilities, particle accelerations, and the structure of the interfaces between collisionless plasmas in different states, can be observed *in situ*. Magnetospheric physics is thus now in the process of transition between the first exploratory stage and that in which space missions must be planned, not just to explore, but also to achieve a more comprehensive, quantitative understanding of the cause-and-effect relationships of the dynamical processes involved.

To date, comparatively little effort has been made to co-ordinate satellite investigations of the magnetosphere, with the result that the scientists, in trying to build up their knowledge of what is going on inside this and the adjacent regions of space, have had recourse only to the results from widely diversified, uncoordinated missions. It was inevitable, therefore, that sooner or later a more logical approach to the problem, by virtue of a world-wide programme of carefully planned missions, should be initiated, and it is exactly this that is emerging from the initiative of COSPAR and the IUCSTP in setting up the International Magnetospheric Study. Although budgetary restrictions will no doubt lead to a wide gap between what is theoretically desirable and what is practical, participation in the IMS has gathered considerable momentum. ESRO is, of course, already committed to a major role in the IMS by virtue of the GEOS mission, which is generally recognised as the focus or reference spacecraft for the Study.

Mission Objectives of the ISEE Programme

A problem inherent in nearly all scientific measurements made from a single space platform is that of determining whether observed phenomena are attributable to spatial differences or to time differences. Instances in which simultaneous measurements from two or more satellites could be correlated have demonstrated the importance of multi-satellite measurements and have strengthened the arguments put forward from several sources for a multi-spacecraft mission as a means of solving these spatial and temporal ambiguities.

The present project arose out of earlier ESRO studies on a higly eccentric magnetospheric satellite (HEMS) and a near Earth magnetospheric satellite (NEMS), and the NASA IMP K-K' and IMP-L proposals. After discussions and negotiations between the two organisations, the separate ideas coalesced into a dual-spacecraft system with variable separation, together with a third (heliocentric) spacecraft in the solar wind upstream of the Earth. NASA will supply the launch vehicles, (Thor-Delta), the larger of the dual spacecraft (A) and the heliocentric platform (C). Both these satellites will be part of the IMP series. ESRO will provide the smaller, more manoeuvrable, spacecraft (B) of the pair – an entirely new concept.

The most interesting areas to be studied will be the bow shock and the magnetosheath, where wave/particle interactions will be investigated. Although the dayside geometry of both the bow shock and the magnetosphere is well described by gas dynamics, information on their internal structure and the physical processes going on inside them is very meagre. It is hoped that the A and B spacecraft, by separating time and space effects, will provide results that will make a detailed study of these areas possible. Transmission of signals between the A and B spacecraft will also enable the properties of the medium between to be measured. Another major aim will be to investigate the mechanism of substorms, the changes in the magnetosphere initiated by changes in the solar wind; for example, a configuration in which one of the tandem space- ▷

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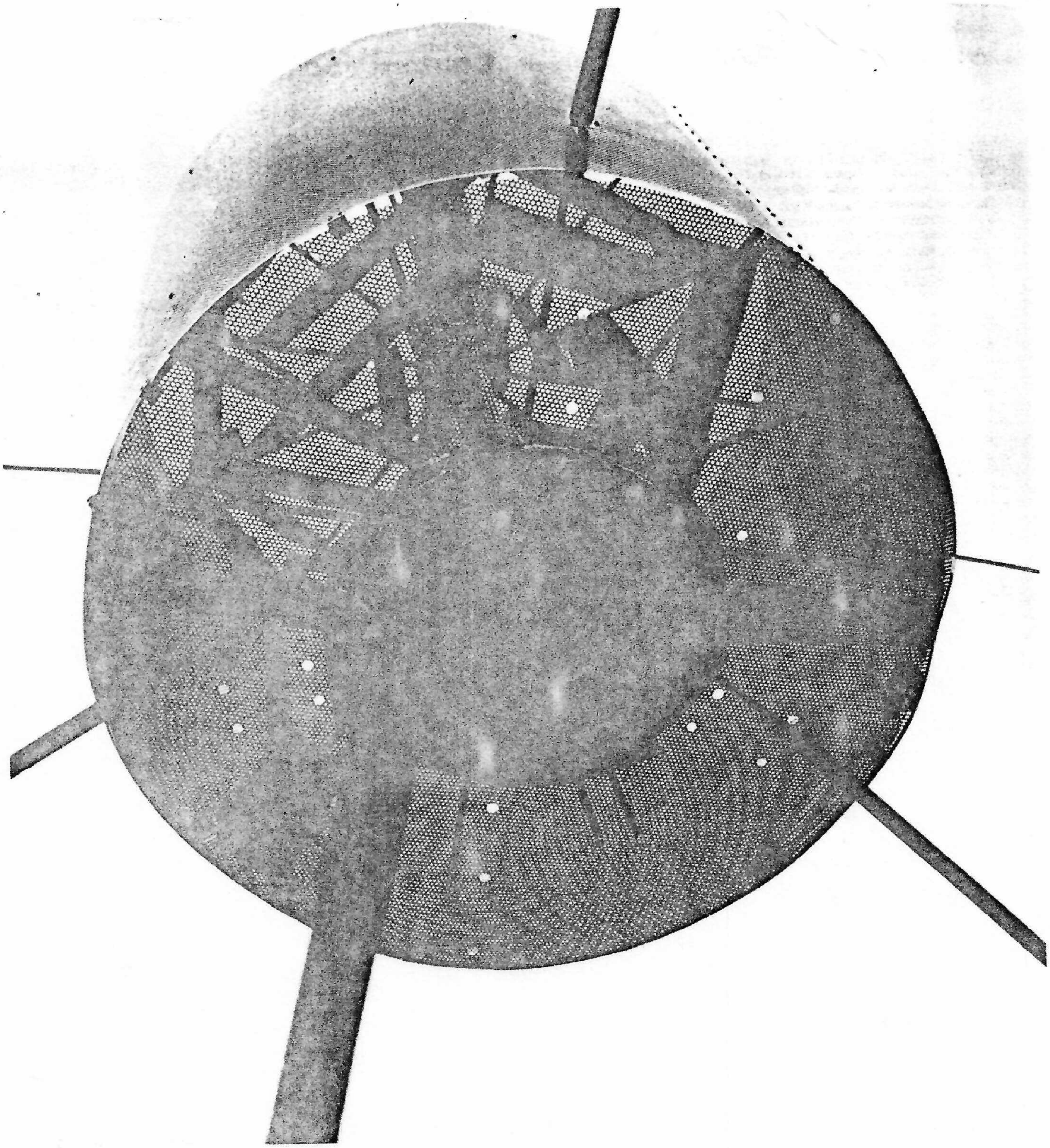
* Formerly the International Magnetospheric Explorer Programme

Shell mock-up of ISEE-B for checking antenna patterns



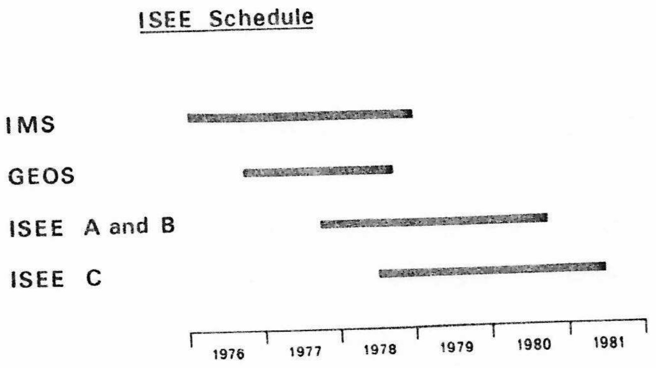


Figure 1

craft is in the magnetotail and the other near the Earth would be suitable for investigating how energy is transferred from the solar wind into the tail during the growth phase.

The third spacecraft (ISEE-C), out towards the Sun, in addition to making important measurements in its own right, will be able to supply information on the solar-wind input to the magnetosphere.

Launch Date

The A and B spacecraft will be launched in tandem into identical orbits by a Thor-Delta 2914 vehicle, in the Autumn of 1977. There will probably be a nine-month gap between this launch and that of ISEE-C into its heliocentric orbit. The planned lifetime of all three spacecraft is three years; the time scale of the mission is shown in Fig. 1, in relation to those of GEOS and the IMS. For A and B, the most critical part of the lifetime will be some time in the second year, when the longest eclipse period (about 5 hours) will occur.

The Orbits

The main orbital parameters, together with certain other satellite data, are given in Table 1. The tandem-launch apogee of 23 R_E was chosen as this gives the maximum number of bow-shock crossings. The perigee height (not given in the Table) is determined from a combination of the launcher performance and the total weight of the two spacecraft, and is at present about 300 km, an altitude which is almost the lowest consistent with a three-year lifetime. This means that there is little room for adjustment in the weight margins.

Table 1. Satellite Data and Mission Parameters

		A	*B*	*C*
Satellite mass (kg)		340	160	465
Payload mass (kg)		77.6	27.7	73
Payload power (W)		73	29	54
No. of experiments		14	8	13
Data rate (bps)	high	16 384	8192	2048
	low	4 096	2048	1024
Inclination		40°	40°	–
Apogee		23 R_E (146 000 km)	23 R_E	Stable on subsolar point at 230 R°
Spin rate (rpm)		19.7	19.7	20
Spin-axis alignment		Perpendicular to the ecliptic plane		
Launch date		Tandem, October 1977		July 1978

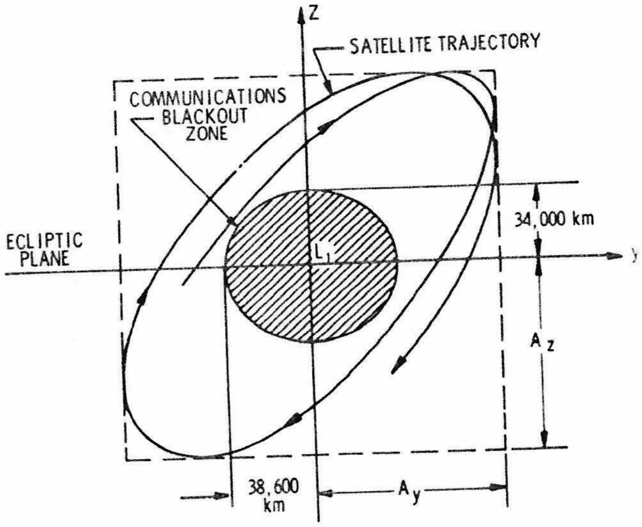


Figure 2

An orbital inclination of 40° was chosen in order to limit the longest eclipse time to five hours, although this does give rise to some antenna problems (see later). The experimental requirement for a full sweep of the bow shock crossings to b made at the start of the mission places the initial line o apsides tentatively as passing through a local time of abou 1600 hours.

All three spacecraft will be spin-stabilised and as a compromis between the slow-spin requirements of the wave experiment and the fast-spin requirements of the particle experiments, a three spin rates were originally set at 20 rpm. However, th

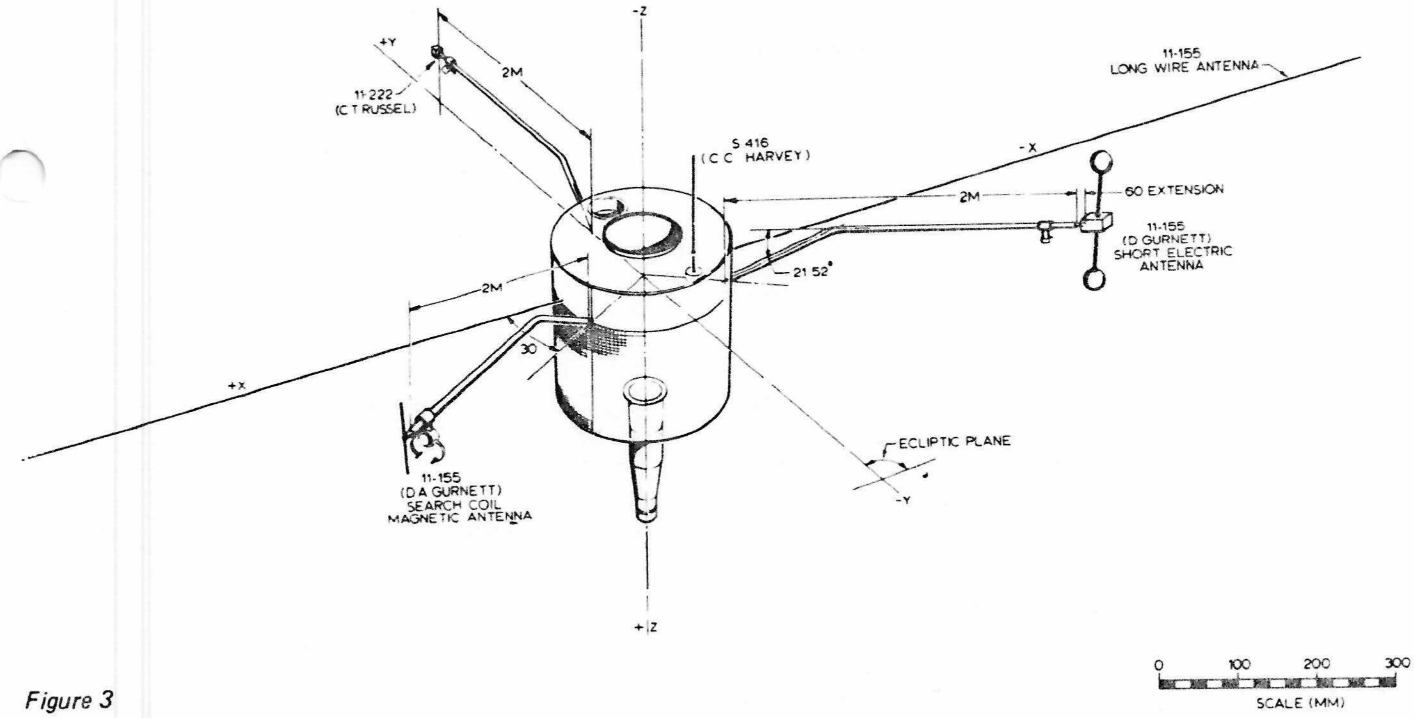


Figure 3

meant that on A and B the time for one rotation was an exact multiple of the telemetry frame time. As it is necessary that these quantities be out of phase, so that the particle experiments can carry out slow scanning, the A and B spin rates were reduced to the unusual figure of 19.7 rpm. All three spacecraft will have switchable telemetry rates, and the higher rates of A and B will be reserved for observation of the most interesting features – probably about 10 - 15% of the time.

The C spacecraft will be in the solar wind upstream of the Earth, and sufficiently far away not to be disturbed by the magnetosphere. The ideal position would be where the gravitational attractions of the Sun and the Earth and centrifugal force balance to give a point of stable equilibrium, but if the spacecraft were in this position the Sun would be directly behind it (as viewed from the Earth) and the telemetry transmission would be swamped by solar radio emission. The spacecraft will therefore be made to gyrate around this point, making a halo orbit around the radio blackout area (see Fig. 2). Injection into such an orbit and the frequent adjustment to the plane of the orbit in order to keep it normal to the Earth-Sun line will require a large amount of energy, and the C-spacecraft will carry a hydrazine gas system to supply this.

Separation Strategy

The distance between the A and B spacecraft will be varied, according to the scale sizes of the quantities to be measured. Because of the greater inertia and boom complexity of A (one of its wire antennas measures 215 m tip-to-tip), it was decided that the smaller (B) spacecraft should carry the gas-jet manoeuvring system. For economic gas use, separation direction will be along the orbit, the B spacecraft being given a 'kick' at perigee, in the form of a series of gas pulses, the number of pulses determining the size of the kick. The two spacecraft will then be allowed to drift slowly apart up to a maximum of 5000 km, after which a reverse impulse will be applied to B to start the spacecraft drifting together again. They will eventually pass each other, then drift apart again and so on. The kind of time scale envisaged is six months per half-cycle, but there are, of course, several variations on this theme. The important thing is that it is a stable system and very economical in gas consumption. The A spacecraft will also carry a small gas supply for spin-vector orientation immediately after launch.

The Experiments

The payload for the B-spacecraft was carefully selected for the measurement of wave/particle interactions, and is both cohesive and comprehensive. Of the eight experiments, six will carry out particle investigations: two of these will concentrate on measurements with high angular resolution, two on measurements with high time resolution, one on solar-wind ion observations and the sixth, the only one with actual communication between A and B, will measure the integral electron density along the transmission path between the two spacecraft. A seventh experiment will carry out measurements on both electric and magnetic waves, and the eighth is a magnetometer so designed that it can supply field reference pulses to the other instruments if need be.

A Principal Investigator (PI) and several co-investigators have been nominated for each experiment, and in many instances there is close trans-Atlantic co-operation, with the result that an American PI may have European co-investigators and vice versa. Also, although the A and C spacecraft will be NASA responsibilities and the B spacecraft an ESRO one, some of the A and C experiments have European PI's and some of the B experiments American PI's. ▷

The main limitation of the B spacecraft is that the boom configuration limits the wave measurements to two dimensions, a restriction that does not apply to the A payload. The latter will carry experiments identical to those on B, together with a reinforced wave section, two more particle experiments and two instruments to measure the isotopic composition of cosmic rays and solar particles, the latter providing a close link with some of the C-spacecraft measurements.

The aims of the C spacecraft are somewhat different from those of A and B. It will carry nine particle experiments, four of which are low-energy instruments that should provide interesting comparisons with the magnetospheric spacecraft, four others will investigate the isotropic composition of energetic particles, and the ninth is a high-energy electron detector. The C payload also contains four non-particle experiments, designed to measure solar X-rays, electric and magnetic waves, and type-III radio bursts, and carries a magnetometer of a more sensitive type than that on the A and B spacecraft. The possibility of including a gamma-ray-burst experiment is still under discussion.

International Co-operation

The very nature of the overall ISEE Programme calls for the optimum degree of co-operation between project teams and experimenters on both sides of the Atlantic. This already exists in most areas, and even at this early stage of the programme common policies on interfaces, subsystems, components, etc., have already been agreed on. One of the major objectives in this connection is that instruments that are identical on the A and B spacecraft should be completely interchangeable. All three spacecraft are already benefitting from the pioneering efforts of the GEOS team in this field.

On a more formal level, an ISEE Joint Working Group (JWG) has been set up to implement the project and to provide the principal interface between the scientific and technical requirements of the mission. The JWG will be co-chaired by the NASA Project Manager for the A and C spacecraft and the ESRO Project Manager for the B spacecraft. The respective Project Scientists will also be members of the JWG, and, in addition, will co-chair an ISEE Investigators' Working Group (IWG). The purpose of the latter will be to assist the JWG, to co-ordinate data exchange amongst the ISEE scientists, and to facilitate the programme's contribution of data to other scientists within the framework of the IMS. The final flight readiness review of ISEE-A/ISEE-B will be carried out by a joint panel with co-chairmen designated by ESRO and NASA.

Problem Areas

In spite of the somewhat complicated arrangements inherent in this joint US/European three-satellite venture, the project has to date proceeded smoothly and according to schedule – although these are early days to speak too optimistically. The main problem at the moment is that a good window has not yet been found for the tandem launch. To help to avoid eclipse times longer than six hours, the orbital inclination has been increased to 40° from the original figure of about 20°. This in turn necessitates a wider angle of coverage for the S-band antenna, so reducing the gain in any one direction and thus losing some of the advantages of S-band transmission. Larger receiving dishes would solve the problem, but a sufficient number of these will not be available in the ISEE epoch. The problem is certainly a real one and is being given serious consideration.

Decisions still need to be taken on matters such as the details of the separation policy, the best method of transferring data across the Atlantic, organisation of the scientific control of the spacecraft, etc.

State of the Project

After selection of the three payloads by a joint ESRO/NASA committee, the successful candidates were formed into a Science Working Team (SWT). The purpose of the SWT, which also included ESRO and NASA scientists and engineers, was to work towards optimisation of the scientific payloads, the overall scientific mission and the spacecraft design. Concurrently with the several meetings held by the SWT, ESRO ran an industrial study on the design of the B spacecraft, and attendance of the study group members at these meetings led to a fast input to the study and a design in which most major problems had been solved by the end of 1973.

The ESRO programme for development of the B spacecraft is nearing the end of Phase B – the competitive Definition Phase. Contracts for this work were awarded in April this year to Marconi Space and Defence Systems Ltd (UK) as prime contractor for the COSMOS consortium, and to Dornier System GmbH (Germany) as prime contractor for the STAR consortium. The Phase C/D proposals were submitted by the two contractors on 11 October, and the main development contract will be awarded towards the end of November, with hardware construction commencing almost immediately thereafter. □

ISEE

Participating ESA Member States:
– Belgium, Denmark, France, Germany, Italy, Netherlands, Spain, Sweden, Switzerland, United Kingdom

In partnership with:
– NASA

Planned launch:
– October 1977

Etats membres participants:
– Allemagne, Belgique, Danemark, Espagne, France, Italie, Pays-Bas, Royaume-Uni, Suède, Suisse

En coopération avec:
– la NASA

Date de lancement prévue:
– octobre 1977

The International Sun-Earth Explorer Project, formerly known as IME, is unique in the history of the European Programme in that:

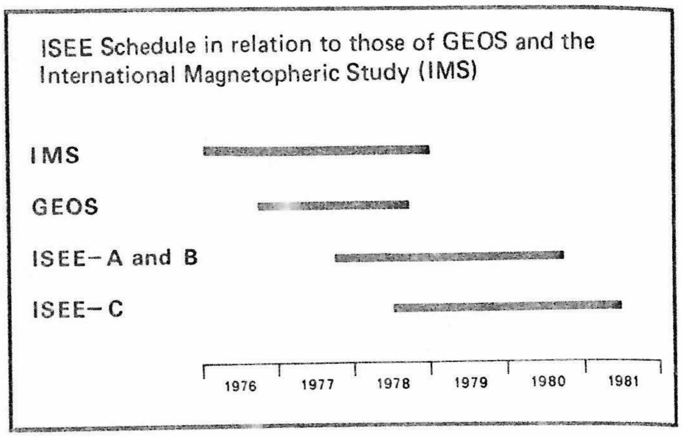
(i) it is a three-satellite project (ISEE-A and ISEE-C will be developed by NASA and ISEE-B by ESA);
(ii) there is a commonality of experiments between ISEE-A and ISEE-B, and it is the correlation between the measurements of these two satellites, traversing the same orbit but at a variable distance from each other, which makes the mission interesting and important from a scientific point of view.

The scientific aims of the mission are:

- to quantify the model of the magnetosphere and the Earth's interaction with the solar wind;
- to explore the plasmasphere and bow-shock sheath regions to study plasma and particle physics as such and for their astrophysics applications.

The payload of the ISEE-B satellite will comprise eight experiments provided by universities and scientific institutions in France, Italy, West-Germany and the USA.

In making simultaneous measurements by the A and B satellites, it is hoped to resolve previous ambiguities between spatial and temporal variations in the magnetosphere. With a



ISEE Schedule in relation to those of GEOS and the International Magnetopheric Study (IMS)

Le projet ISEE (International Sun-Earth Explorer), précédemment dénommé IME, est unique dans l'histoire du programme spatial européen en ce sens:

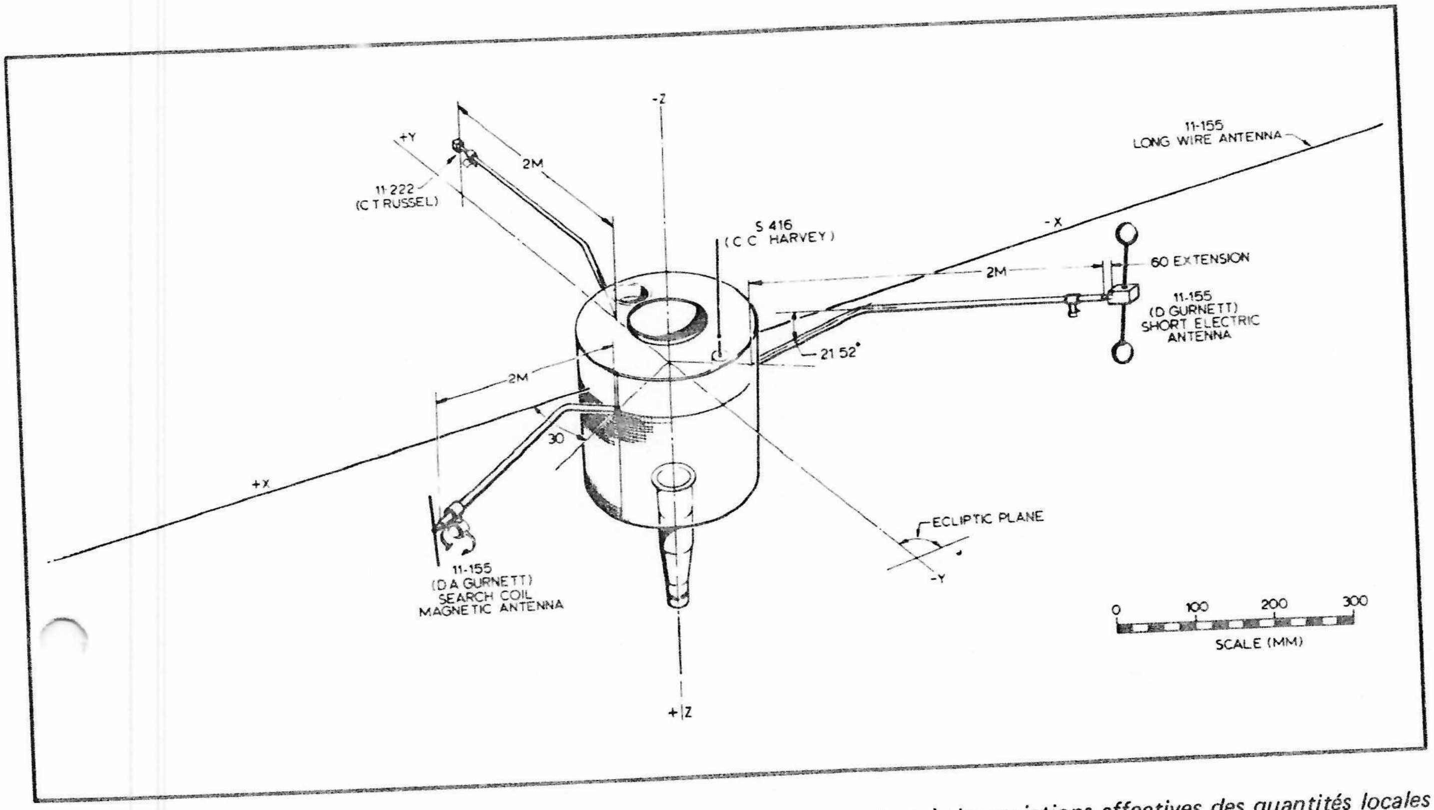
(i) qu'il s'agit d'un projet portant sur un ensemble de trois satellites dont deux, ISEE-A et ISEE-C, seront construits par la NASA, le troisième, ISEE-B, étant construit par l'ASE; et
(ii) qu'il prévoit la mise en oeuvre d'expériences communes sur ISEE-A et ISEE-B; c'est la possibilité d'établir une corrélation entre les mesures effectuées par ces deux satellites, suivant la même orbite mais à distance variable l'un de l'autre, qui rend cette mission particulièrement intéressante et importante du point de vue scientifique.

La mission a deux objectifs scientifiques principaux:

- *quantifier le modèle de la magnétosphère ainsi que les interactions de la Terre avec le vent solaire;*
- *explorer la plasmasphère et les régions de l'arc de choc et de la magnétogaine pour étudier la physique des plasmas et la physique des particules du double point de vue de la recherche fondamentale et de leurs applications à l'astrophysique.*

La charge utile du satellite ISEE-B comprendra huit expériences fournies par des universités et institutions scientifiques d'Allemagne, de France, d'Italie ainsi que des Etats-Unis.

En réalisant des mesures simultanées à partir d'ISEE-A et B, on espère pouvoir lever les ambiguïtés existant entre les variations spatiales et temporelles dans la magnétosphère; en effet, un satellite unique ne permet pas de trancher sur le point de savoir si les variations constatées dans les quantités mesurées



single-satellite mission, it cannot be decided whether variations in measured quantities relate to actual variations in the local quantities or to a static pattern drifting past the spacecraft.

The spin-stabilised ISEE-B spacecraft, the axis of wwhich will be adjusted perpendicular to the ecliptic, can be manoeuvred to vary its separation from ISEE-A from a few hundred to 5000 km. To economise on gas consumption, a "drifting concept" is foreseen, the drift being initiated by a "kick" at perigee produced by a series of gas impulses synchronised with the spacecraft's rotation.

ISEE-A and B will be launched in tandem in Autumn 1977 into the same highly eccentric orbit with a perigee of 282 km, an apogee of about 140 000 km, and an initial orbit inclination to the equator of about 30°. They are intended to have a mission lifetime of 3 years. ISEE-C will be placed, about one year later, into a heliocentric orbit near the Sun/Earth libration point, serving, besides its own objectives, as a reference for the other two. □

correspondent à des variations effectives des quantités locales ou si elles proviennent de la dérive d'un champ statique traversé par le véhicule spatial.

Le satellite ISEE-B sera stabilisé par rotation, son axe étant perpendiculaire au plan de l'écliptique; il pourra être manoeuvré de façon à faire varier la distance le séparant d'ISEE-A de quelques centaines de kilomètres à 5000 km. Pour consommer le minimum de gaz, il est prévu d'appliquer un 'concept de dérive', en amorçant celle-ci par une série d'impulsions, synchronisées avec la rotation du véhicule spatial, données au niveau du périgée.

ISEE-A et B seront lancés simultanément par une seule fusée à l'automne 1977 et seront tous deux injectés sur une même orbite très excentrique dont le périgée se situera à 282 km et l'apogée à environ 140 000 km et dont l'inclinaison initiale sur l'équateur sera d'environ 30°; leur durée de mission prévue est de trois ans. ISEE-C sera placé, environ une année plus tard, sur une orbite héliocentrique proche du point de libration Soleil-Terre, ce satellite ayant pour but, outre la réalisation de ses objectifs propres, de servir de référence pour les deux autres. □

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The International Sun-Earth Explorer (formerly IME)

Abstract

The scientific development of this mission is described, including the basic ideas that generated it and the steps that led to the present concept. The capabilities of the three spacecraft are presented briefly, followed by an overview of some of the scientific areas where these spacecraft should make a significant contribution. A description of the orbits is given, together with the scientific reasoning which decided their parameters and the philosophy behind the separation strategy that has been adopted. The payload contents, the matching of the experiments, the number of investigators and the institutes involved are discussed with the use of tables and the concept of this mission within the framework of the International Magnetospheric Study is outlined. The data processing is described, together with the methods for data exchange and distribution.

Résumé

On décrit la genèse de la mission scientifique d'ISEE ainsi que les principes de base du projet actuel qui s'inscrit dans le cadre de l'Etude Internationale de la Magnétosphère. Les possibilités des trois véhicules spatiaux A, B et C sont brièvement présentées, suivies par une revue des différents domaines scientifiques où leur contribution devrait être importante. On explique le choix des paramètres d'orbite ainsi que les principes du plan adopté pour la séparation des véhicules. La composition de la charge utile, l'agencement des expériences ainsi que le nombre des responsables sont illustrés par des tableaux. On termine par la description des méthodes de traitement, d'échange et de distribution des données.

Introduction

This major mission has been undertaken jointly by ESA and NASA. It will use a three-spacecraft system to make a comprehensive attack on most of the more obstinate magnetospheric problems and is timed to make a contribution to the International Magnetospheric Study (IMS).

The ISEE mission objectives briefly stated are:

- to quantify the picture of the magnetosphere and the solar-wind/planetary interactions built up so far
- to identify how the solar-wind features affect the near-earth environment
- to exploit the natural presence of the plasmasphere and bow-shock-magnetosheath regions in order to study plasma and particle physics for its own sake and for its application to astrophysics
- to measure the isotopic composition of solar and galactic cosmic rays
- to study diverse interplanetary and solar phenomena, providing a baseline support for deep-space probes.

The chief quantities of the three spacecraft are set out in Table 1. For the first time this mission will make it possible to separate spatial from temporal variations in an organised way by the use of two spacecraft separated by a small, controllable distance. This will allow measurement of the dynamic features of the magnetosphere and detailed examination of complex structures. The two spacecraft for this task are named ISEE-A (Mother) and ISEE-B (Daughter). They will be launched in tandem into the same highly elliptical orbit on 14 October 1977 and will carry carefully matched payloads so that their measurements can be easily compared. The third spacecraft, named ISEE-C (Heliocentric), will be placed upstream of the Earth in the solar wind. This launch is planned to take place on 24 July 1978. As well as making important measurements in its own right, this spacecraft will be able to measure solar-wind features as they convect past on their way to the Earth, where they are thought to give rise to many of the processes that occur in and around the magnetosphere.

In this way the Mother and the Daughter will analyse the dynamic processes, and the Heliocentric will observe the trigger features.

Table 1. ISEE spacecraft parameters

	A	B	C
Structure	IMP mod.	New	IMP mod.
Spin rate	19.7 rpm	19.8 rpm	19.75 rpm
Mass	340 kg	166 kg	469 kg
Payload mass	89.0 kg	27.7 kg	97 kg (incl. antennae)
Payload power	76 W	27 W	57 W
No. of experiments	13	8	12
Data rate:			
high	16 384 bps	8 192 bps	2 048 bps
low	4 096 bps	2 048 bps	1 024 bps
emerg. & eng.	—	—	512 and 64 bps
Spin axis alignment	Perpendicular to the ecliptic plane		
Launch date	Tandem October 1977		July 1978

History of the project

The idea of two or more spacecraft moving in closely related orbits to examine the magnetosphere has been current since the discovery of the magnetopause by Explorer 12 and in particular has been strongly advocated by such notable people as Dungey, Greenstadt, Scarf and Fredericks. It has been argued that a cluster of spacecraft is essential for solving the space and time ambiguities which are inherent in measurements from a single platform and the scientific worth of papers based on accidental conjunctions of spacecraft has shown the validity of this view. Whilst it is acknowledged that a quadruple cluster system is much better than a double system, tightening budgets and other pressures from the scientific community have forced ESA and NASA to consider only the latter.

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This background led to the inclusion of three multiple spacecraft missions among the recommendations in a report of the USA Space Science Board 'Physics of the Earth in Space 1968–1975', published in 1969. One of the results of these recommendations was the Goddard Space Flight Center (GSFC) report Mother-Daughter Satellite Systems – A Feasibility Study: IMP K&K' and IMP L&L', released in 1969. At this time the Daughter was visualised as the addition of a subsatellite to IMP's K&L. Around this period ESRO embarked on a series of studies of small magnetospheric spacecraft. These studies were successfully concluded, but were shelved for financial reasons. At the February 1971 NASA-ESRO Programme Review it was suggested that these NASA and ESRO projects could be combined. NASA could build an IMP K and ESRO could be responsible for the Daughter. In September of the same year NASA and ESRO representatives agreed a tentative orbit and programme.

Meanwhile, NASA had completed a short internal study on another of the recommendations of the Space Science Board, 'that continuous observations be made of the interplanetary medium'. This study was again based on an IMP spacecraft. At the suggestion of R. Farquhar of GSFC, a hover orbit about the sunward libration point was proposed. It became clear that this so-called 'Heliocentric spacecraft' would form an essential part of the Mother-Daughter mission and it was accordingly added to the programme.

A joint NASA-ESRO announcement of flight opportunities was made on 8 May 1972 and letters of intent were solicited. Pre-proposal briefings were held in the USA on 12 June and in Europe on 7 July. Tentative selection of experimenters was made by a joint NASA-ESRO committee during November and December and the successful candidates were announced on 15 December. These were immediately formed into a Science Working Team with a mandate to plug any measurement gaps that were found and harden up the mission quantities. This initial task was completed during three three-day meetings, the first on 7-9 February 1973 (ESTEC), the second on 28-30 March (GSFC) and the third on 8-10 August (Sheffield, UK). This series of meetings took place before approval of the mission. It turned out to be a very useful exercise, which ended with a well-defined, cohesive mission and, together with the technical interchanges between meetings, allowed spacecraft structures and subsystems to be developed that satisfied most of the experimental requirements. In particular, the attendance of the Daughter design team ensured that this spacecraft was carefully tailored to the mission and the completed hardware that will be launched this year differs only in minor details from the concept that was produced as a result of these meetings. It is clear that close liaison between investigators and project groups at this early stage produces a better organised payload, shorter launch lead times and reduced costs by identifying, solving and avoiding problems.

ESRO approved the mission in November 1973 and NASA in early 1974. The competitive phase for the Daughter contract was begun on 1 April 1974. The Prime Contract was won by Dornier Systems of Friedrichshafen (Germany) and Phase C/D was begun on 2 December.

At the present time the Mother spacecraft is undergoing thermal vacuum tests. The Daughter has successfully passed the Final Design Review following a testing programme on an integration model, and the protoflight spacecraft is now being assembled. The launch date of 14 October is expected to be met by both groups. The Heliocentric spacecraft has been contracted out to Fairchild and is well on schedule.

During its life, the mission has undergone several changes of name, one of the later ones being the International Magnetospheric Explorer (IME). The name ISEE was finally adopted on 22 July 1974 and for consistency an attempt will be made throughout the rest of this paper to call the Mother ISEE-A, the Daughter ISEE-B, and the Heliocentric ISEE-C.

ISEE-A and B

The A and B spacecraft will be injected into the same orbit as a stacked pair on a single Thor Delta 2914 launch vehicle on 14 October 1977. The orbit has an apogee

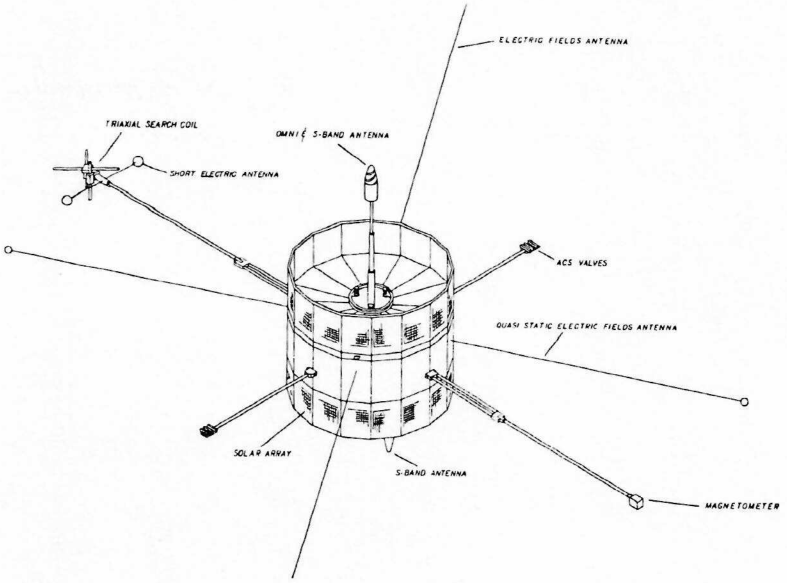


Figure 1. ISEE-A in orbital configuration

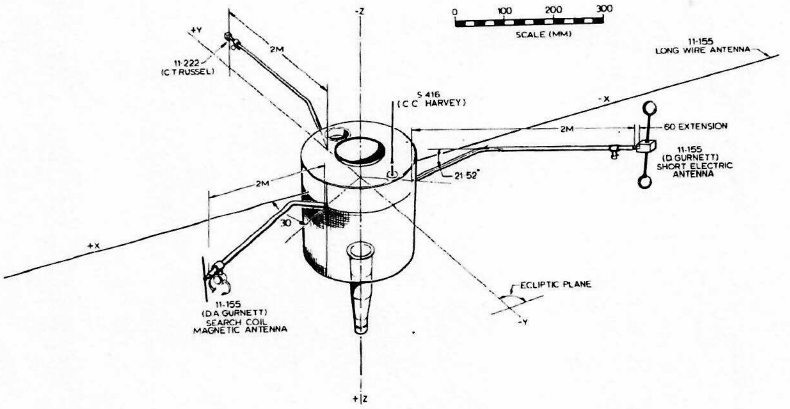


Figure 2. ISEE-B in orbital configuration

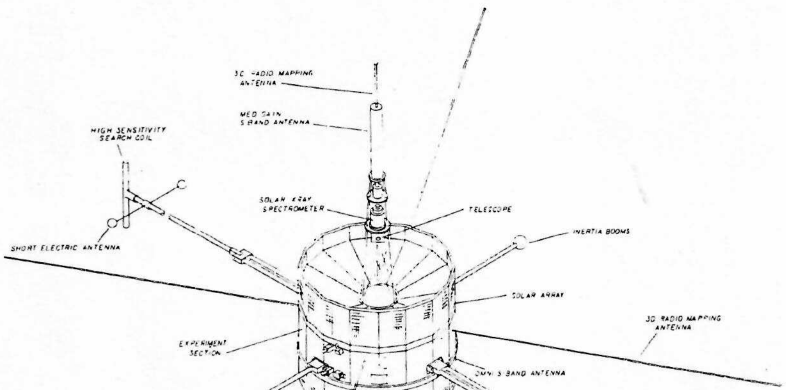
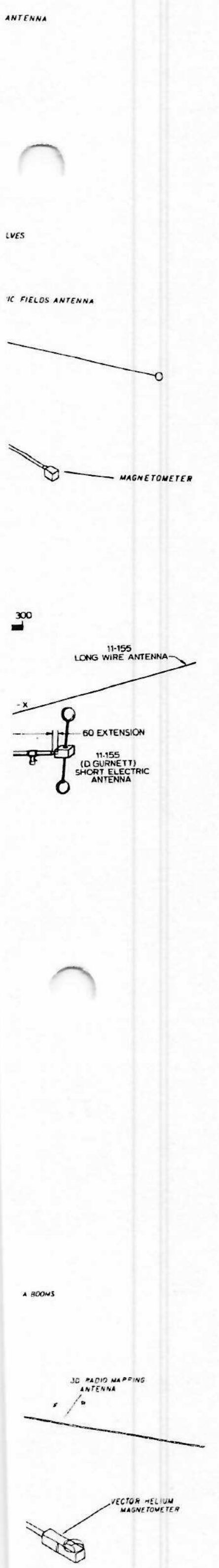


Figure 3. ISEE-C in orbital configuration



of 23 earth radii and is described in more detail in a later section. As correlation is crucial, the instrument packages on the two platforms are similar and the measurement ranges carefully chosen to take full advantage of the separation distances that can be arranged. A variable separation between these two spacecraft is necessary to fit in with the different scale size of the features to be observed and, in turn, different instruments are better for measuring different scale sizes. For this reason it is evident that the separation strategy needs careful planning. This problem is eased somewhat by the three-year life of the mission, which means that the spacecraft will make a complete measurement cycle of the magnetosphere three times, so that there is opportunity for a learning process.

ISEE-A is larger and can carry more instruments than ISEE-B. These extra instruments are to be used to investigate wave-particle interactions more thoroughly than can be done on smaller craft.

Thus the facilities provided by the A and B spacecraft are:
- resolution of space and time ambiguities
- investigation of wave and particle interactions
- correlation of measurements with other observations.

The novel capability of this mission is the resolution of space and time ambiguities. The basic thinking on this subject is outlined below.

Space and time ambiguities

The Earth's environment is not static; almost all the features that can be observed are constantly moving, swirling, boiling, contracting and expanding as the Earth spins on its axis and the solar wind blasts past. A large number of the phenomena have been properly measured and their processes resolved by using the data from single instruments, which have the problem of trying to identify whether the spacecraft passed through the feature or the latter swept past the spacecraft. Because of this problem it is not surprising that a larger number of phenomena are almost entirely unexplained. Features are known to exist, but their nature is not understood. Matched instruments flown close together but a known distance apart and moving at a known velocity can solve these ambiguities by observing the time difference between the arrival of the phenomena at the separate detectors. For three-dimensional measurements a cluster of three spacecraft or more is necessary, but financial constraints have limited the ISEE system to a pair. Thus, a basic limitation of the ISEE-A and B mission is that detailed discrimination of space and time variations will be possible only in the direction of the instantaneous separation vector of the two spacecraft. Fortunately many of the structures are believed to be mainly two-dimensional in nature and, as they vary predominantly in one direction, can be successfully studied by this technique.

ISEE-C

The main scientific goals of ISEE-C may be summarised as follows:
- support for ISEE-A and B
- measurement of the isotopic composition of solar and galactic cosmic rays
- the study of diverse interplanetary and solar phenomena; to include baseline support for deep-space probes and to study recently discovered astrophysical phenomena.

Before discussing each of these goals it is appropriate to mention the reasons for choosing the halo orbit described later. This orbit places ISEE-C on the Earth-Sun line some 234 earth radii (about 0.01 astronomical units) upstream from the Earth. It will thus be far from the disturbing influence of the Earth and yet have a reasonable bit rate (2048 ibps). The measurements of anisotropies, solar-wind electrons and higher energy protons and electrons have all been previously disturbed by the nearness of the Earth; such interference will be negligible in the halo orbit. Of particular importance to ISEE-A and B is the fact that ISEE-C will be in the interplanetary medium continuously.

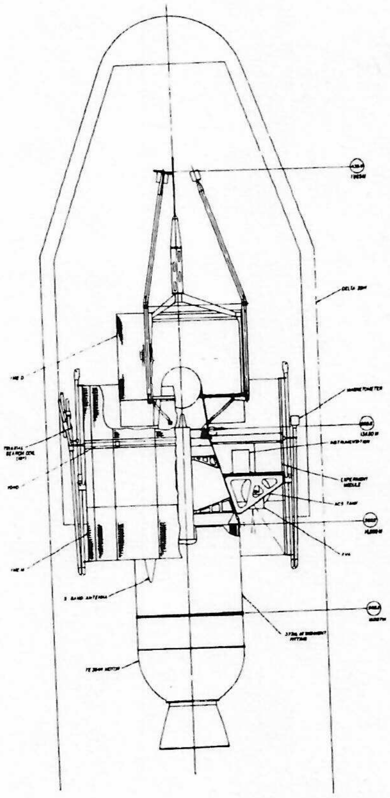


Figure 4. ISEE-B stacked on ISEE-A for the tandem launch

ISEE-C will measure the vector magnetic field, the composition, temperature, density and velocity of the solar-wind plasma, the anisotropies and composition of more energetic particles, and other properties of the interplanetary medium to support ISEE-A and B. Measurements of these quantities will be needed in order to interpret simultaneous observations made by A and B behind the bow shock. Space-time separation of some interplanetary features will be possible by comparing ISEE-C and A – B data, so to some extent ISEE-A and B will support ISEE-C as well. The production of data-pool tapes (discussed in greater detail later) and their circulation to Principal Investigators on all three spacecraft is a new departure and a deliberate attempt to encourage this comparison.

ISEE-C will make a concerted effort to measure the isotopes of heavier nuclei. The instruments proposed by Stone & Vogt and by Heckman & Greiner are designed to resolve individual isotopes for all nuclei of $Z = 1–26$. They will do so by using newly developed position-sensitive detectors which allow removal of previous limiting factors such as the effects of finite telescope opening angle and nonuniformities in detector thickness. This distinctly new capability can open up a whole new dimension for such basic questions as the origin of galactic cosmic rays. Thus, for example, nitrogen may be absent in galactic sources. Galactic cosmic-ray nitrogen would have a large fraction of N^{15} if it were of secondary origin, but this simple test has yet to be made. Until we make such measurements, we cannot tell what surprises may be in store. For these reasons, the study of isotopes is a new and important goal.

Among diverse solar and interplanetary phenomena to be studied are plasma waves, shocks, particle spikes, local acceleration, anisotropies, Forbush decreases, plasma composition, wave-particle interactions, co-rotating regions, quiet-time electron increases, solar modulation, and so on. All of the latter have been studied before, but they can be studied better far away from the Earth and by using a wider variety of recent technological advances. All three ISEE spacecraft, for example, will have a conductive coating to prevent spacecraft charging from interfering with plasma measurements.

Propagation of particles out of the ecliptic will be studied for the first time by the radio investigations of Steinberg *et al.*, while the study of propagation in the ecliptic will be greatly helped by observations in conjunction with deep-space probes. It should be possible to achieve better definition of the geometry of Forbush decreases, to study solar modulation better and the corresponding radial gradients, and to discover the origin of the low-energy oxygen 'turn-up', for example.

In June 1973, well after the experiments had been selected, the discovery of momentary, intense gamma-ray bursts was announced by the Los Alamos group[1]. The Science Working Team immediately suggested modifications to some instruments so that this interesting effect could be studied. These modifications have been made, including one to an instrument on ISEE-A. Improved location of the burst sources will be achieved by time-of-flight triangulation correlated with observations on other spacecraft.

In summary, ISEE-C will provide the complete support needed for the ISEE-A and B effort to be a success and will independently break new scientific ground as well.

Mission objectives

The intention of this section is to give the reader some idea of the extent of the objectives of this mission by describing a few of them. This account is not exhaustive; large, important sections have been left out. We plead shortage of time and space to those investigators whose favourite subjects have not been included. The references in this section cannot, of course, be comprehensive. Many of them are designed to give a point of access to the literature on the subjects mentioned.

Solar wind and upstream phenomena

A large part of the ISEE mission is directed towards making measurements upstream of the bow shock with the intention of using the twin-spacecraft technique

of 23 earth radii and is described in more detail in a later section. As correlation is crucial, the instrument packages on the two platforms are similar and the measurement ranges carefully chosen to take full advantage of the separation distances that can be arranged. A variable separation between these two spacecraft is necessary to fit in with the different scale size of the features to be observed and, in turn, different instruments are better for measuring different scale sizes. For this reason it is evident that the separation strategy needs careful planning. This problem is eased somewhat by the three-year life of the mission, which means that the spacecraft will make a complete measurement cycle of the magnetosphere three times, so that there is opportunity for a learning process.

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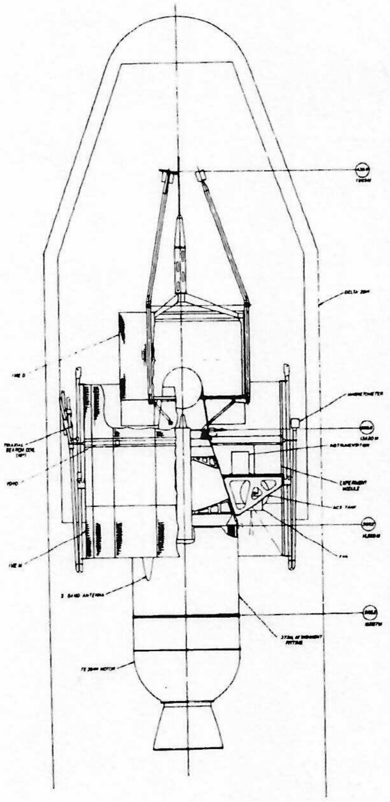


Figure 4. ISEE-B stacked on ISEE-A for the tandem launch

ISEE-C will measure the vector magnetic field, the composition, temperature, density and velocity of the solar-wind plasma, the anisotropies and composition of more energetic particles, and other properties of the interplanetary medium to support ISEE-A and B. Measurements of these quantities will be needed in order to interpret simultaneous observations made by A and B behind the bow shock. Space-time separation of some interplanetary features will be possible by comparing ISEE-C and A – B data, so to some extent ISEE-A and B will support ISEE-C as well. The production of data-pool tapes (discussed in greater detail later) and their circulation to Principal Investigators on all three spacecraft is a new departure and a deliberate attempt to encourage this comparison.

ISEE-C will make a concerted effort to measure the isotopes of heavier nuclei. The instruments proposed by Stone & Vogt and by Heckman & Greiner are designed to resolve individual isotopes for all nuclei of $Z = 1–26$. They will do so by using newly developed position-sensitive detectors which allow removal of previous limiting factors such as the effects of finite telescope opening angle and nonuniformities in detector thickness. This distinctly new capability can open up a whole new dimension for such basic questions as the origin of galactic cosmic rays. Thus, for example, nitrogen may be absent in galactic sources. Galactic cosmic-ray nitrogen would have a large fraction of N^{15} if it were of secondary origin, but this simple test has yet to be made. Until we make such measurements, we cannot tell what surprises may be in store. For these reasons, the study of isotopes is a new and important goal.

Among diverse solar and interplanetary phenomena to be studied are plasma waves, shocks, particle spikes, local acceleration, anisotropies, Forbush decreases, plasma composition, wave-particle interactions, co-rotating regions, quiet-time electron increases, solar modulation, and so on. All of the latter have been studied before, but they can be studied better far away from the Earth and by using a wider variety of recent technological advances. All three ISEE spacecraft, for example, will have a conductive coating to prevent spacecraft charging from interfering with plasma measurements.

Propagation of particles out of the ecliptic will be studied for the first time by the radio investigations of Steinberg *et al.*, while the study of propagation in the ecliptic will be greatly helped by observations in conjunction with deep-space probes. It should be possible to achieve better definition of the geometry of Forbush decreases, to study solar modulation better and the corresponding radial gradients, and to discover the origin of the low-energy oxygen 'turn-up', for example.

In June 1973, well after the experiments had been selected, the discovery of momentary, intense gamma-ray bursts was announced by the Los Alamos group[1]. The Science Working Team immediately suggested modifications to some instruments so that this interesting effect could be studied. These modifications have been made, including one to an instrument on ISEE-A. Improved location of the burst sources will be achieved by time-of-flight triangulation correlated with observations on other spacecraft.

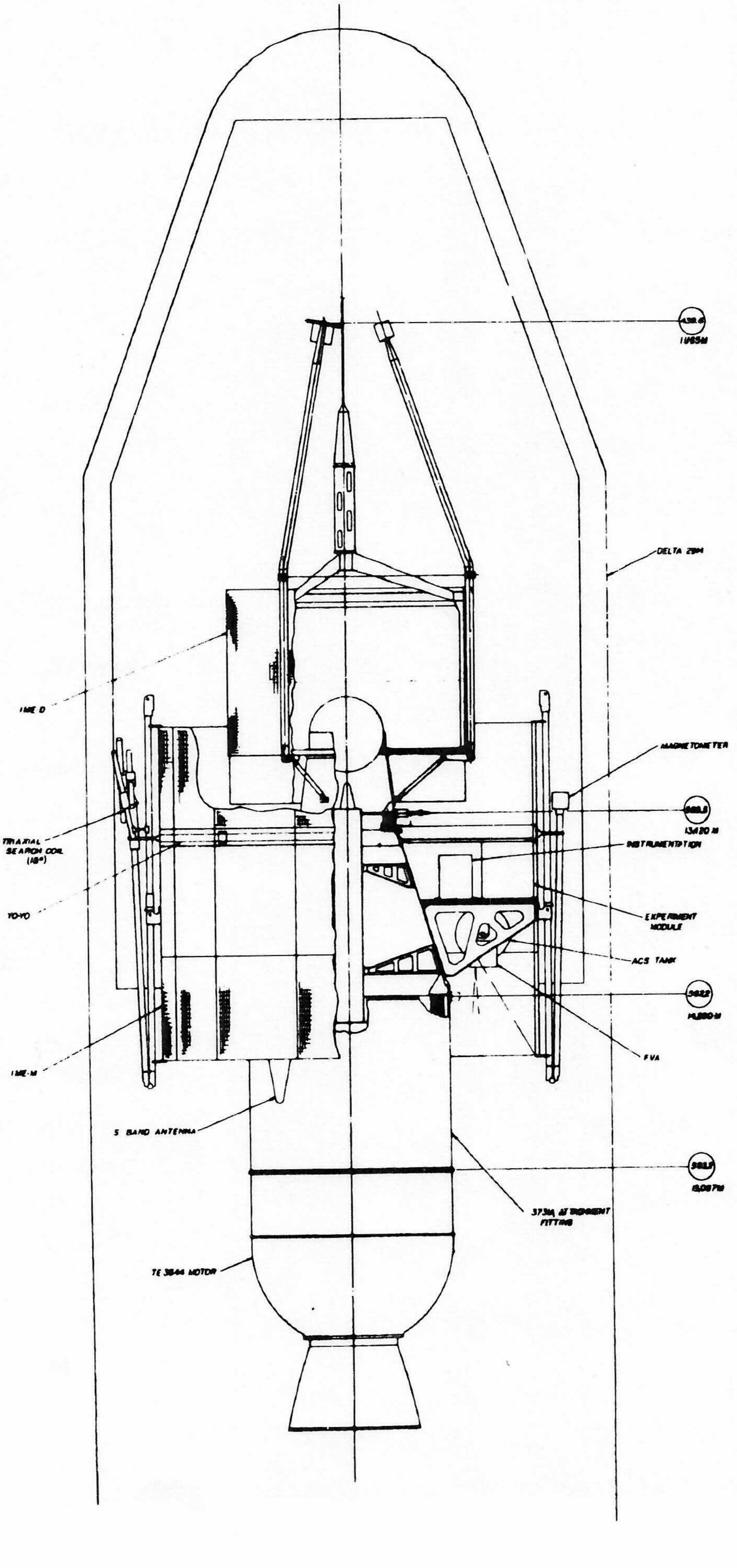
In summary, ISEE-C will provide the complete support needed for the ISEE-A and B effort to be a success and will independently break new scientific ground as well.

Mission objectives

The intention of this section is to give the reader some idea of the extent of the objectives of this mission by describing a few of them. This account is not exhaustive; large, important sections have been left out. We plead shortage of time and space to those investigators whose favourite subjects have not been included. The references in this section cannot, of course, be comprehensive. Many of them are designed to give a point of access to the literature on the subjects mentioned.

Solar wind and upstream phenomena

A large part of the ISEE mission is directed towards making measurements upstream of the bow shock with the intention of using the twin-spacecraft technique



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to observe wave-particle interactions and the movements of features in this region. Again, because of the great interest in this area, any attempt at a complete description of the problems and the measurements proposed would be very lengthy. For this reason, the description has been limited to a brief illustration of a few of the phenomena that will be examined. These can be generalised under several headings.

Solar-wind composition

The elemental and isotopic abundances in the solar wind show strong time variations[2,3]. These could result from diffusion processes in the photosphere-corona boundary, from dynamical friction, from wave-particle interactions or from separation processes that depend primarily on ionisation and energy. All these processes depend differently on mass and energy per unit charge and thus measurements of the time variations in the solar-wind abundances over a wide range of mass and charge are important for understanding how the variations are caused as well as the fundamental problem of solar-wind acceleration. The spacecraft of the ISEE mission are well fitted in both equipment and time resolution to making the necessary measurements.

Solar-flare particles

Energetic solar protons and electrons are observed in the interplanetary medium during solar events. Investigation of these is aimed at discovering how they originate in the Sun and how they are affected by the medium in which they travel[4,5]. Generation models can be tested by the abundance ratios of the particles[6,7] and by the time variations of the intensities and energy spectra. Propagation effects can be investigated by examination of the energy spectra and pitch-angle distributions. Fine structure variations with time can be searched by the three ISEE spacecraft to find differences that may be caused by traversal through the interplanetary regions. Care is needed to differentiate between source and propagation effects, and in this respect the observations of the Heliocentric spacecraft will be very useful.

Reflections at the bow shock

It is known that the presence of the Earth has a disturbing effect in interplanetary space in front of the bow shock and for quite large distances upstream[8-11]. By using the Mother-Daughter techniques it should be possible to look for the types of particles and waves that are reflected from the bow shock; this knowledge is a necessary part of understanding the mechanism. A study can also be made of the effect of the backstreaming protons and electrons on the solar wind itself; an understanding of the dominant kinetic processes that couple particles in the upstream region, for instance, needs detailed measurements of the backstreaming electronic heat flux that has occasionally been observed.

Planetary radio emission

IMP 6 showed the Earth to be a planetary radio source at frequencies below 300 kHz[12]. Jupiter and Saturn have also been identified as noise sources[13], supporting a hypothesis that all planets with internal magnetic fields may be nonthermal radio sources. The Jovian decametric emission has a great variety of frequency-time structures; the Earth noise may be found to be similar. By triangulation, it may be possible to identify closely the regions of emission.

Interplanetary shocks and discontinuities

A great variety of interplanetary discontinuities exist, travelling with characteristic speeds of the order of hundreds of kilometres per second, making large separations necessary for good observation[14]. A knowledge of the thicknesses is important; measurement of thermal ions, electrons and magnetic fields are needed for a good description. Protons in the MeV range have been observed associated with shocks at the same time as a lack of energetic electrons[15]. Simultaneous Mother and Daughter measurements will be able to distinguish shock-accelerated from solar-accelerated protons. This will lead to investigations which can check models for first-order Fermi acceleration and wave-particle interactions. ISEE-A and B spacecraft carry electron-density measuring equipment (Meudon) which should be able to resolve density variations in shock structures and discontinuities, a type of measurement which has not been made up to the present time. Neutral magnetic and current sheets have occasionally been seen in the solar wind[16,17]. A study of this type of feature and its evolution will be made as they sweep past ISEE-A and B. The thickness of these features is typically about 3000 km, which should allow many seconds of observation. The electric-field measurements of these structures will be especially important. The ISEE mission will also be able to distinguish solar co-rotating features from others.

Wave-particle interactions

A major part of the ISEE mission is the study of wave-particle interactions. Although these phenomena will be examined in all parts of the magnetosphere, a great many of these investigations can be made in the interplanetary medium where a wide variety of these interactions take place[18]. Many types of waves and fluctuations exist in the solar wind. These waves can be complex with phase velocities comparable to or less than that of the solar wind so that Doppler shifts become important. Using two spacecraft, it should be possible to remove some of the ambiguities. Because of the variability of the solar wind, the characteristic frequencies of the plasma are also highly variable. Both electromagnetic and electrostatic waves are expected near to the local plasma frequencies; however, no well-developed theory explains the generation of electromagnetic waves between the plasma frequency and the upper hybrid resonance. Suprathermal electrons in the presence of large plasma oscillations may play a part here.

Lower frequency noise bursts have been attributed to ion-acoustic waves which appear to coincide with plasma and magnetic-field discontinuities. The growth of these waves depends on the effectiveness of Landau damping, which in turn is a function of the electron-ion temperature ratio. In addition, the presence of high-energy particles or differential ion-electron drifts can lead to instabilities. All of these mechanisms are probably at work in the solar wind, but the relevant parameters have not been clarified. Other effects that have not been investigated are the growth of right-hand circularly polarised electron whistler waves near to the alpha-particle and proton gyro-frequencies, which may arise because of the field-aligned anisotropy in the positive-ion velocities. This requires investigations at frequencies below 5 Hz and examination of DC fields.

The complexity and variability of the solar-wind velocities, composition and densities together with the presence of particles and waves backstreaming from the bow shock ensures that many known and unknown wave-particle interactions such as are illustrated above will take place in the near-earth interplanetary medium. Hopefully, the ISEE twin-spacecraft investigation will be able to unravel some of the basic processes.

The bow shock

This feature of the Earth's environment has been known to exist since 1963 when it was first seen by IMP 1[19], but identification of even the dominant mechanisms has not yet been accomplished. Although detailed experimental information from single satellites is available, there is a large gap between theory and observations mainly because of the space-time ambiguity. A basic problem here is that the bow shock apparently moves back and forth with an amplitude of about one earth radius and the velocity of this movement seems to vary between 10 and 200 km/s[20]. Both ions and electrons are heated in the shock and the mechanism is thought to be a retardation and heating by some form of electrostatic turbulence[21]. Collisionless shock theory predicts that this heating region is thin; the scale lengths will depend upon details of the electrostatic interaction. Possible candidates are:

- the Debye length (10–100 m)
- the wavelength of a steady whistler profile (up to 100 km)
- the ion larmor radius (100–1000 km)

Detection of regions of this size by a single-point measuring system in the fast-moving bow shock is extremely difficult. Assuming shock speeds of about 100 km/s, simultaneous measurements at two points about 100 km apart by instruments with reasonable time resolution (say 1/10 to 1 s) should be able to detect the larger scale features mentioned above. However, resolution of the Debye length needs a much faster repetition time for ISEE instruments. Fine time resolution is desirable in order to obtain further information about the fluctuations in the bow shock, but because of trade-offs with energy resolution and angular information this is unlikely to be high enough for observation of any Debye-length features.

The bow shock may also be the source of electron spikes seen in the magnetosheath and movement of both ions and electrons towards the Sun upstream of the shock[22,9]. The mechanism for acceleration and reflection of these particles is not understood at present and in particular the transient nature of the observations is baffling[23]. Upstream proton events in the energy interval greater than 30 keV have durations of the order of an hour. It has recently been suggested that bursts of protons with these energies seen in this region may be produced by acceleration processes near to the neutral sheet; twin-spacecraft observations can check the direction of travel. Bursts of energetic electrons (15 keV) are frequently observed in the magnetosheath and interplanetary regions with characteristic times of 30–150 s. Anderson has associated electron spikes with movements of the bow shock. Magnetic-field waves have been observed near the bow shock and appear to co-exist, or may be excited by particles propagating upstream[24]. The intensity of the protons is thought to be associated with these waves, which have frequencies ranging between 0.01–0.05 Hz and 0.3–0.9 Hz. Because of space-time ambiguities, the extent and wavelengths of these phenomena have not been determined and so they too are suitable objects for a twin-spacecraft study. These spacecraft must spend sufficient time outside the bow-shock region for a wide range of solar-wind effects to be encountered to evaluate their influence on the upstream phenomena and the bow shock.

In addition to the features of the bow shock itself, study of this region is important for the investigation of collision-free shocks in general.

The magnetosheath

Magnetic-field fluctuations which occur in different modes and have many different frequencies characterise the Earth's magnetosheath[24]. This complex situation is further complicated because the plasma frame is convecting past the spacecraft at a velocity which is influenced by the solar wind and the position of the spacecraft in the magnetosheath. The dominant mechanisms by which the turbulences in this region are created have not yet been clearly identified and it is accepted that techniques of correlating field and plasma measurements on a single spacecraft are not adequate for an analysis of this structure. Measurements by ISEE-A and ISEE-B will be able to identify propagation velocities which should clarify the picture considerably. There will be unique opportunities to distinguish between waves moving upstream or downstream, to determine whether waves are standing or propagating, and to identify waves generated in the shock. On a larger scale, measurement of particle-density fluctuations can be used to investigate the processes driving the disturbances by making simultaneous measurements (for instance) on either side of the bow shock to discover if upstream features are the cause, or when one spacecraft is near the magnetopause with the other deeper in the magnetosheath to analyse the effects of this boundary, etc. The source of energetic protons and electrons observed in the magnetosheath will also be open to investigation. These particles are often seen with flux values similar to those observed in the magnetotail, and association of them with the occurrence of substorms has led to the suggestion that they originate in the magnetosphere rather than in the sheath region itself. Conversely, it has been argued that if E fields in the magnetosheath are found to have a large component in the B-field direction, then if, as predicted by reconnection theories, the magnetic field lines extend into the sheath[25], such parallel electric fields could be effective in accelerating and transferring particles into the magnetosphere. During solar events too, by watching the movement of solar particles in the magnetosheath insight may be gained into whether the particles enter the tail via the neutral sheet or through the side of the tail itself[26,27]. In this respect, particle density and velocity gradients near the magnetopause are important as well as the type of magnetic discontinuity that occurs there. There have also been difficulties in identifying the topology of the magnetosheath owing to the movement of its boundaries. The ISEE mission should be able to help with this problem.

The magnetopause

For many years the nature of the magnetopause boundary has provided a motive for magnetospheric research. Nevertheless the answers to most of the key questions are still unclear; such problems as the way in which mass and energy are transferred across the boundary, how reconnection works or the mechanism of viscous interaction have not been solved. Is the oscillation of this boundary a simple 'breathing' of the magnetosphere or is it the result of the solar wind blowing past? Theories of reconnection[25] and viscous interaction are incomplete because the treatment of viscous interaction needs more detail of the magnetosheath magnetic fields than is available and reconnection studies have not been able to demonstrate that the process works over a sufficient range of interplanetary field angles because of lack of magnetopause information. Again the problem is associated with the movement of the boundary and with the question of whether the features observed are propagating or not. The magnetopause is in frequent motion with amplitudes as large as $2R_e$ and velocities as high as 200 km/s[28]. These oscillations can be observed by both magnetic-field and particle detectors. However, on at least one occasion when these were measured together, neither the extent nor the positions of the movement coincided[29]. This sort of puzzle demonstrates the size of the difficulties. It is hoped that identification of motions by the ISEE mission will make a large contribution to our understanding of this boundary. Some of the main objectives for investigation are described below.

From particle measurements, the thickness of the magnetopause has been estimated to lie between a few tens and a few thousands of kilometres[30]. ISEE measurements should be able to introduce some order into this chaos. Knowledge of the variation of thickness with longitude can help the testing of models of the magnetopause, such as neutralisation of polarised electric fields or diffusive wave-particle interaction models. The large-scale motions of this boundary are quasi-periodic with a cycle time varying from 3 to 15 min[31,32]. It appears that the inward motion may be connected with reversal of the interplanetary field from north-pointing to south-pointing; this has to be followed up. Particle and field measurements have shown that a smaller, higher frequency motion is superimposed on these[29]. Electric fields as high as several millivolts per metre are frequently seen at frequencies below 100 Hz[28]. These rapid fluctuations appear to be associated with 'holes' that occasionally appear in the magnetopause. These 'holes' are something of a mystery; they are rarely observed for longer than a few seconds – are they real, is this evidence for field merging, what is their extent (important for plasma leakage across the boundary), does particle acceleration occur in these regions? With regard to electric-field measurements, there are so few data of this type that refer to the magnetopause that even single-satellite measurements are important, although twin-spacecraft measurements will give more information about the extent and movement of the fields. One other subject for field investigation is the coherence of the large-scale oscillations – does it exist over large distances, if it exists at all? Ideas of the nature of the boundary itself seem somewhat confused. One tentative observation is that it is marked by neither a rotational nor a tangential magnetic discontinuity, but perhaps by a Kelvin-Helmholtz instability[33,34]. A layer of energetic electrons has been found to lie at the magnetopause[35] and it extends from the sunlit magnetosphere as far as $X_{sm} = -60R_e$. It is also possible that a similar, but so far undetected, proton layer is present. A quasi-persistent plasma regime called the plasma mantle has been found to exist just below the magnetopause[36,37] and has been observed as far as 18 R_e down the tail[38,39]. This cold plasma flows antisunward and appears to enter the magnetosphere in the polar-cusp region. It has been suggested as a source for the magnetosheath plasma[40]. ISEE-A and B will be able to investigate this later in the mission when their inclination becomes greater than 50°.

Particle entry into the magnetosphere

An intriguing subject which has received more attention recently is that of the processes by which solar particles and plasma penetrate the magnetopause and pass into the magnetosphere. Something of the topology of the magnetopause can be learned from the ways in which it affects the particles that pass through it, and knowledge of the processes involved should help to explain the asymmetries and structures that are sometimes seen in particle distributions inside the magnetosphere. The characteristics of entry vary with the energy and type of particle.

Solar electrons show little or no structure or anisotropies inside the magnetosphere (this may not be true inside the plasma sheet), unlike solar protons with energies in the tens of MeV range which show marked variations in the flux distributions and also seem to ignore any discontinuities that exist at the magnetopause[41]. These protons have larger larmor radii than the electrons. The flux variations of the protons seem to be linked with the direction of the interplanetary magnetic field[42]. Observations inside the magnetopause may be able to answer the question of whether these higher energy solar protons penetrate the side of the magnetosphere or enter via the neutral sheet. Lower energy protons show a different behaviour and appear to be sensitive to discontinuities in the solar wind. Access of solar plasma into the magnetosphere seems to require a component of the magnetic field perpendicular to the magnetopause surface. The time history of plasma can be assessed by measuring the time dependence of abundance ratios. Since the composition is a highly variable quantity, ISEE-C will be able to give a reference history of the plasma for such measurements. As an example, all the helium ions in the solar wind are He^{++}, whilst those from the ionosphere are He^{+}, so this element will be a useful monitor for solar-wind entry. These quantities may be able to shed some light on magnetic-field reconnection across the magnetopause, which is generally believed to occur. One way of examining particle entry is to measure anisotropies and flux distributions simultaneously on two spacecraft straddling the magnetopause. Differences in time delays can be used to separate direct access from diffusion processes.

One problem of particle-access measurements related to the ISEE mission is that straddling of the magnetopause by the Mother and Daughter is likely to occur for only a small amount of time over a limited region, and in addition the higher energy particles need a solar event to produce them. These two factors combine to make observations difficult and in the case of the higher energy protons a certain amount of luck is needed for success. However, the amount of luck necessary will be reduced by the long lifetime of the mission and by the inputs of ISEE-C.

The plasma sheet and the tail

The ISEE mission is uniquely fitted to study the dynamics of particle acceleration in the tail: qualitative measurements of the flow of plasma and energetic particles up and down the tail will be made and compared with incoming solar-wind parameters as observed by the Heliocentric.

Single-satellite magnetic measurements imply that a thin neutral sheet, less than 1 R_e thick, is embedded in the much thicker plasma sheet[43]. Detection of the neutral sheet is difficult since the field strengths are very weak and there is considerable upward and downward movement of this region, with velocities of between 10 and 100 km/s[44]. Twin-spacecraft measurements should be able to identify the structural features of the inner plasma sheet by separating out the velocity. Particle measurements will assist the neutral-sheet identification since the particle pressure should increase to a maximum in the centre and decrease to either side. The outer boundary of the plasma sheet is thought to coincide with the last closed field line in the tail, but this has not been fully established experimentally, again because of the movement of this feature. By using low-energy and energetic electrons as tracers, ISEE should be able to resolve this problem and also discover if a particle halo lies outside the last closed field line. The velocities in the movements and the thicknesses of the plasma and neutral sheets can then be studied for different geomagnetic and solar-wind conditions.

Ring current and plasmasphere

The ISEE-A and B spacecraft will be able to provide the first comprehensive observations of the total ring-current energy spectrum, pitch-angle and spatial distributions during quiet times. They will also allow observations of the drift into this region of the low-energy (tens of keV) protons during the main phase of magnetic storms. It is hoped that the way in which these particles filter around the Earth to form a symmetric ring current will be discovered. When the ring-current particles drift into the plasmasphere, the effect on the plasmapause can be studied[45,46]. This field-aligned 'edge' in the plasma densities near $L=4$ is another boundary that can be examined by twin-spacecraft techniques. The scale size of this boundary is of the order of 600–3000 km. Boundary motion can be studied, including the way in which large blobs of plasma drift off and break away[47]. During times of magnetic activity it is known that the plasmapause shrinks. Is this caused by the outer layers of plasma peeling off and breaking away? If so, where does the plasma go? Does inward motion of the plasma have any side effects? These are important questions that still have to be answered.

The total or partial co-rotation of the plasmasphere with the Earth is thought to be driven by the unipolar induction field of the rotating ionosphere. There are obviously opportunities in this area for extensive investigation by electric-field detectors[48]. Magnetic-field fluctuations at frequencies below 100 Hz are known to exist and their effects should be examined[49]. The loss of electrons from the radiation belts is thought to be caused by ELF waves generated at the plasmapause and propagating inwards[50]; this could cause the slot between the inner and outer radiation belt zones. The way in which this ELF hiss is generated and the direction of propagation are again open to investigation by the ISEE-A and B equipment packages.

Magnetospheric substorms

The understanding of the substorm phenomenon is one of the key steps to the understanding of the dynamics of the magnetosphere. However, substorms in themselves are very complex[51]. Violent rearrangements of magnetic fields during the substorm expansion phase associated with strong electric induction fields have drastic effects on plasma flow, charged particles and on the ionosphere[52,53]. It seems probable that the energy needed to drive these processes is extracted from the solar wind by some mechanism in the tail, but this mechanism has not been identified[54]. It is not known how or why substorms are triggered; although particles are accelerated, the region and source of this acceleration have not been discovered. Because geomagnetic substorms involve a large part of the magnetosphere[55], correlated global measurements will be necessary for any attempt at understanding[56]. These measurements must include, as well as ISEE-A and B in the tail, inner magnetospheric observations by Geos and ATS 6, upstream solar-wind measurements by ISEE-C, suitable rocket flights to investigate the ionosphere with other worldwide high-latitude ground-based measurements and, hopefully, assistance from other spacecraft such as Hawkeye and Vela. Co-ordination of all these studies will present a challenge to IMS organisation.

The role of ISEE during these measurements will be to investigate the changing shape of the magnetopause[57] and plasma sheet as storms progress[58] and observe the movement of particles and fields inside the tail during this period. Fast, field-aligned plasma flows have occasionally been observed in the plasma-sheet region. ISEE will be able to identify the direction of travel and the energy and pitch angle spectra of these particles. With a chain of other observations posts such as Geos, it should be possible to decide if plasma sheet particles convect down to the ionosphere (and the aurora). If the field lines of the narrow, well-defined auroral latitudes are projected back to the plasma sheet they spread out and the region suitable for investigation becomes relatively large, which should make features easier to see. However, one of the limitations of the ISEE mission is that the time spent in these important regions will be fairly short and thus it is important to co-ordinate measurements so that the maximum amount of data is taken during these times. For example, ISEE would run at high bit rates, balloons would be at maximum altitude, rockets would be fired in this time slot, Geos would hopefully be on the right flux tube, etc.

Observation of magnetic and electric fields in the region of the plasma sheet will be particularly important in an investigation of what changes take place during the break-up phase. Important things to look for are electric-field changes that correlate in time with the onset, and how the electric field varies at different locations as the substorm progresses. The fast plasma flows sometimes observed imply the presence of large electric fields, but attempts at measurements have hitherto been almost nonexistent for lack of technique.

Aurora is essentially continuous, implying continuous convection of plasma which is enhanced whenever a substorm occurs. Thus, there will always be activity for ISEE to investigate when it is in the plasma sheet. In addition, substorms last about an hour and occur quasi-periodically at three-hourly intervals so that it should be possible to make significant measurements during every pass through the tail region.

Because of the lack of knowledge about and understanding of substorms the subject is wide open, and careful thought has to be made of how the observations have to be distributed. It may be that the optimum configuration of separation strategy and high bit rate will not be found in the first series of passes of ISEE through the substorm generation (?) region, but if a few questions can be raised and/or answered during this time, the time and positioning of intense observations may be better during the second and third years of the ISEE mission, when more time will be spent in the plasma sheet region than during the first.

ISEE-A and B orbit

These spacecraft will be launched in tandem on a Thor Delta 2914 vehicle and put into the same initial orbit, which has to satisfy the following scientific and technical conditions:

1. The number of bow-shock crossings must be a maximum.
2. The initial line of apsides must be such that at least some bow-shock crossings are made early in the life of the mission to reduce the amount of bow-shock information lost in case of early failure.
3. Crossings of the plasma sheet must be made.
4. The orbit must be stable enough to sustain a mission lifetime of 3 yr.
5. The maximum eclipse time must be less than 6 h.
6. The solar-aspect angle at injection should be between 70° and 160°.

For condition 1, the number of bow-shock crossings depends on the apogee. With a higher apogee the orbit will pass through a larger extent of the bow shock, but the orbital period decreases. The opposition of these two factors creates a slow variation of bow-shock crossing with apogee altitude, with a maximum at about 23 earth radii; this value was chosen by the Scientific Working Team.

The original intention was to place the spacecraft into a transfer orbit at 1390 km, which would have made extensive launch windows available. However, since this proposal the total mass of the spacecraft has risen to an estimated 510 kg, and matching this with an apogee of 23 earth radii and the launcher performance gives a perigee height of 280 km. The transfer orbit is thus no longer possible. Calculations showed that the launch windows which satisfied the six conditions were extremely small – a series of 10 min windows in late 1977 and another in the spring of 1978. These have been extended somewhat by relaxing the initial inclination requirement

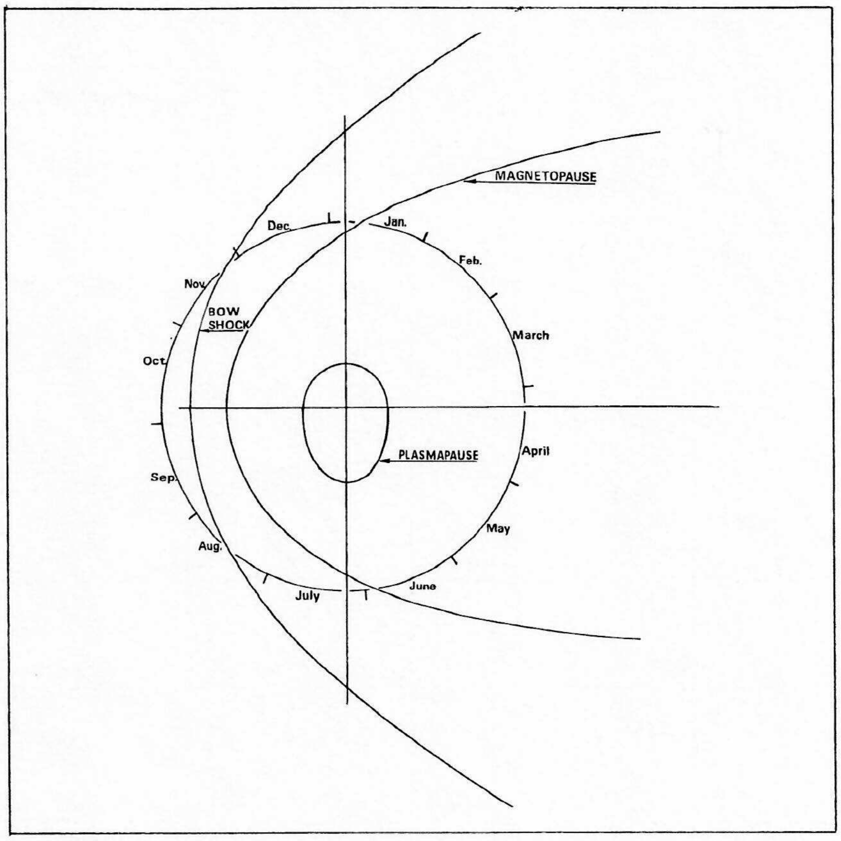

Figure 5. Features of the magnetosphere in the ecliptic plane. The bow shock and the magnetopause positions are taken from Fairfield[59] and the plasmapause position follows R. Grard's interpretation of Chappell *et al.*[60]. The superimposed circle represents a projection onto the ecliptic plane of the predicted position of the line of apsides for any month of the year, following a launch in October or November 1977. For a launch in the Spring of 1978, this circle should be rotated through 180°.

from 15° to 30°. This has made antenna design more difficult and, of course, the inclination in the third year will be above the initial limit of 50°.

Interestingly, for the duration of each of these series of launch windows there is a unique direction in space for the line of apsides (the line between apogee and perigee) if the orbit is to be stable; no matter on what day the launch takes place, the line of apsides will have the same right ascension and declination. This means that the position of the spacecraft at any given time during their three-year life can be predicted without knowing the precise day of launch. This is important because, although estimates of the actual launch dates still have a ten-day fluctuation, such things as the times of neutral-sheet crossings and passes through or near the Geos flux tube can be accurately calculated. In particular, the position of the orbit in the magnetosphere can be accurately predicted, as is demonstrated in Figure 5, where the features of the magnetosphere in the ecliptic plane are illustrated. The bow-shock and magnetopause positions are taken from Fairfield[59] and the plasmapause is R. Grard's interpretation (private communication) of observations by Chappel *et al.*[60]. Superimposed on these features is a circle marked out with the months of the year. For a launch in 1977, the projection of the line of apsides onto this plane will move around this circle according to the date. For a launch in 1978, the date circle should be rotated 180°.

The injection figures for ISEE Mother and Daughter are shown in Table 2 together with the orbital elements derived from them. These figures are not expected to change before launch. Figure 6 shows the predicted times (GMT) of neutral-sheet crossings or approaches as a function of day number for the first year of the mission. The bars indicate the times when the spacecraft will be within 2 earth radii of the neutral sheet, open circles represent the times of closest approach, and closed circles represent actual crossings. These figures were calculated by the Satellite Situation Center at Goddard. Table 3 gives crossing times and positions in solar magnetospheric co-ordinates, again for the first year of the mission.

Figure 7 shows how the ecliptic inclination is expected to vary with time throughout the mission, while Figure 8 shows the major eclipses. There will be an eclipse each orbit as the spacecraft pass behind the Earth, but most of these happen

Table 2. ISEE-A and B launch

Injection parameters:	
Geocentric latitude	20°.659238 south
Geocentric longitude	121°.694719 east
Distance from Earth's centre	6662.051395 km
Inertial velocity	10.70058 km/s
Inertial elevation flight-path angle	1.3606°
Inertial azimuth flight-path angle	69.5270°
Derived initial orbital parameters:	
Perigee distance from Earth's centre	1.044 earth radii
Apogee distance from Earth's centre	23.17 earth radii
Eccentricity	0.913787
Inclination (equator)	28.766°
Launch date:	14 October 1977

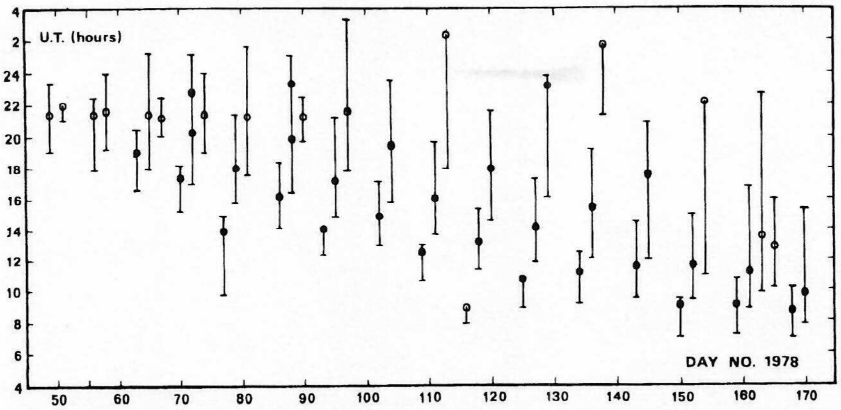

Figure 6. Predicted times of neutral-sheet approaches during 1978. Open circles represent the time of closest approach, discs actual crossing times. The 'error bars' show the time for which the spacecraft are within 2 Earth radii of the neutral sheet.

at low altitudes when the spacecraft are moving fast, and therefore last only a few minutes. The largest eclipse lasts about $5\frac{1}{2}$ h and occurs halfway through the third year of the mission. The Daughter is expected to survive this comfortably, but the Mother has an older thermal design and will get colder, so there may be some failures. This long eclipse was placed as late as possible for this reason.

Table 3. ISEE A/B neutral-sheet crossings in 1978

Day no.	Time (R_e)	$X_{sm}(R_e)$	$Y_{sm}(R_e)$	Day no.	Time (R_e)	$X_{sm}(R_e)$	$Y_{sm}(R_e)$
63	1905	−11.0	−14.4	120	1800	−13.8	− 2.0
70	1720	−10.6	−12.4	125	1040	−10.2	− 1.1
72	2010	−13.3	−13.0	127	1410	−13.2	0.3
72	2240	−11.9	−12.5	129	2315	−10.7	− 1.3
79	1800	−13.0	−11.1	134	1110	−11.7	1.3
86	1610	−12.0	− 9.0	136	1520	−13.4	2.6
88	1955	−14.3	− 9.4	143	1130	−12.5	4.4
88	2340	−11.4	− 8.7	145	1735	−12.6	3.9
93	1405	−10.4	− 7.0	150	0900	−10.5	4.1
95	1710	−13.8	− 7.4	152	1140	−12.7	7.9
102	1455	−12.7	− 5.4	159	0905	−11.0	7.6
104	1925	−14.3	− 5.7	161	1105	−12.0	11.7
109	1235	−10.5	− 3.9	168	0840	−10.4	11.4
111	1600	−13.7	− 3.6	170	0950	−10.3	15.5
118	1220	−13.1	− 1.6				

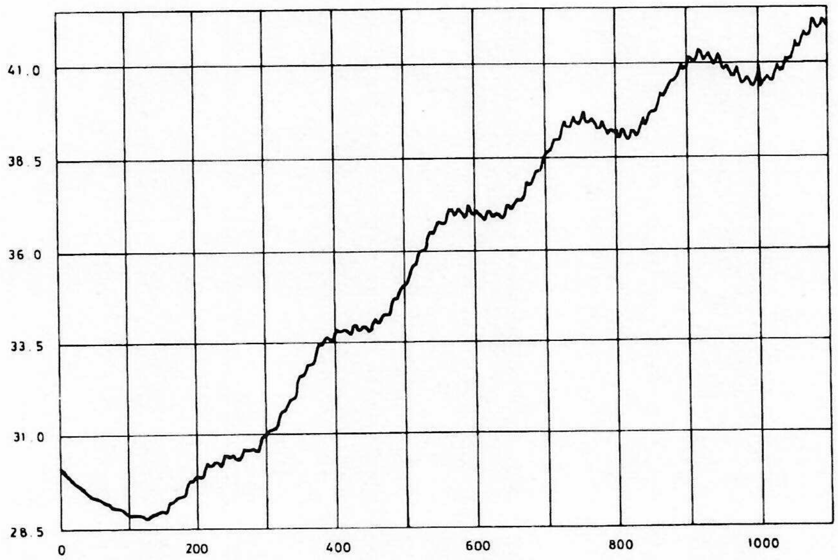

Figure 7. Time variation of orbital inclination with respect to the ecliptic plane over the life of the mission.

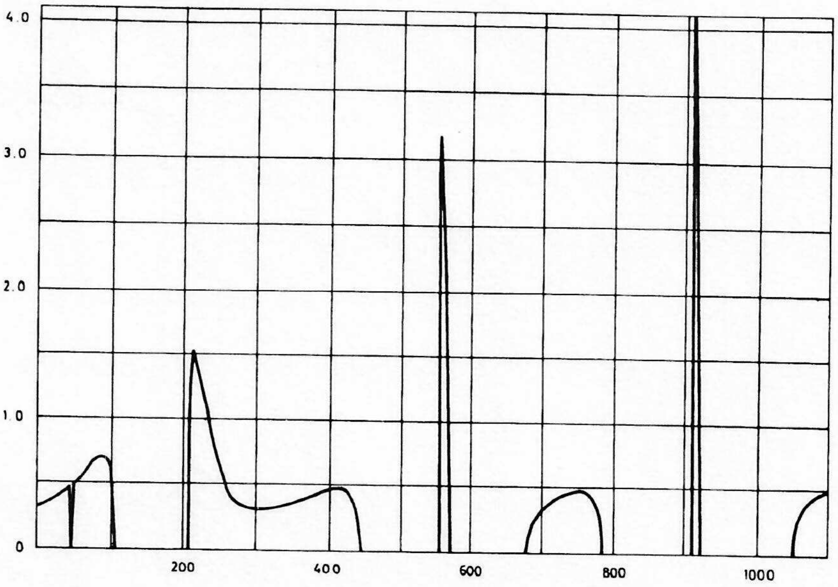

Figure 8. Envelopes of major eclipse times during the mission. The longest eclipses occur during the third year.

The spacecraft will be spin stabilised with the spin vectors perpendicular to the ecliptic with an accuracy of ±3° and pointing north. To give some experiments all-round viewing, the spin rates of the two spacecraft are planned to be slightly different so that there will be a slow beating. The spin rate of the Mother spacecraft is to be 19.75±0.05 rpm, and that of the Daughter 19.8±0.1 rpm.

Separation strategy

Separation of the Mother and Daughter is the heart of this mission. This separation is to be variable to fit in with the scale size of the features to be examined and will have a maximum of roughly 5000 km. Because the Daughter is smaller and therefore more nimble than the Mother, it was chosen to carry the gas-jet system by which the separation will be altered. In case of complete failure of the Daughter equipment, the Mother also carries a gas-jet system (chiefly for placing the spin vector normal to the ecliptic plane) and is capable of limited separation control.

Table 4. ISEE-B propellant budget* (freon 14)

Manoeuvre	∇v(m/s)	Fuel mass (kg)
1. Retro-manoeuvre after separation by springs	1.150	0.473
2. Orbit correction at P2	0.2	0.082
3. Re-orientation normal to Sun and normal to ecliptic (equivalent to total of 120°)	2.368	0.889
4. Spin up	0.500	0.204
5. Available for separation strategy	16.0	5.758
6. Spin-axis maintenance:		
Orbit manoeuvre disturbance	2.416	0.883
Environmental torques	3.00	1.095
7. Spin-rate maintenance:		
Thruster x-coupling	0.812	0.324
Environmental torques	0.020	0.008
8. Residuals (equivalent to pressure in tank of 3 bar)	0.606	0.222
9. Leakage (10 cc/h)	2.825	1.032
Total required	29.897	10.970

* Assumes Daughter spin rate at Mother/Daughter separation of 35 rpm.

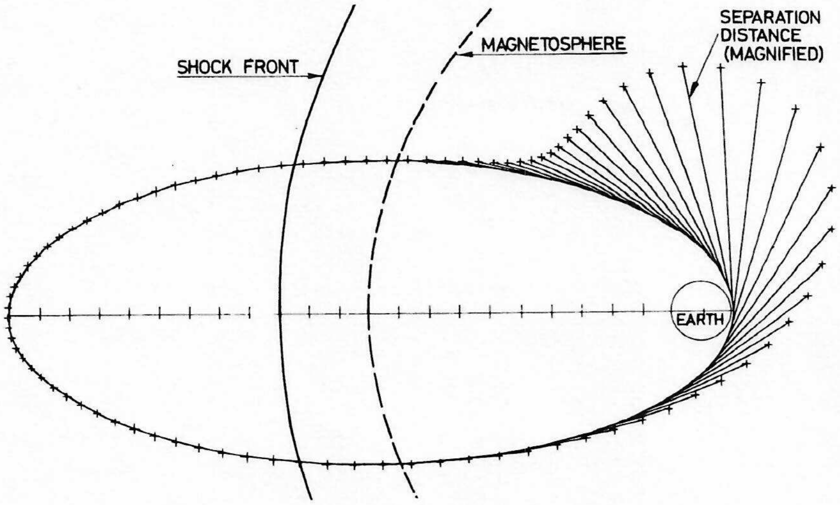

Figure 9. Schematic of the subsolar ISEE-A and B orbit illustrating the varying separation between the two spacecraft as they move around it and the approximate positions of the bow shock and the magnetopause. The length of the lines radiating from the orbit represents the separation distance (not to scale) and direction.

The propellant used by both spacecraft will be freon 14. At the beginning of the project, it was quickly discovered that the only direction of separation which did not need enormous amounts of gas for stability and distance adjustment was along the path of the orbit. This is called the 'true anomaly'. One of the limitations of the mission is the one-dimensional nature of the separation and it is fortunate that the true anomaly puts the Mother-Daughter line perpendicular to most of the moving planes of the magnetosphere, increasing the effectiveness of observations. The distance between the spacecraft will be altered by drifting the Daughter to and fro by giving it a gas-jet 'kick' towards or away from the Mother. The kicks alter the height of the Daughter apogee slightly, thus changing the orbital time period and the differential speed. It is interesting to note that giving the Daughter a kick towards the Mother will cause them to drift apart, and vice versa. The most efficient point at which to give the Daughter a kick is at perigee, and it will be made by a number of gas-jet impulses synchronised with the rotation so that they are all in the same direction. The size of the kick will depend on the number of impulses; the maximum will be about 600 per orbit. This is set by the decreasing efficiency as the spacecraft moves away from perigee (a 10% limit has been chosen) and the increasing amount of gas needed to correct orbit distortions as the kick is increased. In practice, more impulses can be used if a greater inefficiency of gas usage is accepted. The 600 impulses will apply a velocity increment (∇v) of 25 cm/s, which corresponds to a drift-speed change of approximately 500 km per *orbit* at 15 earth radii altitude. Synchronism of the pulses with the rotation is organised by a Sun sensor and so these impulses cannot be given in the Earth's shadow. As the spacecraft will not be in sight of a tracking station at most perigee positions, the gas impulses are pre-programmed by a start and stop timer, which can be set up to 9 h in advance. The error of the timer is such that one impulse can occasionally be lost. It has been agreed that kicks will not be given on consecutive orbits as the tracking support needs at least one complete orbit to stabilise its figures after a manoeuvre. The gas budget is shown in Table 4. A total ∇v of 16 m/s is available for separation manoeuvres.

Because the speed of the spacecraft varies around the orbit, the separation distance changes. This is demonstrated in Figure 9, which shows a diagram of the orbit. The radiating lines show the direction of separation and the length of the lines is proportional to the separation distance. It can be seen that the distance varies enormously around the orbit. This confuses thinking about separation, particularly as the altitude at which the orbit passes through a given feature will vary with time, and it is easier to think of separation time rather than distance. Separation time is almost constant around an orbit, assuming no drift speed. Figure 10 shows a nomogram which can be used to relate separation time and distance for any altitude; it is accurate to about the level of its readability.

The ISEE-A and B manoeuvres will be controlled from the Multiple Satellite Operations Control Center at GSFC. ISEE-B will be operated by a team of ESOC (European Space Operations Centre, Darmstadt, Germany) engineers who will base

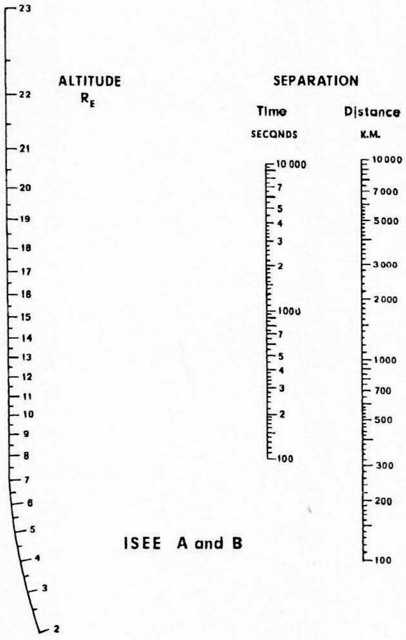

Figure 10. Nomogram which can be used to relate altitude and separation. It makes use of the fact that separation *times* are almost constant for any given orbit and is accurate to about the level of its readability.

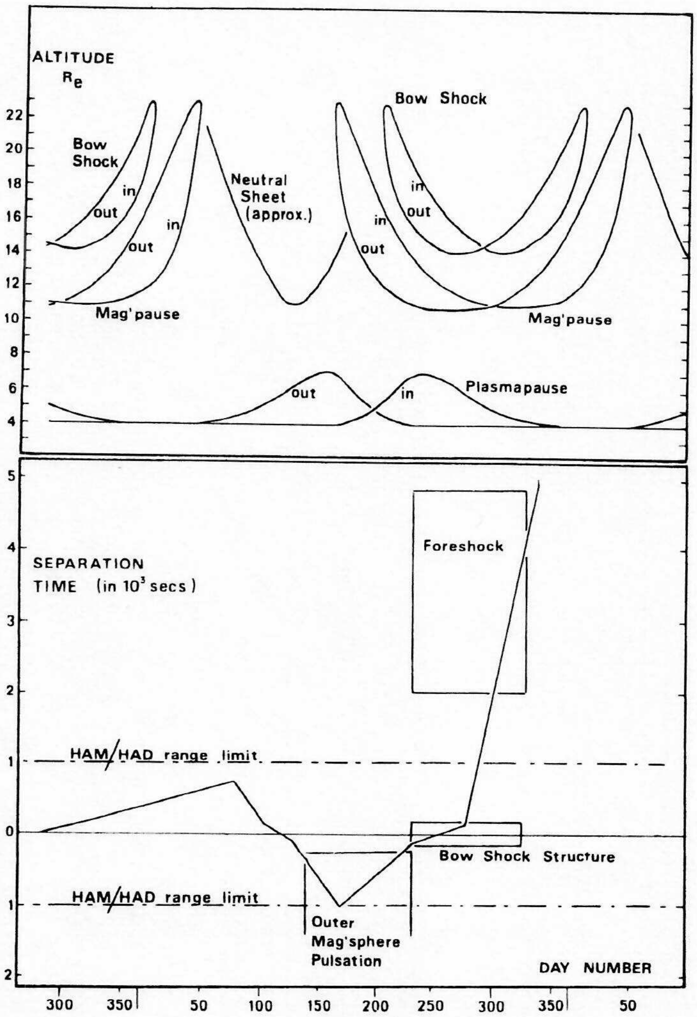

Figure 11. The lower panel illustrates the separation strategy adopted by the Science Working Team to the end of 1978. The upper panel indicates on the same mission time scale the altitudes at which various features are crossed by both the in-bound and out-bound legs of the orbit. A comparison can therefore be made between the feature that can be observed and the separation to be used.

their manoeuvres on tracking information supplied by the NASA network. For changes in separation drift speed, these engineers will have available a selection of pre-programmed 'kick' software packages from which they can choose the one that will supply the desired speed change. This package system was suggested by Mr. D. Eaton, ESA's Project Manager for ISEE-B. It will simplify operations at MSOCC and calculations need not be done on the spot, but can be made in advance elsewhere. It is not expected that packages will give exactly the right kick every time, and for most drifts a correction will be needed. For the design of the packages, it has been specified that separation times must be within 5% of nominal or ±10 s (whichever is greater) at main manoeuvre times, and at other times will be within 10% or ±25 s, again whichever is greater. The actual separation will, of course, be known to a much greater accuracy than this. As separation time is not exactly constant around the orbit, for the purposes of calculation it has been defined as the difference in times of the perigee crossing of the two spacecraft. Separation time has also been defined as positive if the ISEE-B is ahead of ISEE-A and negative if the order is the other way around.

The Science Working Team has agreed upon a separation strategy to be followed from the time of launch up to the beginning of December 1978. This strategy is shown in the lower panel of Figure 11 as separation time against date. The upper panel is a sketch of the approximate crossing altitudes of the main magnetospheric features, taking account of both the in- and out-bound legs of the orbit, derived from the values in Table 5. The general philosophy of the strategy is that it will be cautious for the first year to make sure there are no surprises, and at the same time it has been carefully designed around the feature crossing times. The spacecraft will pass each other (separation effectively zero) on the eighth orbit, after which the separation manoeuvres will be according to the Science Working Team plan. The phase before

Table 5

Prime target	Line of apsides angle (deg)	Crossing altitudes (R_e)						Day no.
		Bow shock		Magnetopause		Plasmapause		
		In	Out	In	Out	In	Out	
Foreshock	0	14.5	14.5	11.0	10.9	5.2	4.0	278
	10	14.2	15.0	10.9	11.0	4.9	4.0	288
	20	14.2	15.5	10.8	11.3	4.6	4.0	298
	30	14.3	16.2	10.8	11.7	4.4	4.0	308
Bow shock	40	14.6	17.0	10.9	12.3	4.2	4.0	318
	50	15.2	18.1	11.0	13.1	4.1	4.0	328
	60	15.9	19.4	11.1	14.1	4.0	4.0	339
	70	17.0	20.8	11.4	15.2	4.0	4.0	349
	80	19.1	22.6	11.8	16.5	4.0	4.0	359
Magnetosheath	90			12.7	18.2	4.0	4.0	4
	100			14.0	19.9	4.0	4.0	14
Magnetopause	110			16.1	21.8	4.0	4.0	24
	120			20.0	23.0	4.0	4.0	34
Tail	130					4.0	4.1	45
	140					4.0	4.2	55
	150					4.0	4.4	65
	160					4.0	4.6	75
	170					4.0	4.9	85
	180					4.0	5.2	95
	190					4.0	5.7	105
	200					4.0	6.2	116
	210					4.0	6.6	126
	220					4.0	6.9	136
	230					4.0	7.0	146
Magnetopause	240			23.0	17.8	4.0	6.8	156
	250			20.8	15.3	4.2	6.2	166
Magnetosheath	260			19.2	13.7	4.4	5.5	176
	270			17.5	12.6	4.8	4.8	187
Bow shock	280	23.0	19.4	16.1	11.8	5.5	4.4	197
	290	21.2	17.0	15.0	11.4	6.2	4.2	207
	300	19.6	15.8	14.0	11.0	6.8	4.0	217
	310	18.4	15.0	13.1	10.9	7.0	4.0	227
Foreshock	320	17.1	14.5	12.4	10.8	6.9	4.0	237
	330	16.2	14.2	11.5	10.8	6.6	4.0	247
	340	15.5	14.2	11.5	10.8	6.2	4.0	258
	350	15.0	14.2	11.2	10.8	5.7	4.0	268

the eighth orbit is taken up with calibration, switch-on and spin-axis alignment manoeuvres. The early part of the 1978 strategy is designed to make detailed examinations of the neutral-sheet and plasma-sheath regions. The measurements of Harvey's electron-density instrument will be important at this time, so the separation will be kept inside his range; during March there are two especially good periods for correlation of neutral-sheet examinations with ground-based observations. There are two recalibration periods, one in April-May and the other in August. The criterion for recalibration is that the spacecraft should be close together and it is planned that they will pass each other at these times. These passes, or flybys, also help to make economies in gas. The second recalibration phase is planned to take place at the time when ISEE-C is placed on station so that correspondence between the instruments on all three spacecraft of the mission can be checked. The separation strategy will be reviewed at a meeting provisionally planned for June 1978.

The Heliocentric spacecraft orbit

This spacecraft is to be placed near the Earth-Sun line, far enough away from the Earth for its measurements not to be affected by waves and particles generated by or reflected at the magnetosphere, yet near enough to allow a reasonable bit rate. A suitable position for this spacecraft is at the sunward point on the Sun-Earth line where the gravitational attractions of the Sun and the Earth together with centrifugal force cancel each other out to produce an equilibrium point. Such points are called libration or Lagrangian points (Fig. 12); the sunward point is 234 earth radii away. The equilibrium at this position is unstable, but even so less gas is needed to keep the spacecraft there than at other points on the Earth-Sun line. However, ISEE-C cannot be held stationary at this point because, as viewed by receivers on the Earth, the Sun would be right behind it and its telemetry would be swamped by solar radiation. This problem will be overcome by making the spacecraft gyrate around this 'blind zone' in a 'halo' orbit. An important parameter here is the width of the blind zone and allowance has to be made for solar flares and side lobes of the Earth antenna responses. The noise rejections of the 26 m radio telescopes to be used by ISEE-C have been checked by allowing the NASA Landsat spacecraft to drift across the Sun. Two of the three telescopes of the network have special noise filtering systems and were found to have adequate noise rejection for an orbit which subtends a minimum half angle of 6°. There may be a problem if the third telescope is used to track that part of the orbit which is near the Sun, but this will be for short times only.

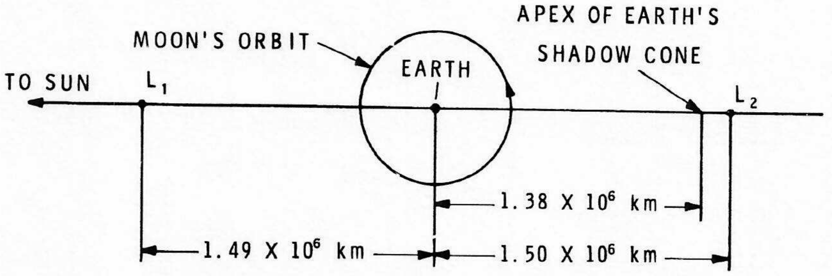

Figure 12. Schematic of the libration points that lie near the Earth on the Earth-Sun line.

This halo orbit will have to be adjusted from time to time to keep its plane nearly normal to the Earth-Sun line. In the latest concept the halo orbit has been enlarged along the axis in the ecliptic plane. This will save gas since plane adjustments will not have to be so frequent as for a more circular orbit and telemetry interference during the solar flares will be reduced because the spacecraft will be up to 28° away from the Sun. This present proposal is shown in Figure 13. The spacecraft goes anticlockwise around the orbit, as seen from the Earth.

ISEE-C will be launched on 24 July 1978, which is as soon after ISEE-A and B as is practicable. The nine-month delay was originally the time taken to finish building the C-spacecraft after A and B had been launched. Subsequently, the construction was contracted out to Fairchild and the delay is now mainly caused by the time necessary to select the prime contractor. The spacecraft will be injected into a transfer orbit shortly after launch. This will be done at night to avoid the need to roll

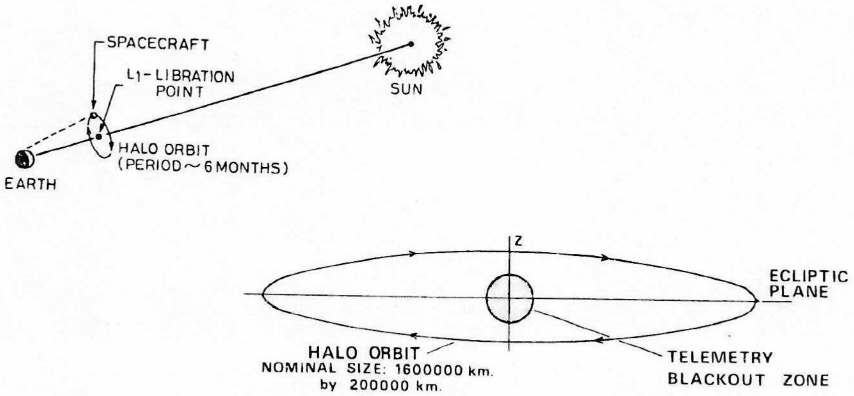

Figure 13. The halo orbit position and its approximate shape as viewed from the Earth.

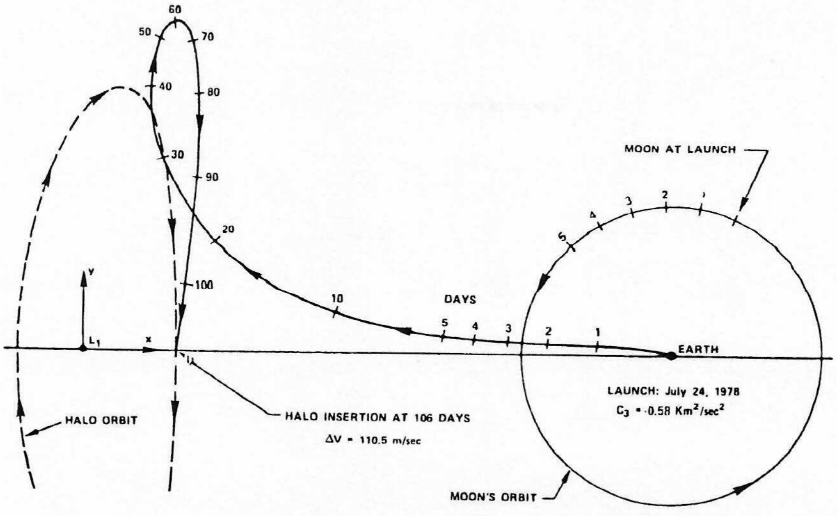

Figure 14. Possible transfer orbit for injecting the ISEE-C spacecraft into the halo orbit.

the Delta rocket (this has to be done for a coast phase in sunlight to avoid 'cooking' one side of the spacecraft; this rolling is unfortunately called the 'rotisserie mode'). The projection of a transfer orbit onto the ecliptic plane is shown in Figure 14. The spacecraft will be near the halo orbit about 30 days after launch, and actual injection will take place 78 days later. The position of the Moon is important as the aspect is one of the factors used to make the mid-course altitude correction of the transfer orbit. This restricts the launch window to 2 or 3 days per month. ISEE-C carries 450 kg of hydrazine for orbit and attitude control. This represents a ∇v of about 400 m/s. It is estimated that about 105 m/s of this will be needed for the transfer-orbit mid-course correction and 110 m/s for deceleration at the halo-orbit injection. The remainder is available for stationkeeping, orbit-plane adjustment attitude manoeuvres, etc., and is estimated to be sufficient to maintain the spacecraft on station for 5 years.

ISEE-C will also be spin stabilised at 20 rpm with the spin vector perpendicular to the ecliptic plane and pointing north.

The experiments

These three spacecraft carry a total of 35 instruments and involve 111 investigators of international repute from 34 institutes. The experiments have been given three-letter code names, the first two letters generally being the first two letters of the principal investigator's surname, and the last letter, M, D or H, denoting whether the instrument is mounted on the Mother (ISEE-A), Daughter (ISEE-B) or Heliocentric (ISEE-C). Table 6 compares the ISEE-A and B measurements in a summary form, demonstrating the comprehensive nature of the common payload.

Table 6. Comparison of ISEE-A and B payloads

PAYLOAD COMMON TO A & B:	
Electric waves	10 Hz – 2 MHz
Magnetic waves	DC – 10 kHz
Protons	1 eV – 2 MeV
Electrons	1 eV – 250 keV
Solar-wind ions	100 eV/N – 10 keV/N
Electron density	Integral A to B
ADDITIONAL EXPERIMENTS ON ISEE-A:	
Static & LF electric fields	
VLF propagation (passive)	
Electrons	6 eV – 10 keV
Electron density	Sounder
Plasma composition	<40 keV/q
Particle composition	<20 MeV/N, $Z=1$ to 20

Table 7. ISEE-A (Mother) payload

Code	Measurement	Investigators	Institute
GUM	Electric and magnetic waves (similar to ISEE-B experiment)	D. Gurnett	Iowa University
		R. Fredericks	TRW
		F. Scarf	TRW
		E. Smith	JPL
RUM	Magnetometer (identical to ISEE-B experiment)	C. Russell	UCLA
		R. McPherron	UCLA
		P. Hedgecock	Imp. College, London
		F. Mariani	CNR, Frascati
FRM	1 eV–50keV protons 1 eV–250 keV electrons (identical to ISEE-B experiment)	L. Frank	Iowa University,
		C. Kennel	UCLA
		V. Vasyliunas	MPI, Lindau
BAM	5 eV–40 keV protons 5 eV–20 keV electrons Solar-wind-ions (similar to ISEE-B experiment)	S. Bame	LASL
		J. Asbridge	LASL
		W. Feldman	LASL
		E. Hones	LASL
		M. Montgomery	LASL
		H. Miggenrieder	MPI, Garching
		G. Paschmann	MPI, Garching
		M. Rosenbauer	MPI, Garching
		K. Schindler	Bochum University
		H. Völk	MPI, Heidelberg
HAM	Electron density (complementary to ISEE-B experiment)	C. Harvey	Meudon Observatory
		R. Grard	ESTEC
		D. Jones	ESTEC
		J. Etcheto	CNET
		R. Gendrin	CNET
		M. Petit	CNET
		J. McAfee	NOAA, Boulder
ANM	8–380 keV protons 8–200 keV electrons (similar to ISEE-B experiment)	K. Anderson	UCB
		R. Lin	UCB
		C. Meng	UCB
		G. Parks	Univ. of Washington
		F. Coroniti	UCLA
		H. Rème	Univ. of Toulouse
		J. Bosquet	Univ. of Toulouse
		R. Pellat	Univ. of Toulouse
WIM	25 keV–2 MeV protons 20–250 keV electrons (similar to ISEE-B experiment)	D. Williams	NOAA, Boulder
		T. Fritz	NOAA, Boulder
		E. Keppler	MPI, Lindau
		B. Wilken	MPI, Lindau
		I. Bostrom	JHU
		G. Wibberenz	Univ. of Kiel
HPM	Quasi-static and low-frequency electric field	J. Heppner	GSFC
		L. Aggson	GSFC
		N. Maynard	GSFC
		D. Cauffman	NASA HQ
		D. Gurnett	Univ. of Iowa
MOM	Quasi-static and low-frequency electric fields; electron gun	F. Mozer	UCB
		M. Kelley	UCB
HEM	VLF propagation	R. Helliwell	Stanford University
		T. Bell	Stanford University
OGM	6 eV–10 keV electrons	K. Ogilvie	GSFC
		S. Scudder	GSFC
SHM	Cold-plasma composition up to 40 keV/q	R. Sharp	Lockheed
		E. Shelley	Lockheed
		R. Johnson	Lockheed
		H. Balsiger	Univ. of Berne
		J. Geiss	Univ. of Berne
		P. Eberhardt	Univ. of Berne
		B. Haerendel	MPI, Garching
		H. Rosenbauer	MPI, Garching
		C. Chappell	MSFC
HOM	Particle composition up to 20 MeV/N	D. Hovestadt	MPI, Garching
		M. Scholer	MPI, Garching
		C. Fan	Arizona
		L. Fisk	GSFC

Table 8. ISEE-B (Daughter) payload

Code	Measurement	Investigators	Institutes
AND	8–380 keV protons	K. Anderson	UCB
	8–200 keV electrons	R. Lin	UCB
	(high time resolution)	C. Meng	UCB
		G. Parks	Univ. of Washington
		F. Coroniti	UCLA
		H. Rème	Univ. of Toulouse
		J. Bosquet	Univ. of Toulouse
		R. Pellat	Univ. of Toulouse
EGD	10 eV/N – 10 keV/N	G. Moreno	CNR, Frascati
	solar-wind ions	A. Egidi	CNR, Frascati
		S. Cantarano	CNR, Frascati
		P. Cerulli	CNR, Frascati
		V. Formisano	CNR, Frascati
		S. Bame	LASL
		G. Paschmann	MPI, Garching
FRD	1 eV–50 keV protons	L. Frank	Iowa Univeristy
	1 eV–250 keV electrons	C. Kennell	UCLA
	(high angular resolution)	V. Vasyliunas	MPI, Lindau
GUD	Electric waves: 10 Hz–2 MHz	D. Gurnett	Iowa University
	magnetic waves: 10 Hz–10 kHz	F. Scarf	TRW
		R. Fredricks	TRW
		E. Smith	JPL
HAD	Integral electron density	C.C. Harvey	Meudon
	between ISEE-A and ISEE-B	R. Grard	ESTEC
		D. Jones	ESTEC
		J. Etcheto	CNET
		R. Gendrin	CNET
		M. Petit	CNET
		J. McAfee	NOAA, Boulder
KED	25 keV–2 MeV protons	D. Williams	NOAA Boulder
	20–250 keV electrons	T. Fritz	NOAA Boulder
	(high angular resolution)	E. Keppler	MPI, Lindau
		B. Wilken	MPI, Lindau
		I. Bostrom	JHU
		G. Wibberenz	Univ. of Kiel
PAD	5 eV–40 keV protons	G. Paschmann	MPI, Garching
	5 eV–20 keV electrons	H. Rosenbauer	MPI, Garching
	(high time resolution)	M. Montgomery	MPI, Garching
		K. Schindler	Bochum Univ.
		H. Völk	MPI, Heidelberg
		S. Bame	LASL
		J. Asbridge	LASL
		W. Feldman	LASL
		E. Hones	LASL
RUD	Magnetometer: range 8192 γ	C. Russell	UCLA
	Max. sensitivity: 0.008 γ	R. McPherron	UCLA
		P. Hedgecock	Imp. College, London
		F. Mariani	CNR, Frascati

Tables 7,8 and 9 list the experiments on the three spacecraft, giving the names and institutes of the investigators. The principal investigators for each instrument are underlined. In addition, there is a ground-based experiment whose principal investigator is D.J. Wilcox of Stanford University. It is his intention to use the Stanford solar telescope to measure large-scale magnetic and velocity fields for comparison with the satellite data. The institutes are given abbreviated names; the full names are listed in the Appendix.

Table 9. ISEE-C (Heliocentric) payload

Code	Measurement	Investigators	Institutes
BAH	150 eV—7 keV protons and electrons	S. Bame	LASL
		J. Asbridge	LASL
		W. Feldman	LASL
		E. Hones	LASL
		M. Montgomery	LASL
DFH	30 keV–1.4 MeV protons	R. Hynds	Imp. College, London
		A. Balogh	Imp. College, London
		H. Elliot	Imp. College, London
		C. de Jager	Univ. of Utrecht
		J. van Gils	Univ. of Utrecht
		R. v.d. Nieuwenhof	Univ. of Utrecht
		J. van Rooyen	Univ. of Utrecht
		V. Domingo	ESTEC
		A. Durney	ESTEC
		D.E. Page	ESTEC
		T. Sanderson	ESTEC
		P. Wenzel	ESTEC
ANH	2–800 keV electrons 6–250 keV solar x-rays	K. Anderson	UCB
		S. Kane	UCB
		R. Lin	UCB
		D. Smith	High Alt. Obs.
OGH	Plasma composition	K. Ogilvie	GSFC
		M. Acuna	GSFC
		D. Lind	MSFC
		M. Copland	Univ. of Maryland
		J. Geiss	Univ. of Berne
HOH	Particle composition up to 20 MeV/N	D. Hovestadt	MPI, Garching
		M. Scholer	MPI, Garching
		C. Fan	Arizona
		L. Fisk	GSFC
		B. Gloeckler	Univ. of Maryland
		S. O'Gallagher	Univ. of Maryland
STH	Particle composition: 2–200 MeV/N	E. Stone	Caltech
		R. Vogt	Caltech
TYH	Particle composition: 0.5–500 MeV/N	T. von Rosenvinge	GSFC
		L. Fisk	GSFC
		M. van Hollebeke	GSFC
		F. McDonald	GSFC
		J. Trainor	GSFC
HKH	Particle composition 31–495 MeV/N	H. Heckman	UCB
		D. Greiner	UCB
MEH.	Electron energy spectra: 5–400 MeV	P. Meyer	Univ. of Chicago
		P. Evenson	Univ. of Chicago
SCH	20 Hz–100 kHz electric waves 20 Hz–1 kHz magnetic waves	F. Scarf	TRW
		R. Fredricks	TRW
		E. Smith	JPL
		D. Gurnett	Univ. of Iowa
SBH	Type III radio bursts	J. Steinberg	Meudon Observatory
		P. Couturier	Meudon Observatory
		R. Knoll	Meudon Observatory
		J. Fainberg	GSFC
		R. Stone	Meudon Observatory
SMH	Vector helium magnetometer	E. Smith	JPL
		B. Tsurutani	JPL
		L. Davis	Caltech
		D. Jones	Brig. Young
		G. Siscoe	UCLA

Table 10. Payload resource requirements: ISEE-A

Code	Mass (kg)	Power (W)	Commands			Telemetry
			power	pulse	serial	(minor frame words)
ANM	5.10	5.00	4	–	2	7
BAM	7.70	5.00	8	4	2	22
FRM	5.00	5.00	4.	6	1	7
GUM	8.00	7.40	2	12	1	16
HAM	5.00	6.00	4	5	2	4
HEM	1.30	1.10	2	–	1	–
HOM	12.90	7.00	8	4	1	8
HPM	8.10	3.70	4	1	1	8
MOM	10.20	4.25	5	6	1	6
OGM	4.40	4.00	6	–	1	12
RUM	2.70	6.00	4	2	1	6
SHM	10.60	8.50	10	6	2	7
WIM	8.00	12.80	4	–	1	12
Total	89.00	75.75	59	46	17	115

Table 11. Payload resource requirements: ISEE-B

Code	Mass (kg)		Power (W)		Commands			Telemetry (minor frame words)	Comments
	specified	actual	specified	actual	power	pulse	serial		
AND	4.60	4.84	3.1	2.23	4	0	2	14	Axial viewing (2 units)
EGD	2.75	2.78	2.0	1.85	2	0	1	8	Channeltrons
FRD	4.60	4.57	5.0	3.80	4	4	1	14	Channeltrons
GUD	3.00	3.06	3.3	3.28	2	7	1	12	Boom-mounted
HAD	1.72	1.69	1.5	1.46	2	1	0	8	Wire and special antenn
KED	4.85	4.86	5.4	4.60	2	1	4	14	Solid-state detectors
PAD	4.75	4.69	3.0	2.20	2	1	2	34	Pyrotechnic windows
RUD	2.65	2.64	6.0	3.92	4	2	1	12	Boom-mounted
Total	28.92	29.13	29.3	23.34	22	16	12	116	

Note: The total mass of payload, specified on 9 August 1973 as 29.64 kg.

Table 12. Payload resource requirements: ISEE-C

Code	Mass (kg)	Power (W)	Commands			Telemetry
			power	pulse	serial	(minor frame words)
ANH	11.60	6.00	4	–	3	19
BAH	5.80	4.70	6	3	2	23
DFH	4.10	3.50	10	–	1	6
HOH	11.50	7.00	6	4	1	8
HKH	8.40	6.00	8	3	1	2
MEM	9.10	4.00	2	2	1	4
OGH	5.60	3.00	2	2	2	1
SBH	15.36	3.45	4	–	1	9
SCH	8.80	4.50	2	6	–	17
SMH	3.07	4.30	2	4	–	12
STH	7.60	7.00	2	–	1	8
TYH	6.50	4.10	4	1	2	7
Total	97.42	57.55	52	25	15	116

The spacecraft resources needed by each experiment are listed in Tables 10, 11 and 12. Telemetry resources are listed in terms of words per minor frame. Each word has 8 bits and there can be a maximum of 128 in a minor frame. The bit rates of the spacecraft will be variable by changing the frame rate, the telemetry format remaining the same.

ISEE and the International Magnetospheric Study

The ambitious aim of the International Magnetospheric Study is a full understanding of all the features and mechanisms of the near-earth environment. The Study will take place from 1976 to 1979 inclusive, and its relationship to the lives of ISEE, Geos and Geosari are shown in Figure 15. It is run by a Steering Committee under the chairmanship of J.G. Roederer of Denver. The American part of ISEE is NASA's major contribution to the IMS. With Geos and Geosari (a second Geos which may be launched into geosynchronous orbit by Ariane) monitoring conditions on or about the 6.6 earth radii flux tube, ISEE-A and B moving through the magnetosphere and ISEE-C continuously monitoring the solar wind, these missions will form the keystone of the study. The Japanese will supply three low-altitude satellites named EXOS-A, EXOS-B and ISS which, although their payloads will not make such comprehensive measurements as ISEE and Geos, will make a large contribution. ISS (Ionospheric Sounder Satellite) was launched on 29 February 1976, but became inactive after one month. A back-up is planned for 1978 after suitable modifications have been made. In addition, there are a number of satellites still operating carrying one or more instruments capable of adding information to IMS investigation. These include IMP 7 and 8, ATS 6, ISIS and AE, for which data collection is likely to be funded in the 1977 financial year.

The success of the IMS relies heavily on data correlation inside the IMS community, between satellite, ground-based, balloon and rocket investigators. Thus, it is crucial that each worker should know what measurements are available and have easy access to them.

Data interchange offices have been set up at Meudon (Prof. P. Simon) in France and at Boulder (J.M. Allen). The Boulder office is called IMSCIE (IMS Central Information Exchange, telex 45897 Solterwarn BDR) and is especially active, producing an informative newsletter each month, which contains details of experiments and campaigns conducted in the past, present or to be conducted in the future. The Satellite Situation Center run by Jim Vette at GSFC calculates satellite orbits and publishes through this newsletter selected periods when correlation of and with spacecraft data is likely to be especially fruitful. For the satellites themselves, the Geos team has set up a sophisticated system in Germany for the digestion of an enormous data rate of 100 kbit/s in almost real time, and daily summaries will be distributed. ISEE is capable of a considerable 26 kbit/s of data, but for 80% of the time will run at 14. However, because it is a 'low-cost project' its data-processing system is more archaic and much slower than that of Geos. Data distribution will be through a 'pool' tape.

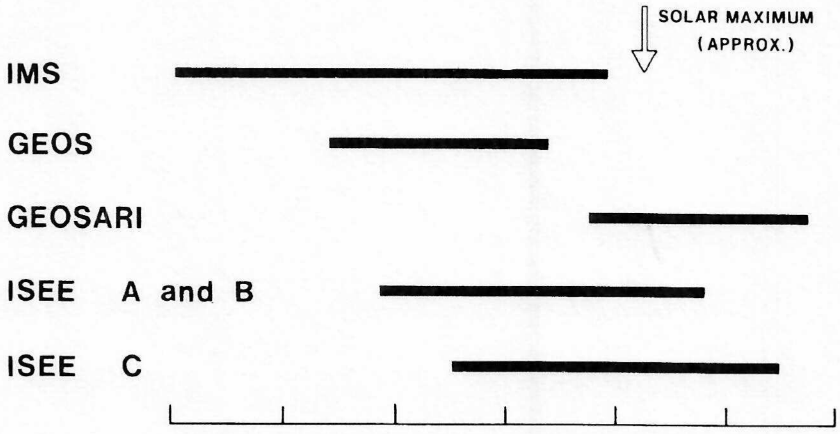

Figure 15. Lifetimes of the ISEE spacecraft, Geos and Geosari in relation to the IMS period.

ISEE data processing and distribution

The ISEE data will be gathered in the conventional manner by NASA S-band tracking stations. Half an hour's data from each spacecraft each day will be taken at Goddard Space Flight Center in real time for housekeeping and operations control. The remainder of the data will be stored at the tracking stations and transmitted to NASA over the NASCOM network within 24 h of aquisition. This means that ISEE data will *not* normally be available in real time. However, the situation is

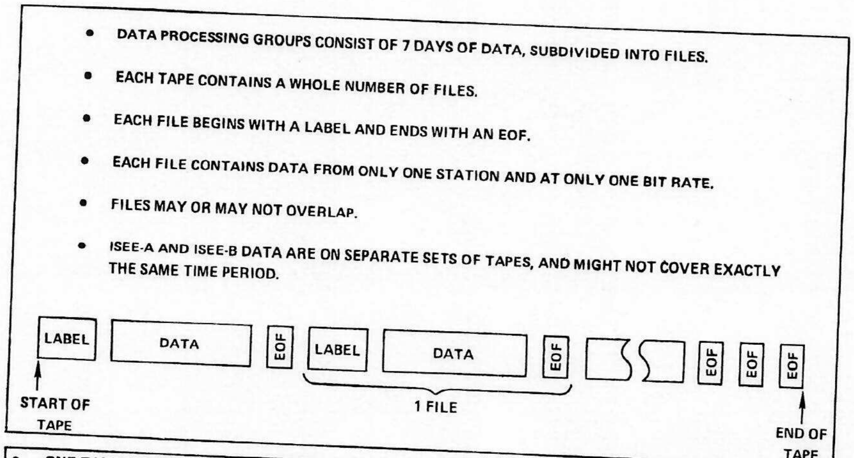

Figure 16. Structure of the experiment data tape.

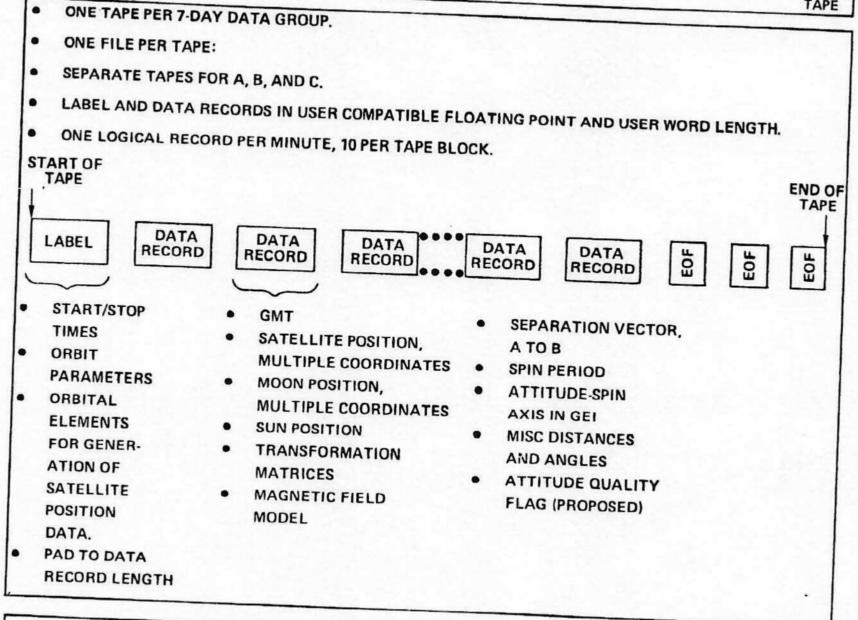

Figure 17. Structure and content of the Multiple Co-ordinate Ephemeris (MCE) tapes.

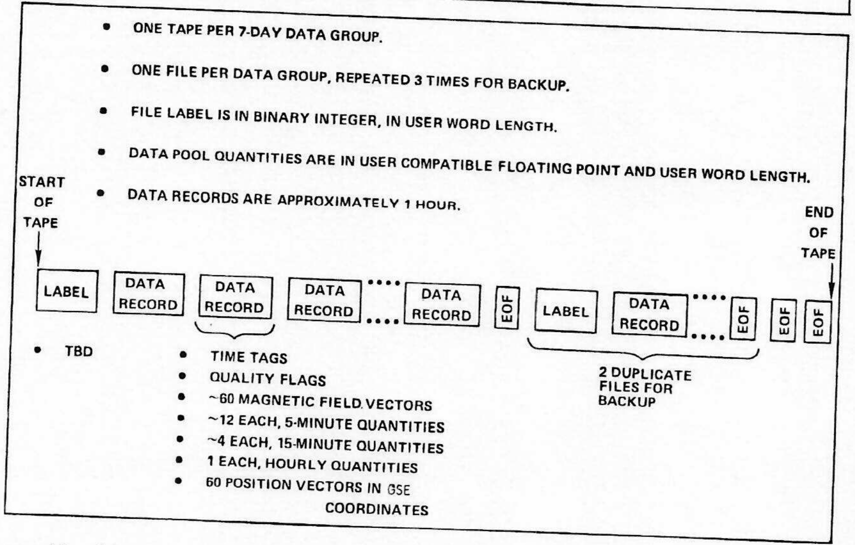

Figure 18. Structure and general content of the data-pool tape. Because of the short length of data (seven days) on each tape, the data group is repeated three times.

considerably worse than this. Twenty-one days after the data has been recorded, corrected orbital parameters are available. This accurate information is needed so that ground reception time can be corrected to spacecraft time, taking account of the travelling time of the signal. After processing, the experimental data are to be decommutated and distributed to principal investigators. This dissemination will take place about 35 days after the data are recorded. The data tapes will contain the spacecraft position in GSE co-ordinates and may have data from other experiments recorded on them. Several investigators have asked for magnetometer data; this will be placed on their tapes in raw form so that any later corrections to processing procedures can be applied retroactively. When the data tapes are sent out, they will be accompanied by Multiple Co-ordinate Ephemeris (MCE) tapes which contain a large number of parameters, many of them irrelevant for this mission. The form of the experiment data and MCE tapes is shown in Figures 16 and 17.

An unsatisfactory 49 days after data has been recorded, data pool tapes and 35 mm microfilm will be distributed to all ISEE principal investigators and will be available to the scientific community at large through the World Data Center at Goddard. These pool tapes will contain quantities stripped out of the original data by simple algorithms supplied by the experimenters. The quantities will be mostly 5 min averages of the data; the format and contents are shown in Figure 18 and Tables 13 and 14. There will be one pool tape for ISEE-A and one for ISEE-C; the time resolution does not justify one for ISEE-B. After discussion it was decided that

Table 13. ISEE-A data pool tape*

Code	Quantities	
RUM	3	spin-corrected magnetic-field co-ordinates, payload co-ordinates (1 min intervals)
	26	magnetic-field parameters (hourly)
BAM	4	electron energy levels
	1	ion pseudo-density
	1	ion average energy
	1	solar-wind peak speed
	1	solar-wind pseudo-density
WIM	1	32–50 keV electrons
	1	32–50 keV protons
	1	80–126 keV electrons
	1	80–126 keV protons
FRM	1	spin-averaged proton number density
ANM	1	8–200 keV electron flux
	1	8–200 keV proton flux
GUM	1	562 Hz wave electric-field magnitude
	1	562 Hz wave magnetic-field magnitude
HAM	1	5 level status word (1 min intervals)
MOM	1	electron gun on/off indicator (1 min intervals)
SHM	1	cold-plasma density
HOM	1	125 keV protons (15 min intervals)
	1	125 keV alpha particles (15 min intervals)
	1	number of particles with $Z > 2$ and energy more than 100 keV/N (15 min intervals)

Table 14. ISEE-C data-pool tape*

Code	Quantities	
SMH	3	spin-corrected magnetic-field co-ordinates (1 min intervals)
	25	parameters (hourly)
BAH	4	electron energy levels
	1	ion pseudo-density
	1	ion average energy
	1	solar-wind peak speed
	1	solar-wind pseudo-density
SCH	1	562 Hz wave electric-field magnitude
	1	562 Hz wave magnetic-field magnitude
ANH	1	2–800 keV electron flux
MOH, TYH	1	sequenced protons: 0.05–0.20, 0.5–1.4, 4–20, 20–80 MeV
ANH	1	20 keV x-rays
SBH	2	200 kHz, 2 MHz radio flux peak values

*Data at 5 min intervals unless otherwise stated electric-field data would not be included in these tapes because of the varying quality of the data and the difficulty of separating out $v \wedge B$. The purpose of the data-pool tapes is to provide low-time-resolution data for intercomparison and indexing, not for data reduction. There is no guarantee that the data are correct, although the investigators will hold back general distribution for 8 weeks after launch to try and ensure that their algorithms are right. The accuracy required for these tapes is not more than a few percent. The user will employ these tapes to identify periods of special interest and can then contact other experimenters to get high-time-resolution data for correlation and interpretation.

As ISEE-C is 234 earth radii away on the Earth-Sun line, it it is about an hour upstream in the solar wind and there is an obvious argument for real-time data to be available occasionally, since it can give a one-hour warning of interplanetary 'weather'. Special arrangements have been made so that for limited periods a few data can be available in real time. The scheme is that, say for a launch campaign, a representative of the campaign would be present at the Goddard Multiple Satellite Operations Control Center during rocket standby, and every half hour he would be given decommutated real-time data from ISEE-C. The data would contain the interplanetary field Z-component and the solar-wind flux velocity. When the correct conditions were observed, the representative could warn the campaign by telex or telephone. The provision of a representative is vital since the project will have no manpower available, the MSOCC is not set up for this kind of operation and this arrangement will not be possible for extended periods. If outside investigators need this service, they should contact, well in advance, Dr. K.W. Ogilvie, Code 692, Goddard Space Flight Center, Greenbelt, Maryland 20771, USA, (telephone 301/982-5904).

Conclusion

ISEE has been able to take advantage of the pioneering work done by Geos and together with the good preparation by the early Science Working Team meetings, this has led to the smooth running of the projects.

The launch date of 14 October 1977 is expected to be met by ISEE-A and B and although it is too soon to make predictions about the July 1978 launch date for ISEE-C, the contractor is well ahead of schedule at present.

Finally, Figure 19 shows some of the objectives which will need simultaneous data coverage in 1978–79 and gives a good illustration of the degree and type of activity than can be expected of the ISEE mission in this period.

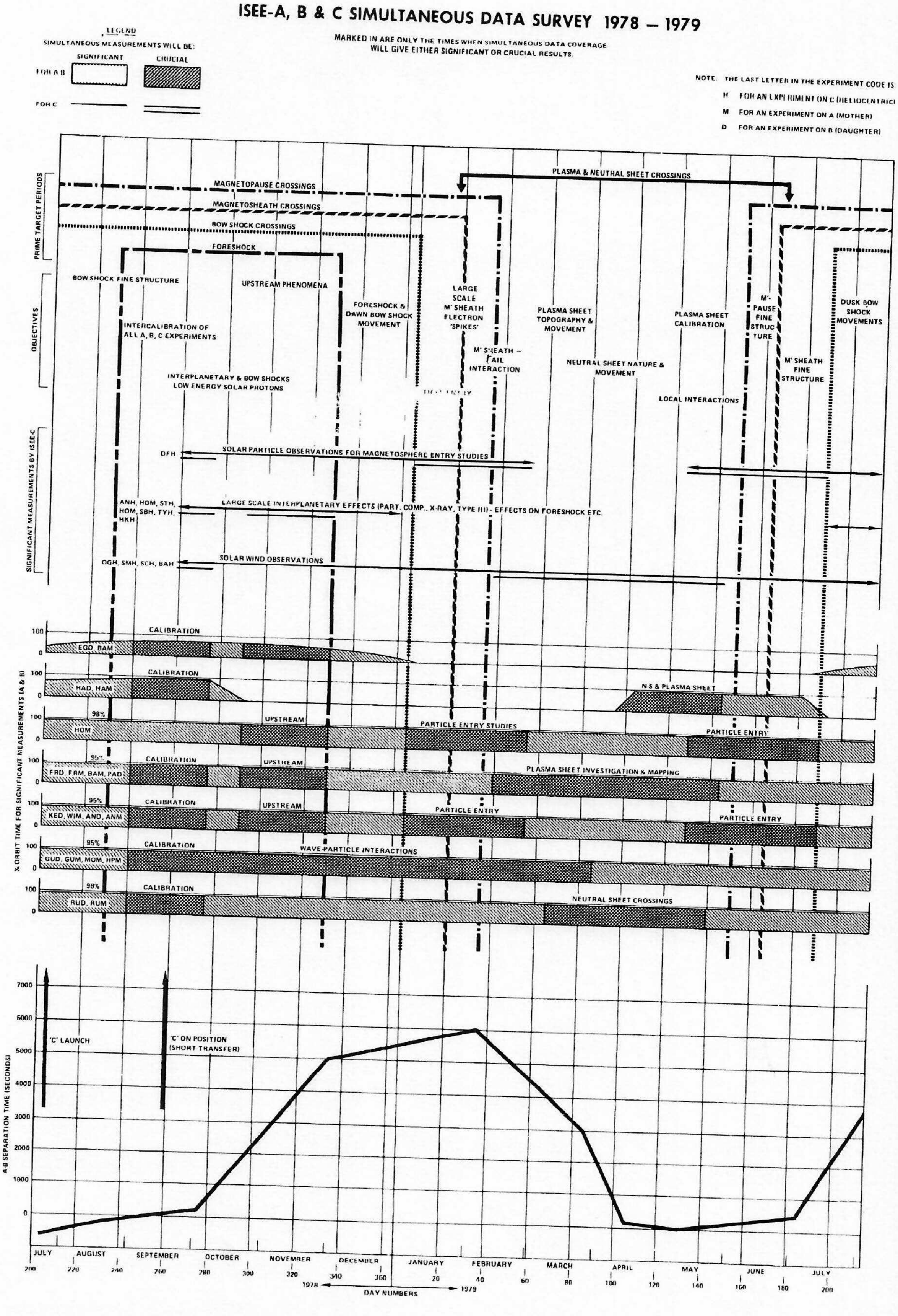

Figure 19. Simultaneous data survey for the second year of the mission to show the importance of simultaneous data and the activity to be expected in this period. The separation strategy after November 1978 is speculative, but fitted to the mission aims.

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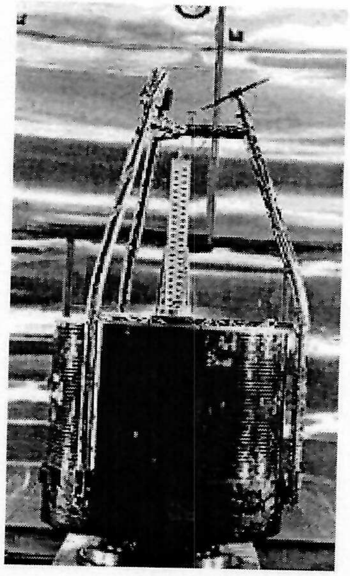
Appendix

Institute abbreviations in alphabetical order

APL	John Hopkins University, Silver Spring, Maryland
Caltech.	California Institute of Technology, Pasadena
CNET	Centre National d'Etudes de Télécommunications, Paris
CNR	Consiglio Nazionale Delle Ricerche, Frascati, Rome
ESTEC	European Space Research and Technology Centre, Noordwijk, Netherlands
GSFC	Goddard Space Flight Center, Greenbelt, Maryland
HAO	High Altitude Observatory, Boulder, Colorado
Imp. Coll.	Imperial College, London
JPL	Jet Propulsion Laboratory, Pasadena
JSC	Johnson Space Center, Houston, Texas
LASL	Los Alamos Scientific Laboratory, New Mexico
Lockheed	Lockheed, Palo Alto Research Laboratory, California
Meudon	Observatoire de Meudon, Paris
MSFC	Marshall Space Flight Center, Huntsville, Alabama
MPI, Garching	Max-Planck Institut für Physik und Astrophysik, Garching, Germany
MPI, Lindau	Max-Planck Institut für Aeronomie, Lindau/Harz, Germany
NASA	National Aeronautics and Space Administration, Wash., DC.
NOAA	Nat. Oceanic and Atmospheric Admin., Boulder, Colorado
RIT	Royal Institute of Technology, Stockholm, Sweden
TRW	TRW Systems Group, Redondo Beach, California
Univ. of: Arizona	University of Arizona, Tucson, Arizona
Berne	University of Berne, Switzerland
Bochum	University of Bochum, Ruhr, Germany
Brig. Young	Brigham Young University, Provo, Utah
Chicago	University of Chicago, Chicago, Illinois
Iowa	University of Iowa, Iowa City, Iowa
Maryland	University of Maryland, College Park, Maryland
Stanford	University of Stanford, Stanford, California
Toulouse	University of Toulouse, Toulouse, France
Utrecht	Utrecht University, Utrecht, Netherlands
Washington	University of Washington, Seattle, Washington
UCB	University of California, Berkeley, California
UCLA	University of California, Los Angeles, California

Explorer: ISEE 2



ISEE 2

The Explorer-class daughter spacecraft, ISEE 2 (International Sun-Earth Explorer 2), was part of the mother / daughter / heliocentric mission (ISEE 1, ISEE 2, ISEE 3). The purposes of the mission were:

- to investigate solar-terrestrial relationships at the outermost boundaries of the Earth's magnetosphere,
- to examine in detail the structure of the solar wind near the Earth and the shock wave that forms the interface between the solar wind and the Earth's magnetosphere,
- to investigate motions of and mechanisms operating in the plasma sheets, and
- to continue the investigation of cosmic rays and solar flare effects in the interplanetary region near 1 AU.

The three spacecraft carried a number of complementary instruments for making measurements of plasmas, energetic particles, waves, and fields. The mission thus extended the investigations of previous IMP spacecraft. The mother/daughter portion of the mission consisted of two spacecraft (ISEE 1 and ISEE 2) with station-keeping capability in the same highly eccentric geocentric orbit with an apogee of 23 Earth radii. During the course of the mission, the ISEE 1 and ISEE 2 orbit parameters underwent short-term and long-term variations due to solar and lunar perturbations. These two spacecraft maintained a small separation distance, and made simultaneous coordinated measurements to permit separation of spatial from temporal irregularities in the near-Earth solar wind, the bow shock, and inside the magnetosphere. By maneuvering ISEE 2, the inter-spacecraft separation as measured near the Earth's bow shock was allowed to vary between 10 km and 5000 km; its value is accurately known as a function of time and orbital position.

The spacecraft were spin stabilized, with the spin vectors maintained nominally within 1 degree of perpendicular to the ecliptic plane, pointing north. The spin rates were nominally 19.75 rpm for ISEE 1 and 19.8 rpm for ISEE 2, so that there was a slow differential rotation between the two spacecraft. The ISEE 2 body-mounted solar array supplied approximately 112 watts at launch. The ISEE 2 data rate was 2048 bps most of the time and 8192 bps during one orbit out of every five (with some exceptions).

Both ISEE 1 and ISEE 2 re-entered the Earth's atmosphere during orbit 1518 on September 26, 1987. Seventeen of 21 on-board experiments were operational at the end.ISEE (International Sun Earth Explorer)

ISEE 2 was not considered part of the Explorer program as it was provided by ESA.

Nation:	Europe
Type / Application:	Research
Operator:	ESA
Contractors:	Dornier
Equipment:	
Configuratation:	
Propulsion:	?
Mass:	?
Orbit:	

Satellite	**Date**	**LS**	**Launcher**	**Remarks:**
ISEE 2	20.10.1977	CC LC-17B	Delta-2914	with ISEE 1

Further IMP / ISEE missions:

- IMP A, B, C
- IMP D, E (AIMP 1, 2)
- IMP F, G
- IMP H, I, J
- ISEE 1
- ISEE 2
- ISEE 3 / ICE
- DE 1, 2
- Explorer Program⇨

Source: NSSDC website

Last update: 30.04.2003
Contact: gunter.krebs@skyrocket.de

Plasma waves: electric & magnetic fields spectra (5.62Hz - 31 1 kHz)

NSSDC ID:1977-102B-5
Mission Name: ISEE 2
Principal Investigator: Prof. Donald A. Gurnett

Experiment mass: 3.4 kg
Average experiment power: 3.3 W

Description

In this experiment, a single-axis search coil magnetometer with a high permeability core and two electric field dipoles (30 m tip-to-tip and 0.61 m) measured wave phenomena occurring within the magnetosphere and solar wind in conjunction with a similar experiment (77-102A-07) flown on the mother spacecraft. The antennas were mounted perpendicularly to the spin axis. The instrumentation was composed of two elements: (1) a high-time-resolution spectrum analyzer with 16 frequency channels (identical to those on ISEE 1) from 5.62 Hz to 31.1 kHz where all channels were sampled 1 or 4 times per s, depending on bit rate; and (2) a wide-band receiver to condition electric and magnetic waveforms for transmission to the ground via the special-purpose analog transmitter. There were two basic frequency channels, from 10 Hz to 1 kHz and from 650 Hz to 10 kHz. In addition, the frequency range could be shifted by a frequency-conversion scheme to any of eight ranges up to 2.0 MHz.

Discipline(s)

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Space Physics: Heliospheric Studies
Space Physics: Magnetospheric Studies
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Personnel Information

Data Set Information
Mission Information

NSSDC Space Physics page

NSSDC home page

For questions about this experiment, please contact:

NSSDC Security and Privacy Statement

NASA Official: D. M. Sawyer, Acting Head, NSSDC (Donald.M.Sawyer@nasa.gov)
Last Updated: 2000-09-07
Output Generated: 2003-05-08
Programming by: Harold Felder(Harold.Felder@gsfc.nasa.gov)

NSSDC Master Catalog: Experiment

Fast Plasma Expt. (FPE): 5eV-20keV(e) 5ev-40 keV (p); 2-D & 3-D distrib. fns

NSSDC ID:1977-102B-1
Mission Name: ISEE 2
Principal Investigator: Dr. Goetz Paschmann

Experiment mass: 4.3 kg
Average experiment power: 5 W

Description

This experiment was designed to study plasma velocity distributions and their spatial and temporal variations in the solar wind, bow shock, magnetosheath, magnetopause, and magnetotail (within the magnetosphere). One-, two-, and three-dimensional velocity distributions for positive ions and electrons were measured using two 90-deg spherical electrostatic analyzers with channeltron electron multipliers as detectors. In conjunction with similar instrumentation (77-102A-01) provided by S. J. Bame/LANL for the mother spacecraft, protons from 50 eV to 40 keV (and electrons from 5 eV to 20 keV) were measured with 10% energy resolution in two ranges each.

Discipline(s)

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Space Physics: Heliospheric Studies
Space Physics: Magnetospheric Studies
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Personnel Information

Data Set Information
Mission Information

NSSDC Space Physics page

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Last Updated: 2002-01-09
Output Generated: 2003-05-09
Programming by: Harold Felder(Harold.Felder@gsfc.nasa.gov)

NSSDC Master Catalog: Experiment

Solar wind ions, 100eV/Q - 10keV/Q 2-D distributions

NSSDC ID:1977-102B-2
Mission Name: ISEE 2
Principal Investigator: Prof. Alberto Egidi

Experiment mass: 2.5 kg
Average experiment power: 2 W

Description

This instrument was designed to measure the angular distributions and energy spectra of positive ions in the solar wind. The main region of interest was outward from and including the magnetopause (greater than 8 earth radii). Two hemispherical electrostatic analyzers were used to cover the energy range 100 eV to 10 keV/Q in up to 64 energy channels. There were two operating modes: one for high-time resolution and one for high-energy resolution. Energy levels were kept constant through a complete spacecraft revolution.

Discipline(s)

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Space Physics: Heliospheric Studies
Space Physics: Magnetospheric Studies
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Personnel Information

Data Set Information
Mission Information

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Last Updated: 2000-09-07
Output Generated: 2003-05-09
Programming by: Harold Felder(Harold.Felder@gsfc.nasa.gov)

Low-Energy Proton and Electron Differential Energy Analyzer (LEPEDEA)

NSSDC ID:1977-102B-3
Mission Name: ISEE 2
Principal Investigator: Prof. Louis A. Frank

Experiment mass: 5 kg
Average experiment power: 5 W

Description

This experiment was designed to study, by means of identical instrumentation on the mother/daughter spacecraft, the spatial and temporal variations of the solar wind and magnetosheath electrons and ions. Protons and electrons in the energy range from 1 eV to 45 keV were measured in 64 contiguous energy bands with an energy resolution (delta E/E) of 0.16. A quadrispherical low-energy proton and electron differential energy analyzer (LEPEDEA), employing seven continuous-channel electron multipliers in each of its two (one for protons and one for electrons) electrostatic analyzers was flown on both the mother and the daughter spacecraft. All but 2% of the 4 pi-sr solid angle was covered for particle-velocity vectors. A GM tube was also included, with a conical field of view of 40-deg full-angle, perpendicular to the spin axis. This detector was sensitive to electrons with E>45 keV, and to protons with E>600 keV.

Discipline(s)

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Space Physics: Heliospheric Studies
Space Physics: Magnetospheric Studies
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Personnel Information

Data Set Information
Mission Information

NSSDC Space Physics page

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NSSDC Security and Privacy Statement

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Last Updated: 2000-09-07
Output Generated: 2003-05-09
Programming by: Harold Felder(Harold.Felder@gsfc.nasa.gov)

Fluxgate Magnetometer, Tri-axial

NSSDC ID:1977-102B-4
Mission Name: ISEE 2
Principal Investigator: Dr. Christopher T. Russell

Experiment mass: 2.43 kg
Average experiment power: 5.7 W

Description

The magnetic fields investigation selected for ISEE 1 and 2 had as its principal objectives the study of the magnetic signatures of magnetospheric phenomena and magnetohydrodynamic waves in and around the magnetosphere, and to provide supporting data for other experiments on the spacecraft such as the electric field, particle and plasma wave investigations. In this triaxial fluxgate magnetometer, three ring-core sensors in an orthogonal triad were enclosed in a flipper mechanism at the end of the magnetometer boom. The electronics unit was on the main body of the spacecraft at the foot of the boom. The magnetometer had two operating ranges of +/- 8192 nT and +/- 256 nT in each vector component. The data were digitized and averaged within the instrument to provide increased resolution and to provide Nyquist filtering. There were two modes for the transmission of the averaged data. In the double-precision mode of operation, 16-bit samples of data were transmitted. This provided a maximum resolution of +/- 1/4 nT or 1/128 nT in the low-sensitivity and high-sensitivity ranges. Operation of this experiment was near nominal until spacecraft re-entry on September 26, 1987. Users of data from this experiment should be aware of the fact that the averaging of 12-bit samples to create 16-bit samples worked well in the spin plane, but in situations during which the field along the spin axis was quiet relative to the size of a digital window, the magnetometer returned only a 12-bit sample. This was particularly noticeable when the spacecraft was in the solar wind and the instrument was operated in its low gain (8192 nT) range, and when the spacecraft was in quiet regions of the magnetosphere in the low gain mode. The former situation limited the resolution of the field measured to 4 nT in the double precision mode in which the magnetometer usually was operated, and the latter situation created, as the spacecraft moved through the large gradient in the Earth's magnetic field, a stair step pattern of field changes of size 4 nT which may be mistaken for waves. Another operational anomaly was the saturation of a sensor during gain changes. At these times, the 3 components of the magnetic field were deduced from one spin tone and the field along the spin axis, limiting the temporal resolution of the instrument to below the spin frequency. Every effort was made to minimize zero level errors, clerical errors and other data processing anomalies within the available resources. However, these resources were very constrained and funding ceased before the entire submitted data set could be checked. It is expected that eventually quality checks of the entire database will be possible, but in the meantime, users of the ISEE 1 and 2 magnetometer data are requested to report all suspicions about data quality to the principal investigator, C. T. Russell, for verification.

Discipline(s)

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Space Physics: Heliospheric Studies
Space Physics: Magnetospheric Studies
```

Personnel Information

Data Set Information
Mission Information

NSSDC Space Physics page

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Last Updated: 2000-09-07
Output Generated: 2003-05-09
Programming by: Harold Felder(Harold.Felder@gsfc.nasa.gov)

NSSDC Master Catalog: Experiment

Plasma waves: electric & magnetic fields spectra (5.62Hz - 31 1 kHz)

NSSDC ID:1977-102B-5
Mission Name: ISEE 2
Principal Investigator: Prof. Donald A. Gurnett

Experiment mass: 3.4 kg
Average experiment power: 3.3 W

Description

In this experiment, a single-axis search coil magnetometer with a high permeability core and two electric field dipoles (30 m tip-to-tip and 0.61 m) measured wave phenomena occurring within the magnetosphere and solar wind in conjunction with a similar experiment (77-102A-07) flown on the mother spacecraft. The antennas were mounted perpendicularly to the spin axis. The instrumentation was composed of two elements: (1) a high-time-resolution spectrum analyzer with 16 frequency channels (identical to those on ISEE 1) from 5.62 Hz to 31.1 kHz where all channels were sampled 1 or 4 times per s, depending on bit rate; and (2) a wide-band receiver to condition electric and magnetic waveforms for transmission to the ground via the special-purpose analog transmitter. There were two basic frequency channels, from 10 Hz to 1 kHz and from 650 Hz to 10 kHz. In addition, the frequency range could be shifted by a frequency-conversion scheme to any of eight ranges up to 2.0 MHz.

Discipline(s)

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Space Physics: Heliospheric Studies
Space Physics: Magnetospheric Studies
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Personnel Information

Data Set Information
Mission Information

NSSDC Space Physics page

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Programming by: Harold Felder(Harold.Felder@gsfc.nasa.gov)

NSSDC Master Catalog: Experiment

Plasma (Total Electron) Density by Radio Techniques

NSSDC ID:1977-102B-6
Mission Name: ISEE 2
Principal Investigator: Dr. Christopher C. Harvey

Experiment mass: 1.58 kg
Average experiment power: 1.3 W

Description

The total electron content between the mother and daughter was obtained by measuring the phase delay introduced by the ambient plasma onto a wave of frequency about 683 kHz, transmitted from the mother (experiment -08) and received on the daughter. The phase was compared against a phase-coherent signal transmitted from the mother to the daughter by modulation onto a carrier of frequency high enough (272.5 MHz) to be unaffected by the ambient plasma.

Discipline(s)

```
Space Physics: Heliospheric Studies
Space Physics: Magnetospheric Studies
```

Personnel Information

Data Set Information
Mission Information

NSSDC Space Physics page

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Last Updated: 2000-09-07
Output Generated: 2003-05-09
Programming by: Harold Felder(Harold.Felder@gsfc.nasa.gov)

NSSDC Master Catalog: Experiment

Medium Energy Particles Instrument - distrib. fns., p > 24 keV, e > 20 keV

NSSDC ID:1977-102B-7
Mission Name: ISEE 2
Principal Investigator: Dr. Ehrhard Keppler

Experiment mass: 4.3 kg
Average experiment power: 5.5 W

Description

This experiment was designed to identify and to study plasma instabilities responsible for acceleration, source and loss mechanisms, and boundary and interface phenomena throughout the orbital range of the mother/daughter satellites. A proton telescope and an electron spectrometer were flown on each spacecraft to measure detailed energy spectra and angular distributions. These detectors used silicon, surface-barrier, totally depleted, solid-state devices of various thicknesses, areas, and configurations. Protons in 5 directions and 12 energy channels between 20 keV and 2 MeV and electrons in 5 directions and 12 energy channels between 20 keV and 300 keV (to 1.2 MeV for the 90-deg direction) were measured. Data were accumulated in up to 32 sectors per spin.

Discipline(s)

`Space Physics: Magnetospheric Studies`

Personnel Information

Data Set Information
Mission Information

NSSDC Space Physics page

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Last Updated: 2000-09-07
Output Generated: 2003-05-09
Programming by: Harold Felder(Harold.Felder@gsfc.nasa.gov)

Electron and Proton Fluxes in the Outer Magnetosphere (1.5-300 keV)

NSSDC ID:1977-102B-8
Mission Name: ISEE 2
Principal Investigator: Prof. Kinsey A. Anderson

Experiment mass: 4.1 kg
Average experiment power: 3.1 W

Description

This experiment was designed to determine, by using identical instrumentation on the mother/daughter spacecraft, the spatial extent, propagation velocity, and temporal behavior of a wide variety of particle phenomena. Electrons were measured at 2 and 6 keV and in two bands: 8 to 200 keV and 30 to 200 keV. Protons were measured at 2 and 6 KeV and in three bands: 8 to 200 keV, 30 to 200 keV, and 200 to 380 keV. The 30-keV threshold could be commanded to 15 or 60 keV. Identical instrumentation on each spacecraft consisted of a pair of surface-barrier, semiconductor-detector telescopes (one with a foil and one without a foil) and four fixed-voltage electrostatic analyzers (two for electrons and two for protons). Channel multipliers were used as detectors with the fixed-voltage analyzers. The telescopes had a viewing cone with a 40-deg half-angle, oriented at about 20 deg to the spin axis.

Discipline(s)

```
Space Physics: Heliospheric Studies
Space Physics: Magnetospheric Studies
```

Personnel Information

Data Set Information
Mission Information

NSSDC Space Physics page

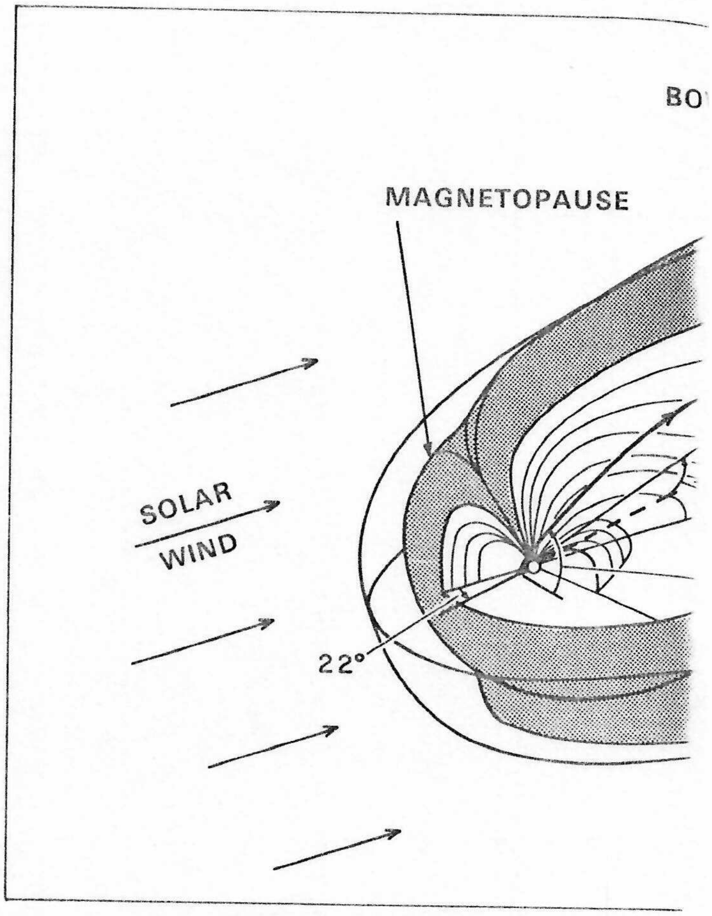
NSSDC home page

For questions about the NSSDC Master Catalog, please contact:

The International Sun-Earth Explorer (ISEE) Mission

A.C. Durney, Space Science Department of ESA, ESTEC, Noordwijk, The Netherlands

This large project has been mounted with the intention of solving many of the scientific mysteries that still remain in the near-earth space environment or 'magnetosphere'. The approximate positions of the magnetosphere's main features are known, but their natures are not necessarily understood (Fig. 1). The ISEE project has the novel ability to identify and to measure the speed of movement of these various features, and by so doing will be the first mission able to watch in detail how the magnetosphere reacts to solar changes.



WHY STUDY THE MAGNETOSPHERE?

The reasons for the study are many. We want to establish the exact interactions between particles and electric and magnetic waves in space, under conditions that cannot be reproduced in a laboratory. We want to know how auroral particles are accelerated, as this is a persistent mystery. We want to discover why about 10% of all solar particles manage to leak through the magnetospheric boundary – the magnetopause – that separates the earth's magnetic field from that of interplanetary space. We want to understand the complicated processes that occur in the magnetospheric 'tail', which extends for thousands of kilometres behind the earth (on the side away from the sun) like a comet's tail, the mechanisms that are at work in the space between the bow shock and the magnetopause, and many other interesting effects that relate to the magnetosphere. We also need to understand the magnetosphere as a whole because it is not unique; Jupiter and Mercury have magnetospheres too, and some exotic astrophysical objects (pulsars) may also possess them. Greater knowledge of our own magnetosphere will undoubtedly help us to understand these others more readily.

The magnetosphere is also important for life on earth, for it protects us from harmful radiation from interplanetary space. The ozone in the upper atmosphere, for example, shields the earth from extreme ultraviolet and x-rays, and there is already concern about how man's activities may affect that ozone content and hence life as we know it. Similarly, man's activities can be detected far out into space. Long power lines carrying megawatts of electricity produce waves that can be measured well out into the magnetosphere. It is known that magnetospheric storms can cause damage to power lines; could there be an equivalent effect in the opposite direction? Atomic bombs exploded at high altitudes have filled the inside of the magnetosphere with radiation that has stayed there for many years, another way of polluting the earth's environment. Recently, evidence has been mounting that short-term (days) disturbances on the sun affect our weather. Since these disturbances also cause large perturbations in the magnetosphere, there may well be a link between magnetospheric processes and the weather. The energy involved in such processes is much smaller than that

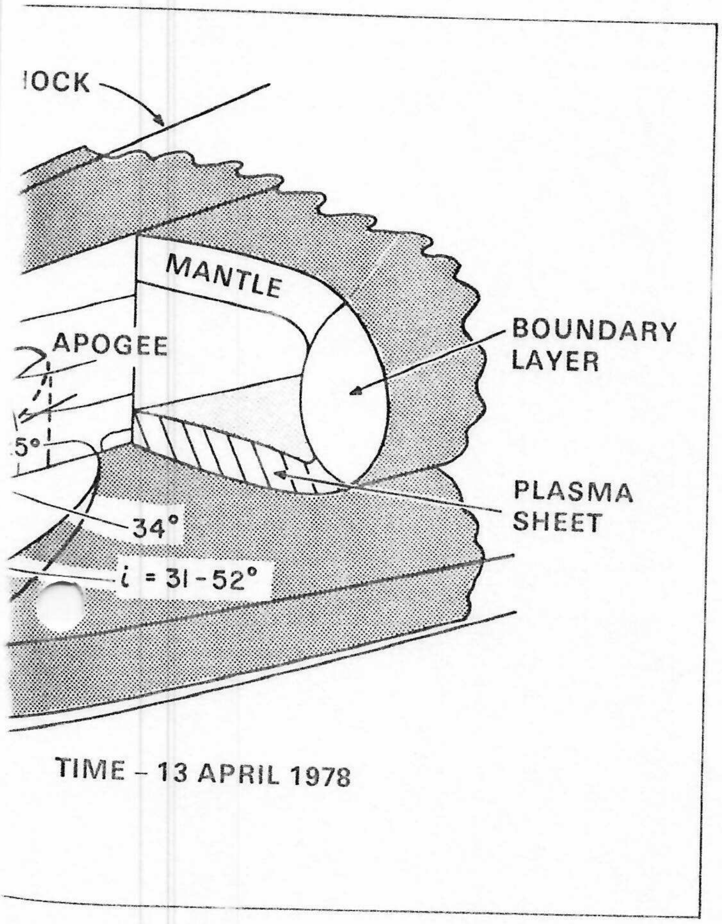


Figure 1 – Three-dimensional schematic of the earth's magnetosphere, showing the main features and the orbit of ISEE-A and B as it will be on 13 April 1978. The main features are places where there is a sharp boundary between different types of magnetic fields and/or particles. The most important of these are the 'magnetopause', which is the boundary between the interplanetary magnetic field and that of the earth, and the 'bow-shock', which is where the solar-wind particles (coming from the sun) first start to change direction because of the presence of the magnetosphere.

contained in the weather system, so that any link would have to be a delicate trigger effect.

To be able to assess the role of such effects in space, we need more exact measurements of the structure and movement of the magnetosphere than we have at present, and the ISEE mission should be able to provide these.

THE SPACECRAFT

The ISEE mission relies on three spacecraft, each of which has been designed for a three-year lifetime (Table 1). It is a joint project with NASA, which is responsible for the ISEE-A and ISEE-C spacecraft. ISEE-B has been supplied by ESA and is a new design, purpose-built for the mission.

ISEE-A and ISEE-B, which circulate in the magnetosphere to measure its perturbations, were launched as a stacked pair on a single Thor-Delta 2914, at 13.53 GMT on 22 October 1977, into the same highly elliptic orbit, with an apogee of 22.64 earth radii (138 000 km altitude) and a perigee of 287 km. The third spacecraft, ISEE-C, will be launched on 24 July 1978 and will be placed at a point 235 earth radii (1 500 000 km) from earth, on the line between the earth and the sun, where the gravitational forces of the two and centrifugal force balance. This point of equilibrium, called a libration or Lagrangian point, is shown in Figure 2. In this position, ISEE-C will be able to observe solar particles that 'boil' off from the sun as they stream past in the so-called 'solar wind' to impinge later on the magnetosphere. It is thought that variations in this wind give rise to many of the disturbances that occur in the magnetosphere. ISEE-C will detect the 'input conditions' for the disturbances to be monitored and measured by ISEE-A and ISEE-B.

TABLE 1
ISEE Spacecraft Parameters

	A	B	C
Structure	Modified IMP	New	Modified IMP
Spin rate, rpm	19.7	19.8	19.75
Mass, kg	340	157	469
Payload mass, kg	89.0	27.7	97 (incl. ant.)
Payload power, W	76	27	57
No. of experiments	13	8	12
Data rate, bps:			
high	16 384	8 192	2 048
low	4 096	2 048	1 024, 512, 64
Spin axis alignment	Perpendicular to the ecliptic plane		

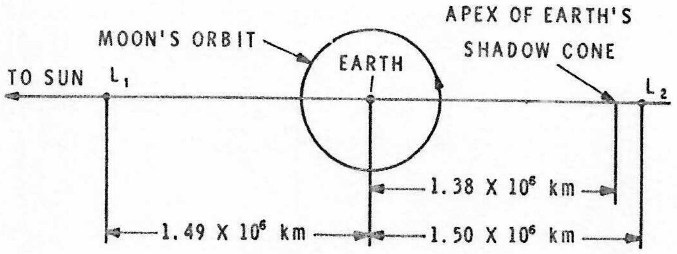


Figure 2 – Schematic of the libration points that lie near the earth on the earth-sun line. ISEE-C will be placed at L_1.

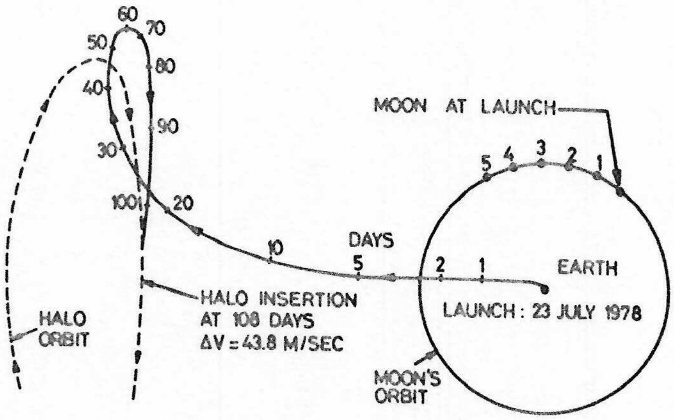


Figure 3 – The transfer orbit that will be used for injecting ISEE-C into its halo orbit.

SPATIAL AND TEMPORAL AMBIGUITIES

The near-earth environment is not static: almost all of the features that can be observed are constantly moving, swirling, contracting and expanding at speeds that often far exceed those of the spacecraft. Because of these movements, when a single spacecraft measures some change it is difficult to decide whether it was a real change in local conditions or was caused by a feature sweeping past. In addition, when a moving phenomenon is observed, its speed, and in many cases its direction of motion, cannot be ascertained.

This problem has beset single-spacecraft measurements since the first scientific satellite was launched and it is one of the main reasons why very many magnetospheric phenomena are still unexplained. Features are known to exist, but their nature is not understood. By following each other around the same orbit a known and controllable distance apart, ISEE-A and B will be able to determine whether a feature is static or in motion (and with what velocity). For the first time, it will be possible to separate and measure spatial and temporal variations in an organised manner, a manner that is expected to lead to the detailed understanding of the earth's environment that we lack at present.

SCIENCE AND THE ORBIT

The scientific aims of the ISEE mission shaped the orbit for the A and B spacecraft through three main demands:

1. The spacecraft must make a maximum number of crossings of the bow shock.
2. The axis of the orbit should allow bow-shock crossings to be made early in the mission to reduce the amount of bow-shock information lost in the event of early failure of a unit.
3. Crossings of the plasma sheet must be made.

To these scientific criteria were added a number of technical constraints:

4. The orbit must be stable enough to sustain a three-year lifetime.
5. The maximum eclipse time must be less than 6 h to prevent the spacecraft becoming too cold when not sunlit (during 'eclipses' when passing through the earth's shadow).
6. The solar aspect angle at injection should be between 70° and 160° to prevent the sun from overheating the spacecraft during launch.

The number of bow-shock crossings depends on the height of apogee. With a higher apogee, the orbit will intersect the bow shock for a longer period each year, tending to increase the number of crossings. But a higher apogee also means that the time the spacecraft takes to travel around the orbit will also increase, thus tending to reduce the number of crossings. The combination of these two effects creates a slow variation in the number of bow-shock crossings with apogee height, with a maximum for

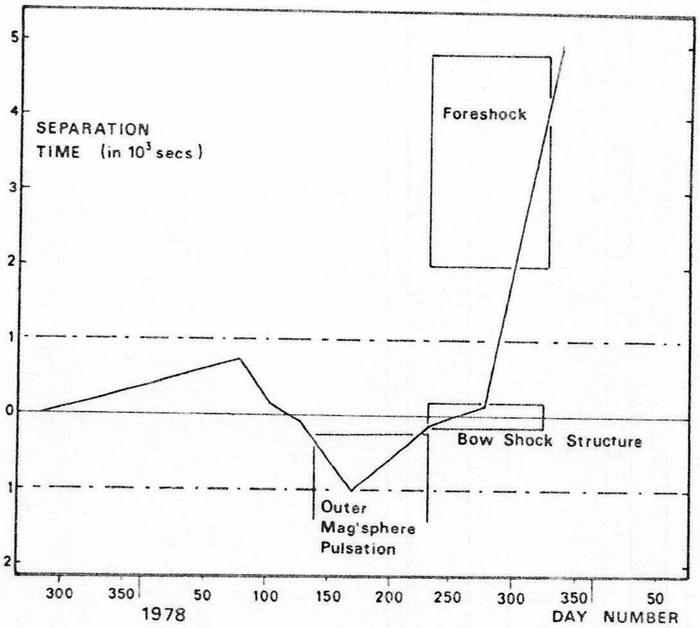


Figure 4 – The separation strategy adopted by the ISEE Science Working Team for the period up to the end of 1978. Separation time is used because it is more constant around an orbit than distance, which varies very considerably. Some areas are shown where significant measurements will be made.

an altitude of 23 earth radii (140 000 km altitude). This was the figure chosen by the investigators to satisfy condition 1. Combining it with the total mass of the two spacecraft and the performance of the launcher gave a perigee of 280 m, which was just acceptable (a lower perigee would make the orbit susceptible to air drag in the atmosphere, probably resulting in early re-entry).

Given this shape of orbit, it was difficult to find a launch time that would satisfy scientific conditions 2 and 3 whilst still giving the spacecraft a three-year lifetime and an eclipse time of less than 6 h. The calculation of these launch 'windows' is a highly complex business, involving many orbital parameters such as air drag, the fact that the earth is not exactly spherical, the gravitational pull of the moon, the pressure of solar radiation on the spacecraft (an appreciable effect), the earth's magnetic field, and so on.

Many hours of computer calculation were needed to determine a launch window that met all the conditions and it was eventually found that a stable orbit could be achieved if the spacecraft were launched on any day between 13 October and 5 November within a few minutes of 14.00 h GMT. Unfortunately, stability also demanded that the angle between the orbital plane and the earth's equatorial plane be increased on each successive day which meant that for a launch on or after 28 October the fixed directional antenna on ISEE-B would no longer point towards the earth and telemetry signals would not be received satisfactorily from high altitudes. The two spacecraft were, in fact, ready for launch on 13 October, but some problems with the launch vehicle delayed lift-off until 22 October, only five days before the closing of the window.

ISEE-C falls into a different orbital category, the scientific requirements here being:

1. that it should be positioned between the sun and earth where it can observe the passing solar-wind conditions that subsequently affect the magnetosphere, and
2. that it must be far enough away from the earth not to observe waves and/or particles generated by or reflected from the magnetosphere.

The chief problem in satisfying these demands was that the spacecraft would have needed a prohibitively heavy propulsion system to keep it on station, had not the clever solution of placing it at the Lagrangian point been adopted. As mentioned earlier, this point where the various interplanetary forces balance lies on the earth-sun line and is sufficiently far from the earth to satisfy condition (2). Although the equilibrium at this point is unstable, the amount of propulsion necessary to keep ISEE-C there is relatively small.

The second problem for ISEE-C was that the sun is an intense radio source and if the spacecraft were placed directly in front of it at the exact Lagrangian point the telemetry signals would be swamped. This difficulty has been overcome by making the spacecraft gyrate around the sun (as seen from the earth) in a so-called 'halo' orbit, the plane of which is to be adjusted from time to time to keep it normal to the earth-sun line.

ISEE-C will be launched as soon after ISEE-A and B as possible, namely in July 1978. The position of the moon is important for this launch as its attitude as seen from the spacecraft will be used to assess the trajectory correction that will probably be necessary as the spacecraft approaches the Lagrangian point. Figure 3 shows how ISEE-C will be put into its halo orbit, the launch window being 2 days per lunar month.

TABLE 2
The ISEE-A and ISEE-B Experiments

Instrument Title	Principal Investigator
Electrons and protons (A and B) Protons, 5 eV to 40 keV; electrons, 5 eV to 20 keV (high time resolution)	K.A. Anderson
Low-energy protons and electrons (A and B) 1 eV to 50 keV in 63 bands with 16% resolution and large solid angle	L.A. Frank
Plasma waves (A and B) Magnetic field: 10 Hz to 100 kHz (three axes, 16 channels; one axis only on B) Electric field: 10 Hz to 10 kHz (three axes, 12 channels). Sweep frequency spectrum analysis of electric field signals: 10 kHz to 200 kHz (128 steps)	D.A. Gurnett
Flux-gate magnetometer (A and B) $\pm 256\gamma$, ± 8192 (command); frequency response, 0 – 10 Hz	C.T. Russell
Fast plasma (A) Protons: 5 eV to 40 keV; electrons: 5 eV to 20 keV (high time resolution)	S.J. Bame
Plasma density (A) Resonance experiment on A, 0 to 350 kHz. Phase-related waves at 683 kHz and 272.5 MHz	C.C. Harvey
Very-low-frequency wave propagation (A) Reception from Siple transmitter	R.A. Helliwell
Direct-current electric field (A), 0.1 to 3200 Hz, nine steps	J.P. Heppner
Low-energy cosmic rays (A) Solar-wind iron: suprathermal, multiply charged ions ($Z \leqslant Q \leqslant 26$): 5 to 50 keV/nucleon; 0.05 to 20 MeV/nucleon; 0.05 to 6 MeV/nucleon; 5 keV/Q to 20 MeV/nucleon	D. Hovestadt
Energetic electrons (A) Protons, 25 keV to 2 MeV (8 channels); electrons, 25 keV to 1 MeV (8 channels) (B) Protons, 25 keV to 2 MeV (4 and 16 channels); electrons, 25 keV to 2 MeV (4 and 16 channels) Time-of-flight composition and angular scanning on A	D.J. Williams
Quasi-static electric fields (A), 0 to 5 mV/m; 0 to 12 Hz	F.S. Mozer
Fast electrons (A) 7 to 500 eV; 10 to 2000 eV; 105 to 7050 eV 7% FWHM resolution; 0.5 s time resolution	K.W. Ogilvie
Ion composition (A) 0 to 40 keV/Q; 1 to 138 atomic mass units and plasma density	R.D. Sharp
Solar-wind ion measurements (B) Ions, 50 eV/Q to 25 keV/Q; electrons, 35 eV to 7 keV	G. Moreno
Fast plasma (B) Ions, 50 eV to 40 keV; electrons, 5 eV to 20 keV	G. Paschmann

SEPARATION STRATEGY

The separation between ISEE-A and B can be varied from 50 to 5000 km to make it appropriate to the scale of the feature being studied. A gas (freon 14) propulsion system on ISEE-B is used for this purpose, because ISEE-B has lower inertias and is more nimble than ISEE-A. In practice, ISEE-B is given a 'kick' so that it drifts away from or towards the other spacecraft. The 'kick' takes the form of a series of small gas impulses synchronised with spacecraft rotation. The size of the 'kick', and thus the drift rate, can be adjusted by varying the number of impulses, which are given at perigee to maximise their effect and conserve gas. As the spacecraft is travelling too fast at perigee to receive commands, the number of impulses to be given must be loaded into a memory higher up in the orbit.

The separation strategy selected by the investigators for the first part of the mission (Fig. 4) is very cautious and intended to explore the capabilities of the system while still giving good science. It will be reviewed in mid-1978, when a bolder 12 month plan will be adopted based on the experience of the early months. Two recalibration periods are planned, next April/May and next August, when the A and B spacecraft will approach and pass each other. The second recalibration period is timed to coincide with the arrival of ISEE-C on station, so that correspondence between the instruments on all three spacecraft can be checked.

THE PAYLOAD

More than 100 investigators from 33 different institutes are involved in this heavily instrumented mission. Most of the magnetospheric scientific community are represented and the investigator list contains many well-respected names. After the initial choice of instruments, the

TABLE 3

The ISEE-C Experiments

Instrument Title	Principal Investigator
X-rays and electrons x-rays, 8 to 72 keV; electrons, 2 to 1000 keV	K.A. Anderson
Solar-wind plasma Ions, 150 eV to 7 keV, 4.2% FWHM; electrons, 5 eV to 2.5 keV, 10% FWHM Three-dimensional distribution function	S.J. Bame
High-energy cosmic rays Species H through Fe (resolution, 0.15 atomic mass unit, $1<Z<26$)	H.H. Heckman
Low-energy cosmic rays Particle composition; up to 20 MeV/nucleon	D. Hovestadt
Energetic protons Protons, 30 keV to 1.4 MeV; alpha-particles, 1.4 to 6 MeV	R.J. Hynds
Cosmic-ray electrons and nuclei Electrons, 5 to 400 MeV (DES); protons, 36 to 13 000 MeV (DES); 13 GeV (IES) Elements separated: helium-sulphur, 60 to 13 000 MeV/nucleon (DES); >13 GeV/nucleon (IES)	P. Meyer
Plasma composition 470 eV/Q to 10.5 keV/Q: M/Q 1.4 to 6.5; 3% FWHM resolution	K.W. Ogilvie
Plasma waves Magnetic field: 8 channels, 60-dB range, 20 Hz to 1 kHz Electric field: 16 channels, 80-dB range, 20 Hz to 100 kHz (continuous, no switching)	F.L. Scarf
Radio mapping Three-dimensional tracing of paths of type III bursts in band from 20 kHz to 3 MHz	J.L. Steinberg
Helium vector magnetometer Eight ranges (±4, ±14, ±42, ±640, ±4000, ±22 000, and ±140 000 γ); Frequency response 0 to 3 Hz with three bands (0.1 to 1, 1 to 3, and 3 to 10 Hz) for measurements of fluctuations parallel to the spacecraft spin axis	E.J. Smith
High-energy cosmic rays Ranges: $Z=3$ to 28 (Li to Ni); $A=6$ to 64 (^{6}Li to ^{64}Ni); energy = 2 to 200 MeV/nucleon Mass resolution: Li, 0.065 to 0.83 proton masses; Fe, 0.18 to 0.22 proton masses	E.C. Stone
Medium-energy cosmic rays Nuclei, $Z=1$, 0.5 to 4 MeV/nucleon (SPA) and 4 to 500 MeV/nucleon (MPA); $2\leqslant Z\leqslant 26$, 0.5 to 500 MeV/nucleon (MPA) Electrons, 0.7 to 0.2 and 0.3 to 12 MeV Isotopes, $Z=1$ and 2, 4 to 80 MeV/nucleon; $3\leqslant Z\leqslant 7$, 8 to 120 MeV/nucleon; $8\leqslant Z\leqslant 16$, 10 to 200 MeV/nucleon	T. von Rosenvinge
Ground-based solar studies Solar spectral observations	J.W. Wilcox

investigators of the chosen experiments were formed into a Scientific Working Team, with a mandate to make the mission cohesive, to fill any gaps, and generally to 'round off the corners' (Tables 2 & 3). The instruments have cost an average of 1 million dollars each, which gives a measure of their sophistication and complexity.

In order to use spacecraft separation to differentiate effectively between movements and intensity changes, the ISEE-A and B payloads have been carefully matched. ISEE-A carries 13 instruments, eight of which are similar or complementary to the eight carried on the smaller B spacecraft; some are identical.

The instruments on A and B can be divided roughly into three groups. First, there are those intended to measure both static and fluctuating electric and magnetic fields. The measurement of electric fields is a relatively new and important development in spacecraft technology, while magnetic-field measurements are important as a reference for all other observations since the various parts of the magnetosphere can be recognised by their magnetic signatures.

The second group of instruments measures particles. Such instruments are quite commonplace on satellites, but they do not generally form such a close-knit group as those on ISEE. Proton and electron measurements start at energies of 1 eV and extend all the way up to 2 000 000 eV for protons and 250 000 eV for electrons. Two different techniques are necessary to cover this wide range, and so two instruments measure the low energies and two the high energies. One pair of instruments concentrates on measuring the distribution of energies accurately, the other on measuring intensity changes with time. In addition, one instrument on each spacecraft is specially designed to make comprehensive measurements of solar-wind particles.

The third group are active instruments which transmit radio waves. Their purpose is to measure electron densities around the spacecraft. This is the only investigation in which there is contact between the two spacecraft in space, all other measurements being transmitted to the ground separately from each platform. Operation of these active experiments has to be time-shared with the field experiments, which are completely saturated during active transmissions. ISEE-A, being larger, contains more instruments than ISEE-B and the extra instruments have been chosen so that together they can measure very accurately the effect that magnetic and electric waves have on particle movements, and vice-versa. Finally, ISEE-A carries an instrument which will measure the energies and intensities of very high-energy ions (cosmic rays) for special comparison with some investigations on ISEE-C.

ISEE-C carries a similar package of wave and particle experiments for its measurements of the solar wind. It also carries a group of newly developed, highly sophisticated instruments which will make the first measurements of all the separate high-energy isotopes up to iron produced by the sun and other stars. These are important measurements in their own right.

ANALYSIS OF THE DATA

The purpose of any spacecraft is to gather data and their analysis forms the most important part of any mission. For ISEE, the crucial factor for mission success is inter-comparison of the data after or even before it has been digested by the separate experiment groups. Special 'pool' tapes carrying compressed results from most of the mission's experiments will be produced for ISEE-A/B and C and distributed to each investigator. They will form an index to which an investigator can refer when searching for interesting events to correlate with his own data. He can subsequently contact the appropriate principal investigator for accurate, high-resolution data.

In addition to comparison and correlation of data inside the Project, ISEE results must be compared with outside observations. This is especially important at present with the intensive collaboration between ground-based, balloon, rocket and satellite investigators in the programme that constitutes the 'International Magnetospheric Study' (IMS). ISEE-B and Geos, the time scales of which are shown in Figure 5 in relation to the duration of the IMS, form the major part of Europe's contribution to this Study.

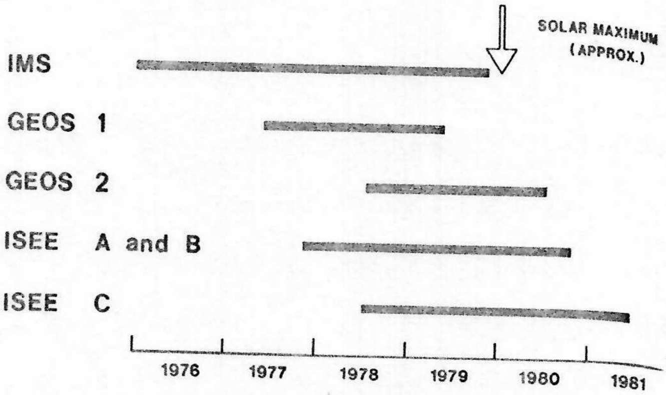


Figure 5 – Lifetime of the ISEE spacecraft in relation to those of the two Geos platforms and the duration of the International Magnetospheric Study.

The ISEE data pool tapes will be made available to any member of the IMS programme. Aside from this, a programme of ISEE workshops is being set up which will include collaborative meetings with Geos investigators and other members of the IMS. These could prove especially fruitful as Geos carries a similar experiment payload to ISEE-A and B and some investigators have instruments on both missions.

OPERATION OF THE SPACECRAFT IN ORBIT

At the time of writing, the switch-on of the spacecraft has barely been completed and no significant scientific data are available. Nevertheless, electric-wave movements have already been identified, ion-cyclotron resonances have been observed in unexpected places, and the magnetosphere has been found to be in a very compressed stage. There is general satisfaction with the data and excitement about the prospects. All experiments on ISEE-B are working well, and everything seems set for a highly exciting and successful mission. □

le tracé du faisceau, approximativement selon un facteur 10 (à savoir de 6 à 60 s).

L'exploitation quotidienne et le traitement des données à l'ESOC se déroulent sans incident après un certain nombre de changements de logiciel qui ont été rendus nécessaires eu égard aux difficultés rencontrées avec l'expérience S-331.

Les résultats fournis par Geos-1 et 2, qui sont présentés à chaque conférence importante sur la physique de la magnétosphère, sont maintenant publiés dans la littérature consacrée à cette discipline. Trois ateliers pour lesquels les données de Geos joueront un rôle important sont prévus pour une date ultérieure au cours de l'année.

Parmi les résultats nouveaux d'un grand intérêt fournis jusqu'ici par Geos-1 et 2, on peut citer la première observation dans l'espace de résonances fq (ondes électrostatiques d'une vitesse du groupe zéro), la découverte, par instants, de concentrations inattendues d'ions très lourds (des concentrations d'ions He pouvant atteindre 60% de la population totale ont été observées conjointement avec l'apparition d'harmoniques de la fréquence cyclotron de He) et l'identification d'une population stable de particules près de l'équateur géomagnétique avec des angles d'attaque voisins de 90° (distributions en galette). En outre, des distributions de particules et des configurations de champ intéressantes, mais jusqu'ici inexpliquées, ont été observées par instants lorsque l'orbite de l'un des deux satellites était presque tangente à la magnétopause.

ISEE

La mission continue de se dérouler normalement. Toutefois, comme dans toutes les missions, quelques difficultés sont apparues.

ISEE-3 fonctionne maintenant depuis un an. Des difficultés ont été rencontrées dans les mesures tridimentionnelles de l'instrument consacré au plasma énergétique, une défaillance de circuit intégré dans l'un des spectromètres pour particules énergétiques ayant considérablement réduit la résolution et le débit de données et l'autre spectromètre ayant son indicateur de situation bloqué et une résolution légèrement réduite à gain élevé. Sur ISEE-1, lancé avec ISEE-2 en octobre 1977, la défaillance d'un détecteur de l'instrument pour l'étude des rayons cosmiques a réduit les mesures à deux dimensions et la dégradation des performances du multiplicateur de l'instrument d'étude du plasma énergétique a mis celui-ci complètement hors d'action. Aucune défaillance d'instrument n'a été enregistrée sur ISEE-2 depuis le dernier rapport.

Les batteries d'accumulateurs de ISEE-1 et ISEE-2 ont vu leurs performances dégradées de façon presque identique. La batterie d'ISEE-2 a été débranchée pour éviter une explosion. Les deux batteries n'ont été prévues que pour mettre à feu les dispositifs pyrotechniques, de sorte que les incidences sur la mission sont négligeables. Il est apparu que les difficultés rencontrées avec un détecteur d'orientation étaient dues à des oscillations du bras en aiguille; le problème a été résolu par une petite modification du logiciel.

Les chercheurs de l'équipe scientifique ont récemment demandé de faibles écarts entre les véhicules spatiaux, l'alignement des orbites, des mesures perpendiculairement aux axes de rotation et une prolongation de la mission pour couvrir l'intervalle de temps séparant ISEE et OPEN – (OPEN: mission multisatellite proposée par la NASA pour l'étude de l'origine des plasmas dans le voisinage de la Terre).

Les documents sur ISEE publiés à ce jour dépassent largement le nombre de 100 et se situent au premier rang dans les assemblées internationales consacrées à ce domaine scientifique. Plusieurs ateliers très utiles ont été organisés et l'on s'attend à une contribution majeure d'ISEE au symposium IMS qui doit avoir lieu en décembre prochain.

IUE

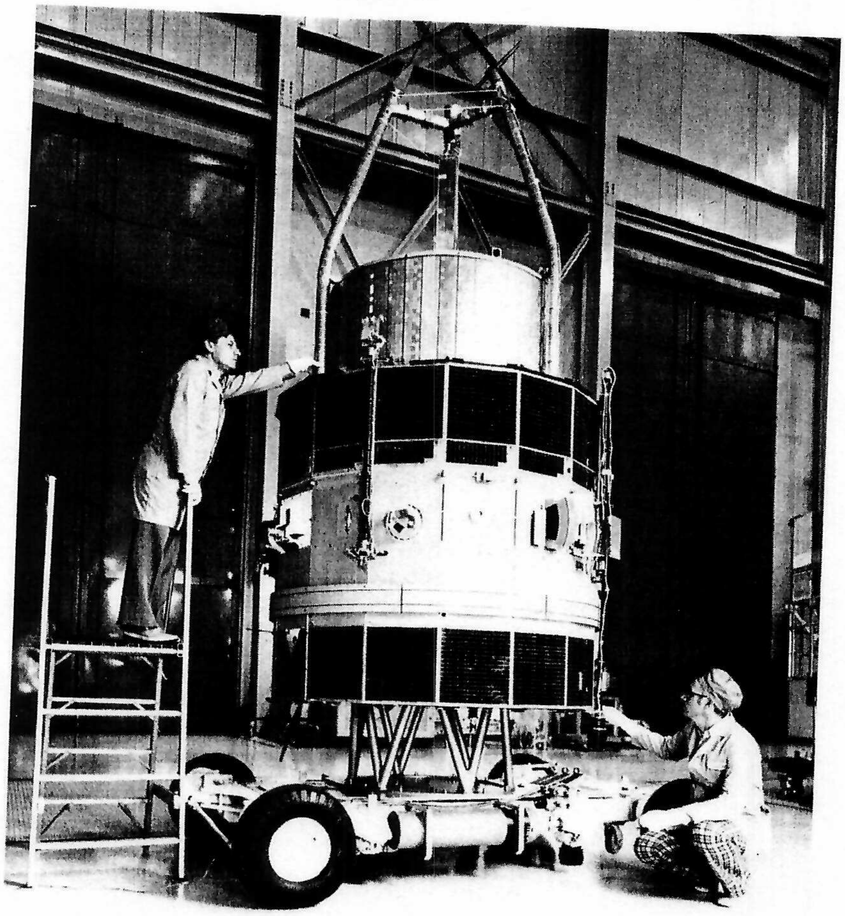
Engagé désormais dans sa seconde année d'opérations, IUE est en bonne voie avec son programme d'activités complet jusqu'à avril 1980. Son rendement opérationnel continue à croître depuis que des experts de la NASA et du Conseil britannique de la Recherche scientifique (SRC), en collaboration avec du personnel de l'ESA, on consacré, à la Station de Vilspa, un certain temps à optimiser encore davantage le fonctionnement de la chambre. Ceci s'est traduit par un total mensuel record de 252 images en juillet.

Des statistiques récentes montrent comment est constituée l'importante communauté des utilisateurs du temps d'observation réservé à l'ESA au cours des deux premières années.

On a constaté qu'un problème de fonction de transfert d'intensité (il s'agit d'un équipement réalisé par la NASA mais utilisé également par l'ESA) a affecté la chambre de prises de vues ondes courtes. Il s'ensuit que les images ondes courtes traitées à la Vilspa entre juin 1978 et juillet 1979 comporteront des erreurs photométriques. Dans l'ensemble ces

Répartition des chercheurs utilisant IUE au cours des deux premières années d'opération.

Pays	Chercheurs principaux	Chercheurs associés	Total
Italie	22	45	67
Allemagne	14	34	48
Suisse (ESRO compris)	12	6	18
France	10	38	48
Pays-Bas	9	5	14
ESA	1	8	9
Belgique	7	–	7
Suède	4	8	12
Espagne	2	5	7
Autriche	2	1	3
Pologne	1	3	4
Danemark	1	1	2
Argentine	1	–	1
Royaume-Uni	–	10	10
Australie	–	2	2
Iran	–	1	1
Chili	–	1	1
Total	86	168	254



ESA's ISEE-B is mounted atop NASA's ISEE-A for vibration tests prior to launch.

INTERNATIONAL SUN EARTH EXPLORER

ISEE 1 & 2

SPACECRAFT DESCRIPTION

The International Sun Earth Explorer (ISEE-1) is a 16-sided polyhedron measuring approximately 1.73 meters across and 1.61 meters high. Its main body consists of an 84-centimeter conical center tube. The lower end of the center tube mates with the launch vehicle and the upper end with the ISEE-2.

ISEE-2 is a cylinder with a diameter of 1.27 meters and a height of 1.14 meters. Solar cells are mounted on these detachable curved panels.

PROJECT OBEJCTIVES

Measurements by instruments on the pair of spacecraft will permit ambiguities associated with the motion of near-Earth space boundaries to be resolved.

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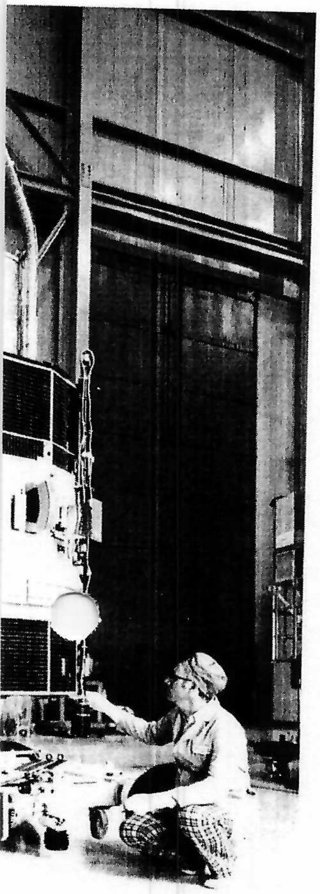

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PAYLOAD

Use of two spacecraft, separated by a variable distance, allows scientists to study the boundaries in near-Earth space and the nature of their fluctuation. These include plasma pause (the position at which there is a dramatic drop in the density of the magnetosphere, which is the magnetic envelope surrounding the Earth); the magnetopause, where the magnetic field of the Earth meets that of the solar wind; the bow shock, a sort of bow wave created by the motion of the solar wind past the Earth; and several less obvious features of the Earth's magnetic tail.

RESULTS

ISEE 1 and 2 were successfully launched on October 22, 1977 from the Kennedy Space Center, Florida. ISEE-1's orbit is 138,124 by 280.1 kilometers, inclined at 28.73 degrees and with a period of 57 hours and 26.8 minutes. ISEE-2 is in a similar orbit — 138,300 by 279.4 kilometers and 28.6 degrees.

LAUNCH VEHICLE

Delta 2914 (see NATO III Launch Vehicle Description).

MAJOR PARTICIPANTS

ISEE-1 is a NASA Goddard Space Center designed spacecraft, built, fabricated, and tested at Goddard with all of its components made either at Goddard or supplied by industries or universities. ISEE-2 is an ESA — European Space Technology Center satellite design. The STAR consortium of 10 countries supervised construction under contract to ESA. STAR consists of industries in Belgium, Denmark, France, Spain, Germany, Italy, the Netherlands, Sweden, Switzerland, and the United Kingdom. Dornier Systems in Germany headed the contractor team.

Goddard directs the Delta rocket program for NASA's Office of Space Flight and McDonnell-Douglas Astronautics Co., Huntington Beach, California, is the prime contractor.

NATO III

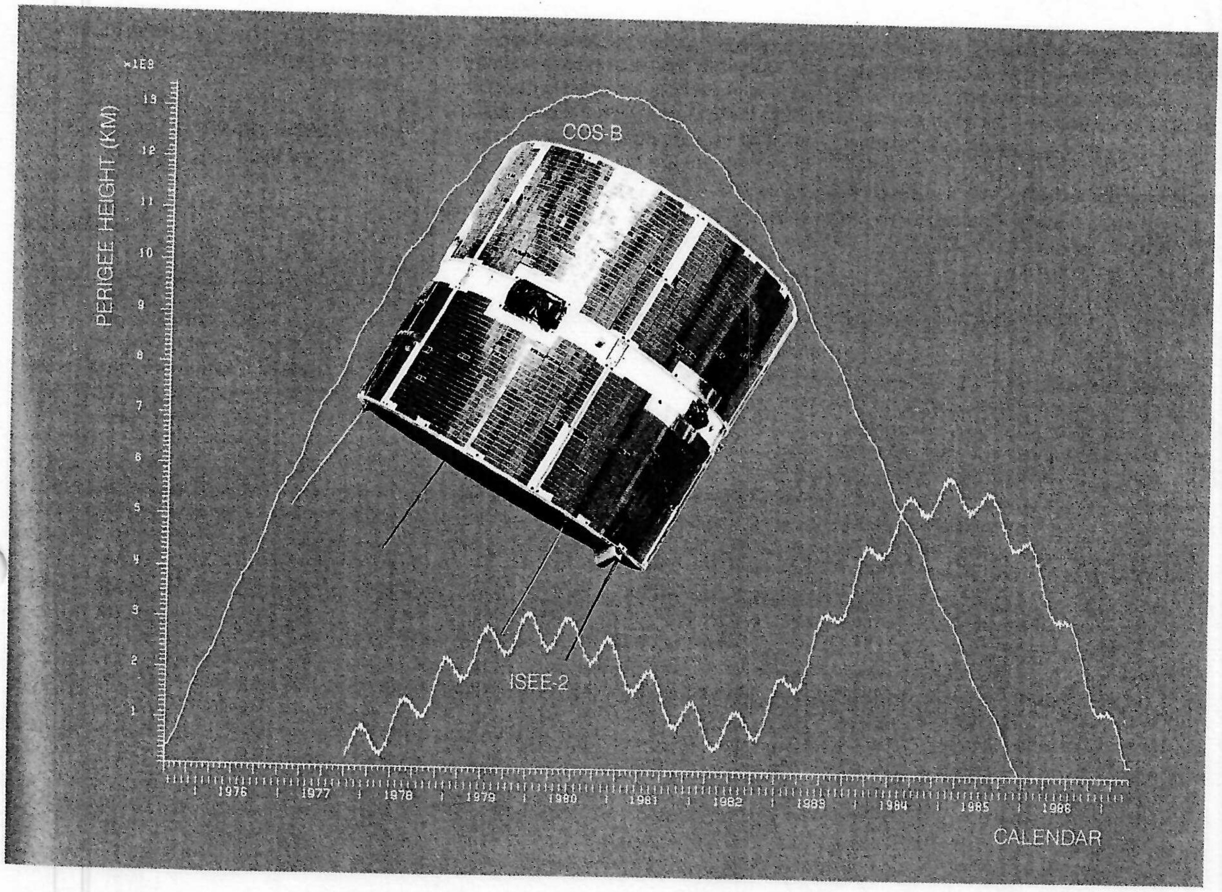
This third-generation spacecraft series provides communications services for North Atlantic Treaty Organization alliance countries — Belgium, Canada, Denmark, England, Germany, Iceland, Italy, Luxembourg, The Netherlands, Norway, Portugal, Turkey and the United States. NATO IIIA, launched in April 1976, is in service over the Atlantic. NATO IIIB is described below. A third spacecraft is being prepared for launch in 1978.

NATO IIIB

SPACECRAFT DESCRIPTION — Drum-shaped, the NATO IIIB is about 2.2 meters (86-inches) in diameter, 2.23 meters (88-inches) long, with an overall length of 3.1 meters (122-inches), including antennas. At launch it weighed 720 kg (1,528-;bs.) and after firing its onboard apogee kick motor to place it in stationary orbit, the weight reduced to 376 kg (830 lbs.) Design life of NATO IIIB is expected to be seven years.

PROJECT OBJECTIVES — Offering considerably more power than the two NATO II satellites already in operation, NATO III provides real-time communication for the nations of the NATO military alliance. The NATO Satcom System Control Center in Belgium near Supreme Headquarters, Allied Powers,

Figure 2 — Perigee histories of Cos-B and ISEE-2



and often unpredictable variations due to solar activity. At an altitude of 240 km, for example, it can vary by a factor of 3; at 500 km altitude, this factor can reach more than 20! Consequently, estimation of the air-drag perturbation is a difficult problem and the re-entry predictions for near-Earth satellites are subject to large inaccuracies, sometimes of several years, as was the case for Skylab. Even with the most sophisticated prediction methods, lifetime estimates for near-Earth satellites are accurate to only 10% at best.

The last phase of a re-entry

When a satellite decays and begins to enter the Earth's dense atmosphere, it experiences an increasing amount of drag, leading to a gradual reduction in its horizontal forward velocity. The point at which the satellite begins this deceleration phase is called the 're-entry point'. For most satellites, the re-entry point is about 130 km above the Earth's surface.

This deceleration phase is illustrated in Figure 3 for the ESRO satellite HEOS-A1. During the descent from a height of 100 km to 60 km, the satellite experiences a very high deceleration and consequently also a high heat loading. It is therefore during this period that the satellite is most likely to disintegrate and burn up. Any remaining debris will follow individual paths, depending on its cross-section to mass ratio.

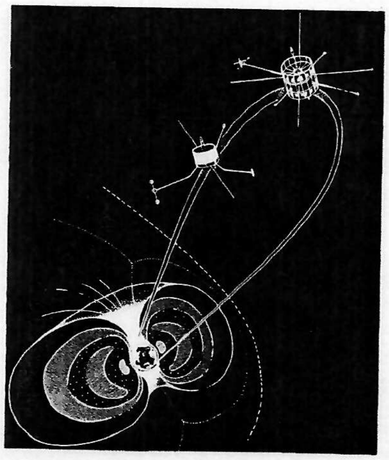
Lifetime estimation for satellites and associated launch items

A list of all ESRO/ESA objects that have been put into space is given in Table 1, which indicates the situation on 1 November 1985. Such a table is updated at ESOC at regular intervals.

The satellite orbital element data are obtained from the latest orbit-determination results for satellites operated by ESOC, and from the NASA Prediction Bulletin for the other objects.

Satellites in geostationary orbits can have very long lifetimes, of the order of 10 million years. Geostationary satellites such as Meteosat-1 which has completed its mission, are no longer controlled and do not remain geostationary because they are subject to a periodic drift in longitude and a change in orbital inclination.

In order to reduce the number of 'dead' objects sited along the geostationary ring,



The International Sun-Earth Explorer Satellites — Ten Years of Operations and Science

A. Pedersen, Planetary and Space Science Division,
ESA Space Science Department,
ESTEC, Noordwijk, The Netherlands

As early as the late nineteen sixties, scientists in Europe and the USA were discussing plans for a pair of spacecraft that would follow each other in the same orbit, a controllable distance apart, through regions of the Earth's magnetosphere. The aim was to be able to disentangle varations in space from variations in time in a system that expands, shrinks and changes topology sometimes in a matter of minutes.

The ISEE-1 spacecraft, developed by NASA, and ISEE-2, developed by ESA, were launched together by the same launch vehicle on 22 October 1977. The third spacecraft of the trio, ISEE-3, was launched less than one year later and placed in an orbit around the sunward Lagrangian point, 235 Earth radii sunward of our planet. There it was to provide reference measurements in the solar wind that would later impinge on the Earth's magnetosphere where ISEE-1 and ISEE-2 were orbiting.

European scientists have been involved in experiments on all three ISEE spacecraft, and the overall programme has been an outstanding success both operationally and in terms of the scientific results derived by the combined European and American scientific communities.

ISEE-3 has been exploited for two spectacular additional programmes that were not foreseen in the original plans. In mid-1982, this spacecraft was moved from its original position at the sunward Lagrangian point, and directed into a series of orbits in the Earth's extended, tail-like magnetosphere, taking it out to more than 200 Earth radii. Then, towards the end of 1983, ISEE-3 was dispatched, via a lunar gravity-assist manoeuvre, on a trajectory to rendezvous with Comet Giacobini-Zinner. This encounter took place in September 1985.

On 26 September 1987, ISEE-1 and ISEE-2 re-entered the atmosphere as predicted. This of course marked the end of operations, but the scientific results that they have provided will be analysed for several years to come.

This article briefly reviews the main results obtained so far from the three ISEE spacecraft.

Historical background

Between 1960 and 1970, spacecraft launched by the USA and the USSR had crossed the boundaries of the Earth's magnetic field and observed the charged-particle population trapped there. They had also explored the solar wind, a stream of ions and electrons moving radially outwards from the Sun with velocities of several hundred kilometres per second.

It became clear from these early results that the Earth's magnetic field assumes a comet-tail-like form under the influence of the solar wind. Given this exploratory knowledge of solar-terrestrial physics, further questions quickly arose about the physical processes involved and the mechanisms controlling the Earth's magnetosphere. The interaction between the solar wind and the Earth provides, it was decided, an unique opportunity to study, at close quarters, the fundamental processes that are at work both in the neighbourhood of the planets and comets in our own solar system and near other planetary systems in the Universe also.

The early years of space research had created an awareness of the space environment that was to prove extremely useful to the designers of the ISEE spacecraft. One of the first major discoveries had been the existence of the Van Allen radiation belts, shells of energetic electrons and ions trapped and mirroring within the Earth's magnetic field at a distance of a few Earth radii. This discovery led to the need to adopt protective measures for spacecraft solar cells as well as for the electronic components on board.

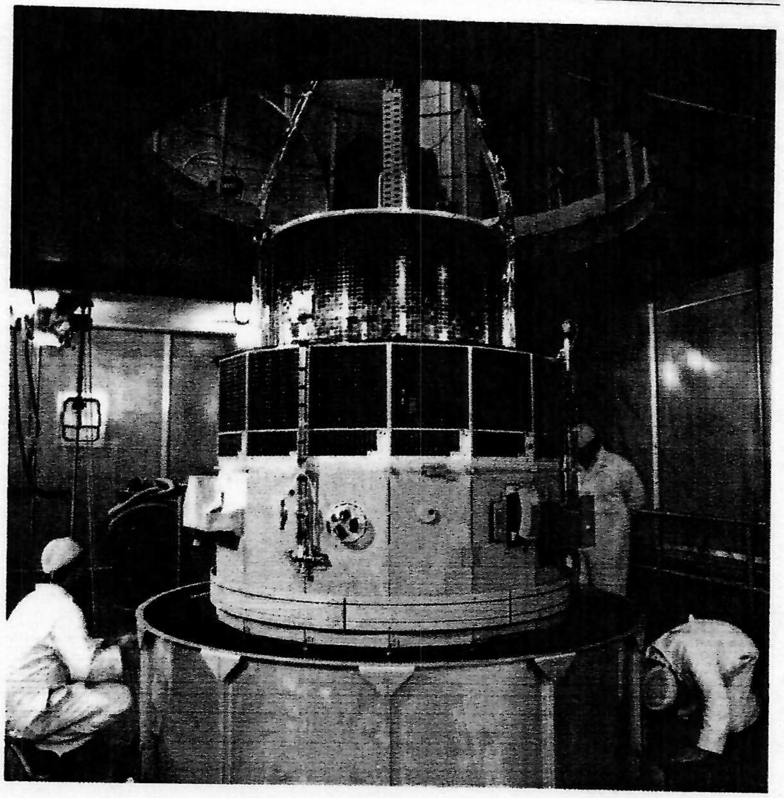
At the time of planning the ISEE mission, the European space-science community had gained considerable experience with the ESRO-I, ESRO-II and Heos

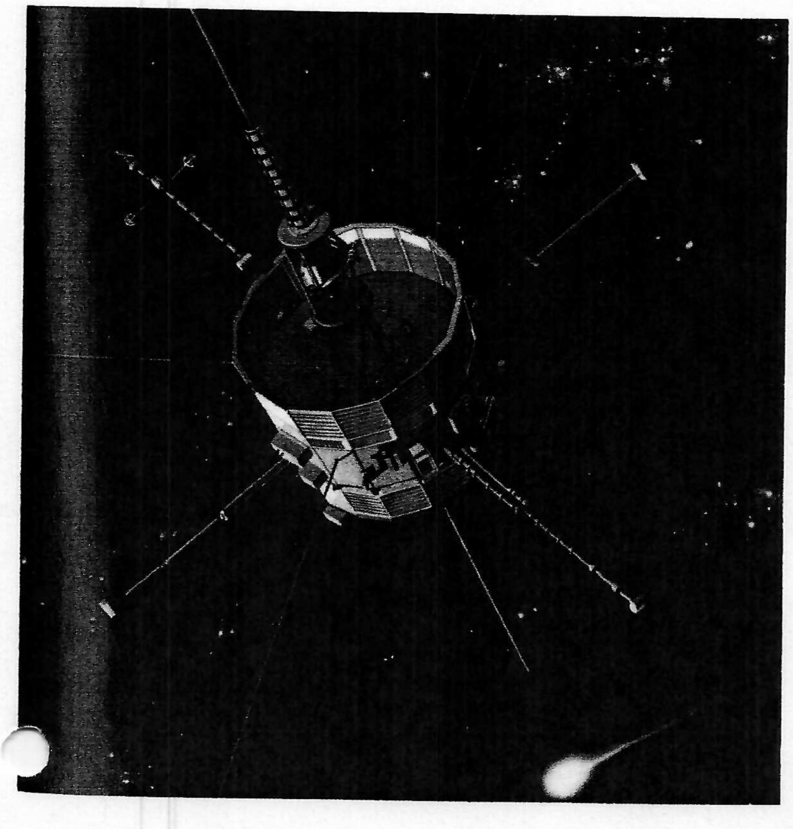
Figure 1 — The ISEE-1 and 2 spacecraft pair

Figure 2 — The ISEE-3 spacecraft, which served first as a solar-wind monitor, later as a magnetotail explorer, and finally as a cometary explorer (rendezvous with Comet Giacobini-Zinner in September 1985)

spacecraft. Together with their American colleagues, they began a strong lobby, on both sides of the Atlantic, for the launching of a mission that would put two spacecraft (ISEE-1 and ISEE-2) into the same elliptic orbit, with an adjustable separation between the two. This would allow the observation of moving boundaries by both spacecraft, and thereby allow the velocities of these boundaries to be determined.

The rationale for the launch of a third spacecraft (ISEE-3) was that it would provide a reference for the two magnetospheric spacecraft and also furnish long, uninterrupted measurements of the solar wind, if it were stationed near sunward Lagrangian point, 235 Earth ii (R_E) from our planet.





The Council of ESRO (ESA's forerunner) approved the joint ESRO—NASA ISEE programme in the spring of 1973, with ESRO being responsible for the development of the ISEE-2 spacecraft.

The spacecraft and their scientific instruments

Although, due to the limited finances available, there was a need to strive more for financial restraint than technical sophistication, each of the three spacecraft that finally flew had a number of features worth recalling (Figs. 1,2).

All had conductive surfaces to render the complete spacecraft uniformly charged, an important feature for the measurements that were to be made of low-energy particles and electric fields with boom-mounted probes. All three spacecraft carried radial wire antennas for electric-field measurements, these antennas being kept deployed by centrifugal force. The longest was on ISEE-1, extending 215 m tip-to-tip. ISEE-1 also carried two spherical electric-field sensors, 72 m apart, on radial booms.

ISEE-2, the smaller of the ISEE-1/ISEE-2 pair of spacecraft, was assigned the task of controlling its separation relative to ISEE-1, by use of a freon cold-gas system. Figure 3 shows how the separation varied over the orbit. Typical separations near 10 R_E in the central part of the orbit were actively controlled to be in the range of a few hundred to a few thousand kilometres.

This orbit-control system functioned perfectly during its almost ten years of operation. It was, however, necessary to adopt a careful and inventive manoeuvring stategy towards the end of the unexpectedly long mission, because ISEE-2's gas supply was by then running very low.

The scientific instruments carried by the three ISEE spacecraft and the groups responsible for them are shown in Table 1. The instruments were of a 'new generation', based on the experience of the first decade of embarking scientific experiments on spacecraft launched into the Earth's magnetosphere. It can be

Table 1 — Scientific experiments on the ISEE-1, 2 and 3 spacecraft

Experiments	Spacecraft	Principal investigator	Affiliation	European collaborating institute
Electrons, protons	ISEE-1, ISEE-2	K.A. Anderson	Univ. Cal. Berkeley	Toulouse
Electrons, protons	,,	L.A. Frank	Univ. Iowa	
High-energy particles	,,	D.J. Williams/ E. Keppler	APL Maryland/ MPAe Lindau	Univ. Kiel
Magnetometer	,,	C.T. Russell	Univ. California Los Angeles	Imp. College London
Plasma waves	,,	D. Gurnett	Univ. Iowa	
Electron density	,,	C.C. Harvey	Meudon	CNET Issy les Moulineaux
Fast Plasma	ISEE-1	S. Bame	Los Alamos	MPI Garching
Electric fields	,,	J. Heppner	NASA/GSFC	
Electric fields	,,	F.S. Mozer	Univ. Cal. Berkeley	RIT Stockholm/ SSD ESTEC
Radio receiver	,,	R.A. Helliwell	Stanford Univ.	
Fast electrons	,,	K.W. Ogilvie	NASA/GSFC	
Ion composition	,,	R.D. Sharp	Lockheed	Univ. Berne
Cosmic rays	,,	D. Hovestadt	MPI Garching	
Solar-wind ions	ISEE-2	V. Formisano	CNR Rome	
Fast plasma	,,	G. Paschmann	MPI Garching	
X-rays, electrons	ISEE-3	K.A. Anderson	Univ. Cal. Berkeley	
Solar wind	,,	S.J. Bame	Los Alamos	
High en. cosmic rays	,,	M. Wiedenbeck	Univ. Chicago	
Low en. cosmic rays	,,	D. Hovestadt	MPI Garching	
Cosmic rays	,,	P. Meyer	Univ. Chicago	
Energetic protons	,,	R.J. Hynds	Imp. College London	SRC Utrecht, SSD ESTEC.
Ion composition	,,	K.W. Ogilvie	NASA/GSFC	Univ. Berne
Plasma waves	,,	F.L. Scarf	TRW Los Angeles	
Radio mapping	,,	J.L. Steinberg	Meudon	
Magnetometer	,,	E.J. Smith	JPL Pasadena	
High en. cosmic rays	,,	E.C. Stone	Cal. Inst. Tech.	
Cosmic rays	,,	T. von Rosenving	NASA/GSFC	

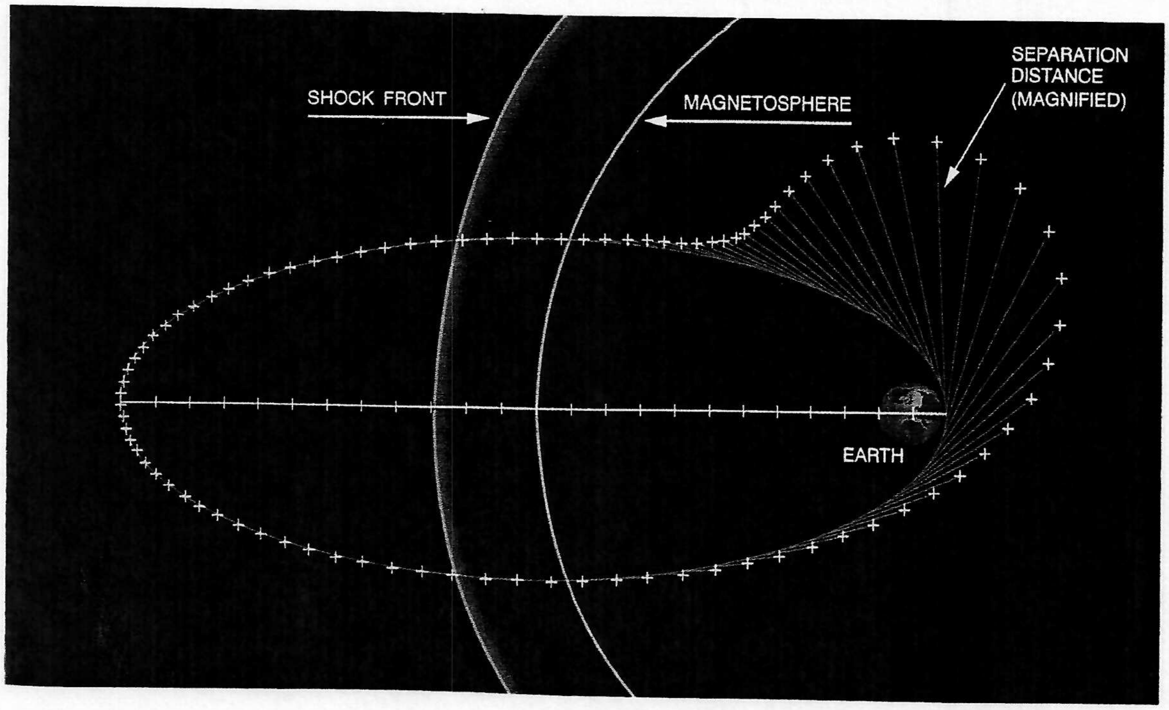


Figure 3 — The orbit of ISEE-1 and 2, showing the average front-side magnetospheric boundaries, and the variation in separation of the two spacecraft over the orbit (illustrated by distance vectors)

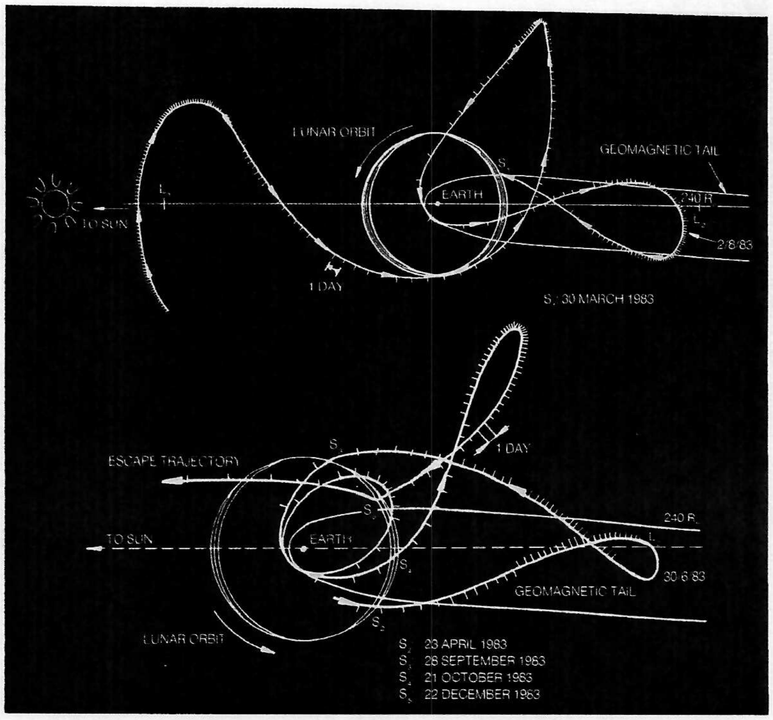


Figure 4 — The orbits of ISEE-3, taking it first to the sunward libration point, and then into multiple orbits in the magnetotail and finally on a trajectory to Comet Giacobini-Zinner

seen from the table that European groups were involved in all three ISEE spacecraft as 'Principal Investigators'. In several of the other experiments, European scientists were involved as 'Co-Investigators'.

The operations
The ISEE-1/ISEE-2 spacecraft combination was lauched successfully on 22 October 1977 and the two satellites started an active observation programme shortly afterwards, in an orbit crossing the front side of the magnetosphere (Fig. 3). The annual precession of that orbit took the two spacecraft through many different regions of the magnetosphere during their ten years of ations, until their re-entry on 26 ember 1987.

ISEE-3 was launched in August 1978 and reached its final position at the sunward Lagrangian point in early 1979, after a long cruise phase. There it remained until mid-1982, when it was dispatched into a number of orbits in the distant tail of the Earth's magnetosphere by means of several lunar gravity-assist manoeuvres (Fig. 4).

The most spectacular of these orbital manoeuvres took place on 22 December 1983, when ISEE-3 passed within 100 km of the lunar surface and was sent on to rendezvous with Comet Giacobini-Zinner. The ISEE-3 spacecraft, renamed the International Cometary Explorer (ICE) in honour of this mission, passed the comet on 11 September 1985 (see ESA Bulletin No. 44, pp. 32—39).

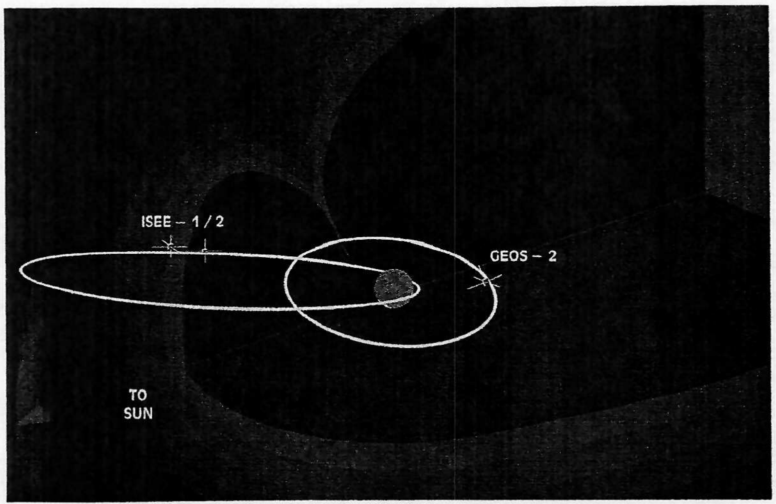
The main scientific results
Results from the orbital acrobatics of ISEE-3 in the Earth's magnetotail, and the passage of this spacecraft near Comet Giacobini-Zinner, have led to a number of recent publications, including two articles in earlier issues of the ESA Bulletin (No. 37, February 1984 and No. 44, November 5).

We will restrict ourselves here to a summary of the main scientific results from the ISEE-1/ISEE-2 combination, mentioning ISEE-3 only in the cases where its results were coordinated with those of the other two spacecraft.

The Earth's magnetic field and the plasma that it constrains form an obstacle to the solar wind, which flows around it with variable speeds and charged-particle densities. Consequently, the solar wind compresses the magnetosphere, as sketched in Figure 5.

The first magnetospheric 'boundary' is the bow shock, where the solar wind meets the Earth's magnetosphere as an obstacle via waves transmitted from the magnetopause, which represents the transition from solar wind to terrestrial magnetic fields. The two ISEE spacecraft have made it possible to conclude that these boundaries are surprisingly thin, being of the order of only 1/100th of the cross-section of the magnetosphere, and that they move and oscillate with velocities varying from 10 to more than 100 km/s. Part of the energy of the solar wind impinging on the bow shock is transformed into electromagnetic energy, i.e. currents and magnetic stresses. At the magnetopause, the opposite type of energy conversion, from electromagnetic to kinetic, occurs.

This acceleration of ions and electrons by electric and magnetic forces is a fundamental process in our Universe, and the ISEE spacecraft have made it possible to understand it more clearly. It has also become apparent, however, that such acceleration processes do not occur smoothly over the boundaries. There is a general tendency for explosive or hot magnetic field lines to occur, often intertwined between magnetospheric regions, next to quieter ones. These 'magnetic flux tubes' are often less than



5a

5b

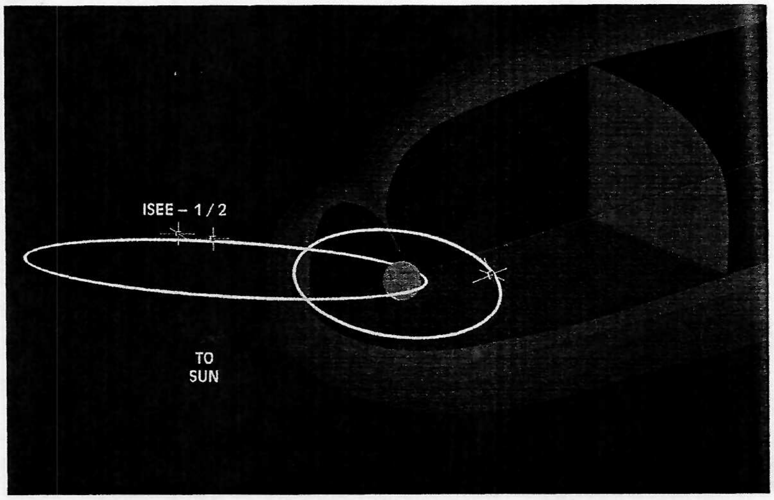


Figure 5 — The solar wind sometimes compresses the magnetosphere in such a way that the magnetopause is near the geostationary orbit. On other occasions, the magnetopause has been observed near the apogee of ISEE-1 and 2

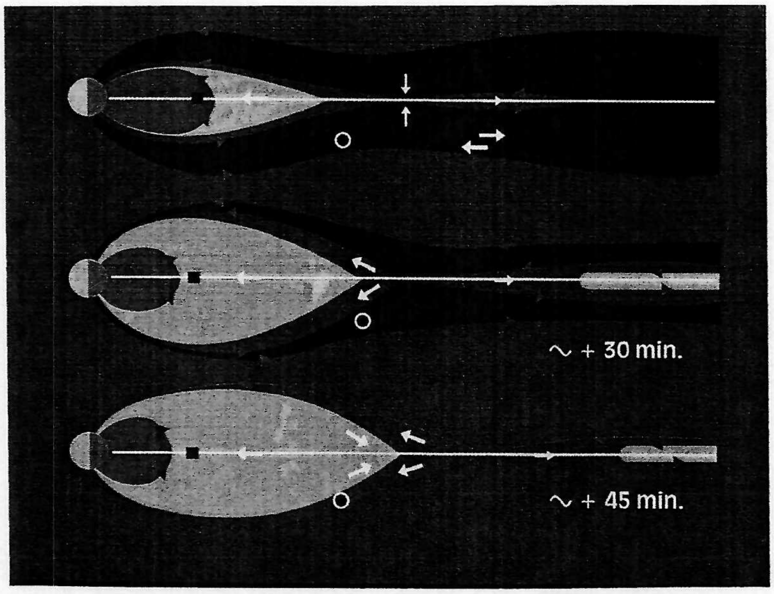


Figure 6 — A magnetic storm manifests itself as auroral light emissions due to precipitation of ions and electrons. It is probably triggered by a release of magnetic energy in the magnetotail

100 km across, which means that they pass a single spacecraft in just 10 s if the structure is moving at 10 km/s. This problem will be addressed by the next generation of magnetospheric spacecraft, within the Agency's Cluster project, which will study such phenomena by means of four spacecraft flying in a three-dimensional configuration.

Some of the solar-wind ions and electrons that hit the Earth's bow shock are reflected and accelerated back towards the Sun. At times, more than 1% of the solar wind is turned around and accelerated and ISEE-3, more than 200 R_E sunward, observed these particles. The Earth can therefore be seen as a source of energetic ions and electrons, rather like a small-scale analogy of the distant stellar systems that spread the cosmic rays detected on Earth.

The instruments on ISEE-1/2 were well suited for measurements of the total ion density, composition and energy distribution. Data from these spacecraft confirmed and extended much earlier data from the Agency's Geos-1 and Geos-2 spacecraft, which had shown that the magnetospheric cavity is to a large extent filled with low-energy ions (1 eV) originating in the Earth's atmosphere. It also appears that the density of terrestrial ions is much higher than would result from the expected escape of ions from the top of the atmosphere. There is therefore obviously an active mechanism pumping terrestrial ions (and accompanying electrons) into the magnetosphere.

ISEE has contributed to the understanding of magnetic storms in the magnetosphere and of how terrestrial ions are pumped away from the Earth on such occasions. Magnetic storms are explosive events in the tail of the magnetosphere (Fig 6). The drawn-out magnetotail represents a tremendous reservoir of energy which is partially drained when the magnetosphere attempts to return to the dipolar shape that it would assume in the absence of the solar wind. This 'reconnection' of magnetic fields causes, as near the front-side magnetopause, acceleration of plasma, which moves easily along magnetic field lines. The precipitating particles give rise to the ring-shaped a[illegible] regions around the magnetic poles, which constitute a visible sign of magnetic storms.

The auroral displays are not only beautiful to observe, they also represent dynamic regions influencing our daily life on Earth. The atmospheric currents generated are mirrored by currents in and below the Earth's surface, and these can upset power transmission as well as telecommunications. These magnetic storms are also responsible for pumping ions into the magnetosphere, as illustrated in Figure 7. There are, moreover, indications that the energy input to the auroral atmosphere can have a triggering effect on atmospheric circulations and on the weather.

The auroral particle precipitation triggers very strong radio emissions at frequencies around 1 MHz. It may not seem impressive at first sight that more than 1% of the kinetic energy on an auroral magnetic flux tube is converted into electromagnetic radio emissions. This phenomenon is, however, a surprisingly strong and efficient converter that is beaming radio signals out into the Universe. This could perhaps be one of

Figure 7 — The concentrations of O^+ of terrestrial origin can increase dramatically in the magnetosphere, particularly in the magnetotail, following magnetic storms

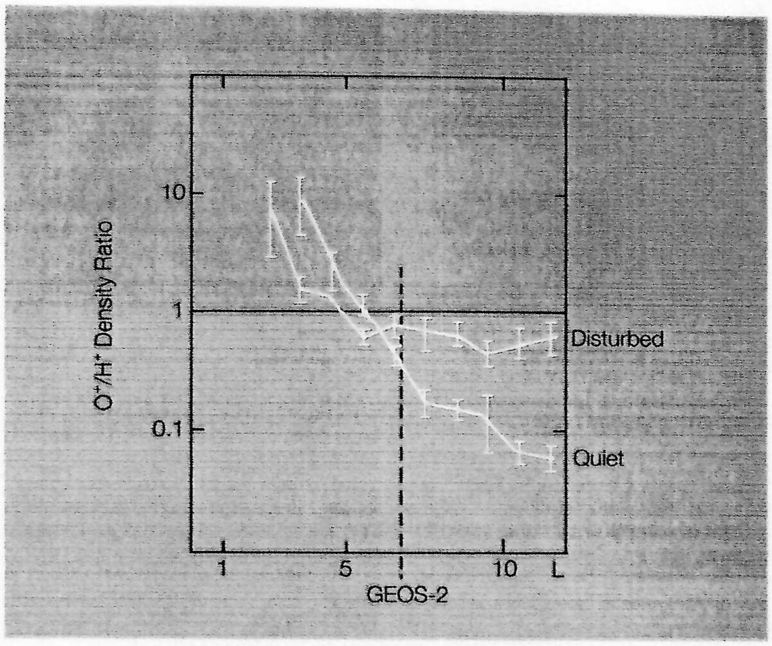
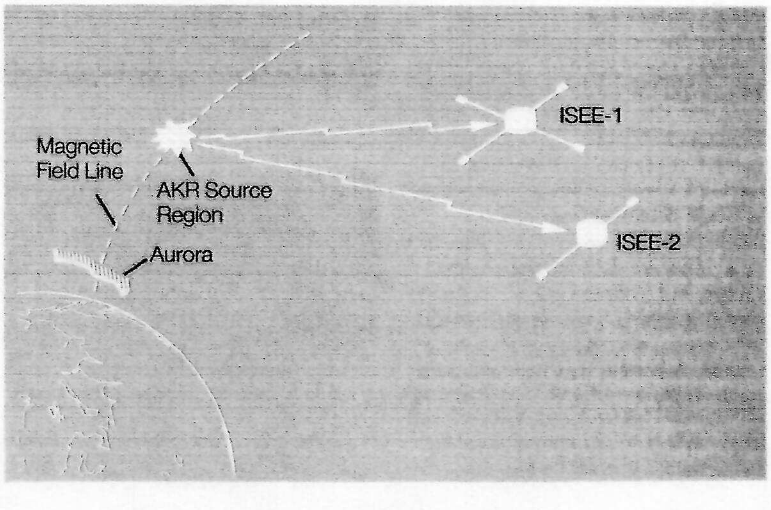


Figure 8 — Interferometry of auroral radio emission using the ISEE-1 and 2 separation baseline



still not fully explained, but ISEE-1 and 2 have certainly contributed to a better understanding of it via the interferometry

distances by another means. The energetic particles in the Van Allen radiation belts and on auroral magnetic regions around the Earth. Such energetic neutrals move in straight lines, irrespective of the magnetic field and a global image of 'hot' particles could therefore be obtained, as illustrated in Figure 9.

The ISEE database has already been used a great deal in combination with data from other spacecraft, including ESA's Geos-2 (Fig. 10), which was operational from mid-1978 until mid-1983. Coordinated Data Workshops have been held, at which large numbers of scientists from Europe and the USA have pooled their processed data on one computer and then met to work together on this composite database. These Workshops have been very stimulating for a number of studies, particularly for those concerned with the understanding of magnetic storms.

The ISEE-1 and 2 spacecraft were operational at the same time as many other magnetospheric projects and several international coordinated data-collection campaigns have been organised, one of the most recent taking place during the spring of 1986 (Fig. 10).

Conclusion

The ISEE operations have come to an end, but the scientific research based on the wealth of data that has been collected will continue for many years to come. There are currently plans to put digested ISEE data on optical discs in order to provide a common data set for the numerous scientific groups involved in the study of ISEE data both in Europe and the USA.

Figure 9 — 'Imaging' of emission of energetic neutral ions created by charge exchange in regions of the magnetosphere where ions and electrons are accelerated

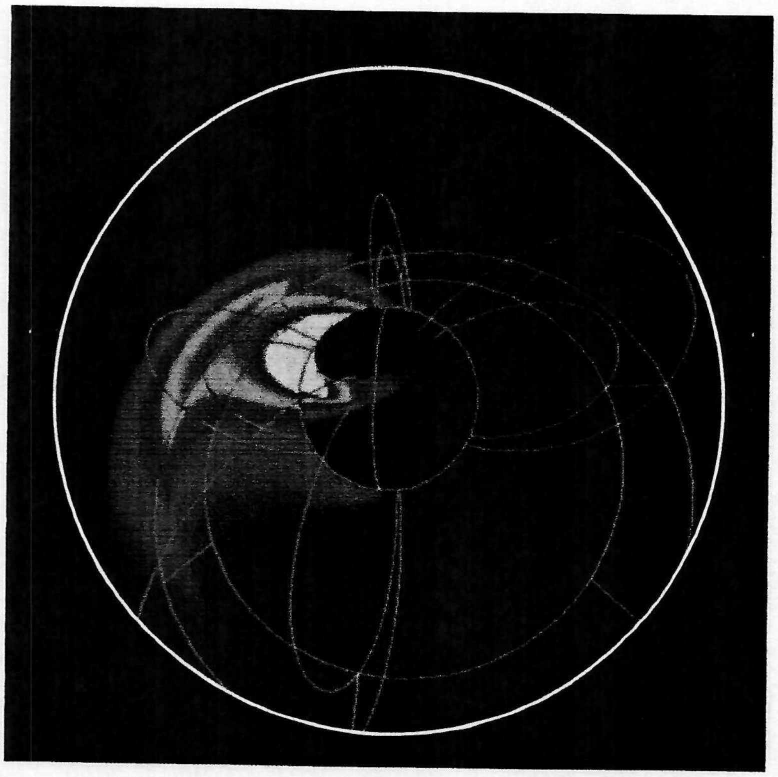
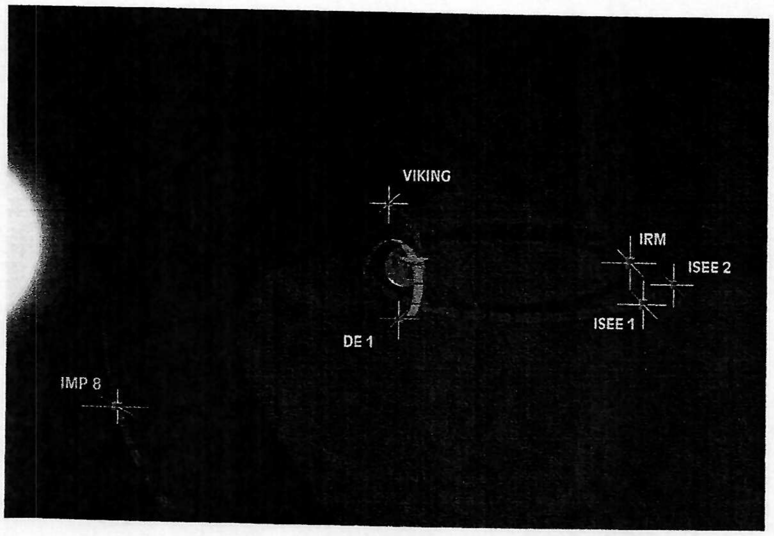


Figure 10 — Orbits of the various spacecraft during a coordinated observation period in spring 1986



ISEE

ISEE-1 and ISEE-2 were both launched on the same Delta rocket from Cape Kennedy on 22 October 1977. ISEE-2 represented ESA's investment in this collaborative programme with NASA, which besides ISEE-1 and ISEE-2 as tandem spacecraft in the Earth's magnetosphere, also included ISEE-3 far upstream in the solar wind.

On 26 September 1987, ISEE-1 and ISEE-2 re-entered the Earth's atmosphere as foreseen due to orbital degradation resulting in low perigee passes. This marked close to 10 years of successful operations of these spacecraft without any significant degradation of spacecraft systems, and with scientific payloads still providing the prime scientific parameters (see article on pages 38 – 44 of this issue).

The International Sun–Earth Explorer (ISEE) programme has been a very successful one, contributing to the understanding of physical processes in the Earth's plasma environment under the influence of the Sun and the solar wind. As such the programme was a natural continuation of the exploratory phase carried out by earlier US and Soviet spacecraft. The ISEE programme also enhanced the cooperation between American and European science communities in this field and resulted in a large number of high quality publications and presentations at scientific conferences.

The European community gained an extra bonus from this programme when ISEE-3 was re-routed first to make passes deep in the Earth's magnetotail in 1983 – 1984 and was then sent, assisted by the Moon's gravity, to Comet Giacobini Zinner, which was passed in September 1985.

IUE

The International Ultraviolet Explorer (IUE) started its tenth year of observations on 1 June 1987. At its annual meeting the European IUE Allocation Committee allocated time to 138 of the 201 observing proposals submitted. The observations for this period started nominally, although some delays were incurred due to the backlog caused by the supernova SN 1987A observations in the previous months. The unanticipated behaviour of SN 1987A disrupted the schedule more than was expected but this unique opportunity (see article on pages 31 – 37) certainly justifies these delays.

La salle de contrôle IUE à la station de poursuite de Villafranca

The IUE control room at the Villafranca tracking station (Vilspa)

On the spacecraft side, the problem due to the failure of the third electrode in one of the on-board batteries is reasonably well understood after detailed analysis. It is most likely that one cell of this battery has lost capacity. This does not, however, significantly affect the science operations. During the shadow seasons the batteries were found to share the full spacecraft power load in a regular way and it was not necessary to change the science operational procedures. A new policy was established to limit the use of heavy over-exposures on the IUE cameras. This was mainly driven by the desire to limit the effect of such exposures on the spectra taken in subsequent shifts. The IUE spacecraft continues to support the science operations without significant degradation.

Development of a new IUE output product — the remotely accessible Uniform Low Dispersion Archive (ULDA) — has progressed satisfactorily and the first version of this data set, together with its access support software (USSP), has been integrated at Vilspa. Installation of the ULDA/USSP in national host institutes will start shortly.

Giotto

Giotto has been in a hibernation configuration since 2 April 1986, orbiting the Sun with a period of 10 months. It is currently planned to switch on and check out the spacecraft and all experiments at the end of 1989 or early 1990, when the spacecraft will again be approaching the Earth, to find out whether the spacecraft and experiment health will allow a continuation of the Giotto mission for an encounter with the short-period comet Grigg Skjellerup in July 1992.

During the preliminary planning studies in preparation for these activities, examination of the Giotto attitude records indicated that the attitude was outside the preferred range. On investigation it was found that a translation error of 180° had arisen in setting the attitude. This was only revealed following recent submission of an industrial report which reviewed the solar aspect angle and solar distance history during hibernation. If the spacecraft had been under full and normal operational conditions this would have quickly been detected and corrected. An initial engineering

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SPACECRAFT POTENTIAL CONTROL ON ISEE-1

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ABSTRACT

The paper reports on the active control of the potential of the ISEE-1 satellite by the use of electron guns. The electron guns contain a special cathode capable of emitting an electron current selectable between 10^{-8} and 10^{-3}A at energies from approximately .6 to 41 eV.

Results obtained during flight show that the satellite potential can be stabilized at a value more positive than the normally positive floating potential. The electron guns also reduce the spin modulation of the spacecraft potential which is due to the aspect dependent photoemission of the long booms. Plasma parameters like electron temperature and density can be deduced from the variation of the spacecraft potential as a function of the gun current. The effects of electron beam emission on other experiments is briefly mentioned.

INTRODUCTION

The prime purpose of the electron guns mounted on the ISEE-1 spacecraft was to improve double probe electric field measurements. The scientific aim of the electric field experiment is to measure quasi-static fields in a range of about .1 to 200 mV/m (ref. 1). The spin plane component of the field is obtained from the spin modulation of the potential difference between a pair of 8 cm diameter vitreous carbon spheres separated by 73.5 m. The emission of beam of electrons parallel to the spin axis should have reduced the asymmetry in the potential produced by the photoelectrons. Several on orbit tests have shown that the electron guns have no significant influence on the electric field experiment. The interpretation of this unexpected result is that even without the electron beams the electric dipole moment of the photoelectron cloud is small enough for its effect on the double probe measurement to be negligible (ref. 2). The cloud symmetry is more favourable than expected from simplified model calculations (ref. 3).

The operation of the gun can still be a tool for the study of phenomena induced by the injection of a charged particle beam into a natural plasma. The intensity of the beam is far below intensities usually considered for active experiments (ref. 4) but can be sufficient to investigate active potential control of a body immersed in a plasma, plasma-beam instabilities, and waves.

Control of the spacecraft potential may also be a prerequisite for electric fields and low energy particle measurements in the vicinity of Jupiter (ref. 5) where the photoemission rate is 30 times less than at the Earth orbit or even at geosynchronous orbit to avoid negative charging during eclipses (ref. 6). Previous experiments have shown that thermoionic electron emission from a thruster could be used to reduce negative charging (ref. 7). It is shown in this paper that electron guns can be used to clamp the potential of a conductive spacecraft a few volts positive with respect to the plasma potential.

SYMBOLS

I	current
V	voltage
I_e	electron current collected by a conductive body in a plasma
I_o	value of I_e at the plasma potential
I_{pe}	photo electron current collected by a conductive body in sunlight
I_g	electron gun current
V_{sc}	potential of the spacecraft
V_{pl}	plasma potential
V_k	accelerating voltage of gun electrons with respect to the spacecraft potential

EXPERIMENTAL TECHNIQUE

Figure 1 illustrates the structure of the electron gun (ref. 8). The primary concern was in this case to reduce as much as possible the weight and the power needed for the emission of the electron beam. The cathode used in the gun is a tungsten impregnated cathode developed by Philips (ref. 9) from which a current of 500 µA at an energy of 41 eV could be drawn. Risks of contamination of the cathode were carefully studied and the following measures resulted in the safe operation of the guns. The two guns were opened at 600 km altitude where the concentration of oxygen is low, 15 days had elapsed since the launch so that the outgassing of the spacecraft was reduced, the opening system described in reference 8 was clean and finally a reactivating program was incorporated in the electronics of the experiment.

Tests were conducted before launch to simulate the effects of beam emission on spacecraft potential. The electron guns were attached to a metallic structure which could be biased (potential of the structure during the simulation is called V_{sc}) with respect to the walls (potential called V_{pl}) of a vacuum chamber (diameter 3 m, length 7 m). Figure 2 which summarizes the results shows that the beam current falls off with a slope of about 20 µA per volt and that at low energies ($V_k < 20$ V) spacecharge effects reduce the efficiency of the gun. The mechanism of formation of a virtual cathode in front of the gun at low energies may be invoked to explain the reduction in efficiency: at low energies the emission of electrons from the virtual cathode back to the anode of the gun is greater than the emission to the walls of the chamber at larger distances.

The configuration of the ISEE-1 spacecraft is illustrated in figure 3. In order to minimize potential disturbances originating at the spacecraft or in its vicinity an electrostatic cleanliness specification on the spacecraft surface was implemented at an early stage in the project with the result that the skin is essentially an equipotential surface (surface conductivity approximately $10^5 \Omega / \square$). Potentials can be measured between the satellite body and the probes at the end of the booms; the body of the spacecraft, as will be shown in the last section, can be considered as a large collecting probe.

On board, 13 instruments measure electron and ion populations, magnetic field, plasma waves and other plasma parameters (ref. 10). The orbit is highly elliptic with an apogee of 22.6 Earth radii and a perigee at about 300 km so that the plasmapause, the magnetopause and the bow shock are crossed successively. The measurements presented here were obtained on the 7th November 1977, starting at 17.00 hrs 49 min 40 sec UT when the spacecraft was in the solar wind at a distance of about 17.6 RE.

MEASUREMENTS

The current collection of a conductive body immersed in a space plasma is represented qualitatively as a function of potential in figure 4: the voltage reference is that of the undisturbed plasma at large distances from the body; I_e represents the current collected in shadow or when the photoemission rate is low, I_{pe} represents the contribution of the photoelectron current.

Plasma Potential Measurements

The vitreous carbon probes at the end of the wire booms can be used as conventional Langmuir probes with the difference that their current is swept rather than their voltage. The passage of the probe through the plasma potential has a clear signature indicated by a sudden change in the photoelectron current emitted by the probe. Biasing the probe with a negative current of about -60 nA maintains it within a fraction of a volt of the plasma potential for the data considered here.

Spacecraft Potential Control

The spacecraft potential is measured between the satellite body and one probe biased to be slightly positive relative to the plasma potential. Figure 5 a, b and c show the variations of the spacecraft potential and the electric field signals for 3 different values of the emitted gun current, as a function of the energy of the beam. The accelerating beam voltage V_k is maximum at the left of the figure and is stepped down automatically by steps of 1.6 Volt from 40.8 V to .58 V. The time necessary to step from one level of energy to the next may vary and the arrows indicate the times when the beam energy is equal to 8.6 eV and can be used as reference points. As mentioned earlier the sinusoidal signal representing the electric field is not affected by changes in beam energy or in gun current. (The spikes appearing regularly are due to the sudden change in potential of the probes as they pass in the shadow of the spacecraft).

When the gun current is set at 120 µA (fig. 5 a) the spacecraft potential follows closely the beam energy down to an energy of 8.6 eV where the gun looses its control of the potential. At this energy and lower, space charge effects limit the emission of the gun as was observed during the tests, and as is shown in figure 2 for $V_k < 20$ V. A detailed examination of the voltages indeed shows that decreasing the beam energy from 40 eV to 15 eV changes the spacecraft potential by only 23 V giving a ratio of .92 for V_{sc}/ V_k. As will be shown in figure 6 this is due to the fact that beam electrons are not monoenergetic but have a spread in energy around a mean value. When the gun current is set at 60 µA (fig. 5 b) a modulation of the spacecraft potential at twice the spin frequency appears for high values of the beam energy; the modulation disappears betwen 24 V and 8.6 V where the modulation appears again. When the beam current is set at 30 µA the range where the control occurs is limited between 14 V and 8.6 V.
The modulation of the potential at twice the spin frequency is due to the changing photoemission of the shields of the long booms as they spin with the spacecraft. In the particular case of figure 5, the shields were biased at the potential of the probes minus 4 V which means that they are more negative than the plasma and consequently they are a source of photoelectrons. To compensate the changing photoelectron current of the booms the spacecraft potential adjusts to values where incoming and outgoing currents are equal.

The explanation for this behaviour is illustrated in figure 6 which shows current-voltage characteristics of the gun and of the spacecraft including the booms. The dotted line represents the emitted gun current at various energies, the fall off of the beam current has been assumed to be similar to the measured value of 20 µA/V (as shown in figure 2). The continuous lines represent the current collected by the spacecraft (similar to the current collected by a positive conductive body as was shown in the first quadrant of figure 4). The thick line corresponds to the minimum photo-emission from the booms, the thinner line to the maximum photo emission. These two curves have been constructed from the data shown in figure 5 where the potential of the spacecraft can be measured for different values of the gun current.

The modulation of the spacecraft potential at twice the spin frequency occurs when the curve representing the current collected by the body cuts the gun current curve on the plateau, control of potential occurs when the gun current is larger than the current collected by the spacecraft body, the amount of gun current emitted into space is equal to the collected current. At voltages less than 8.6 V the modulation reappears with a smaller amplitude because the gun current ceases and the potential oscillates between 10 V and 5 V as is shown in fig. 6; as the slope of the collected current curves is larger at low energies the potential modulation decreases with the spacecraft potential.

DISCUSSION

As was shown in the previous section, the satellite potential can be stabilized at a specified value positive with respect to the plasma potential by operating electron guns at appropriate energies. The guns can be used to compensate for small variations in spacecraft potential due to the aspect dependent photoemission of the long booms which, in the case considered, were biased negatively and thus were a source of photoelectrons.
Limited possibilities to measure the ambient temperature exist in the experiment complement on board ISEE-1. In the following a method to determine the plasma density and temperature from the gun measurements is outlined.
A simple model for electron collection is assumed $I_e = I_o\ (1 + V_{sc}/V_e)$ where $I_o = n\ e\ v\ S/4$ with n the density, e the electron charge, v the thermal speed ($eV_e = mv^2/2$) and S the collecting surface of the entire spacecraft, approximately 10 m^2. The value of I_o is obtained by extrapolating towards low voltages the curve representing the electron saturation current.
As an indication the values obtained from figure 6 are $n \approx 30\ cm^{-3}$ and $V_e = 14.6$ V.

When the control of the spacecraft potential by the electron gun is effective a fraction of the gun current returns to the spacecraft. As noted by the particle experimenters on ISEE-1 this return flux increases considerably the countrate of particle detectors in the vicinity of the return area.
The beam also excites plasma instabilities which have been observed in a frequency range around 20 kHz and detected by the other electric antenna on the spacecraft.

It therefore appears that in spite of their low electron beam intensities, some fundamental plasma physics phenomena can be investigated with the electron guns on board ISEE-1 in the future.

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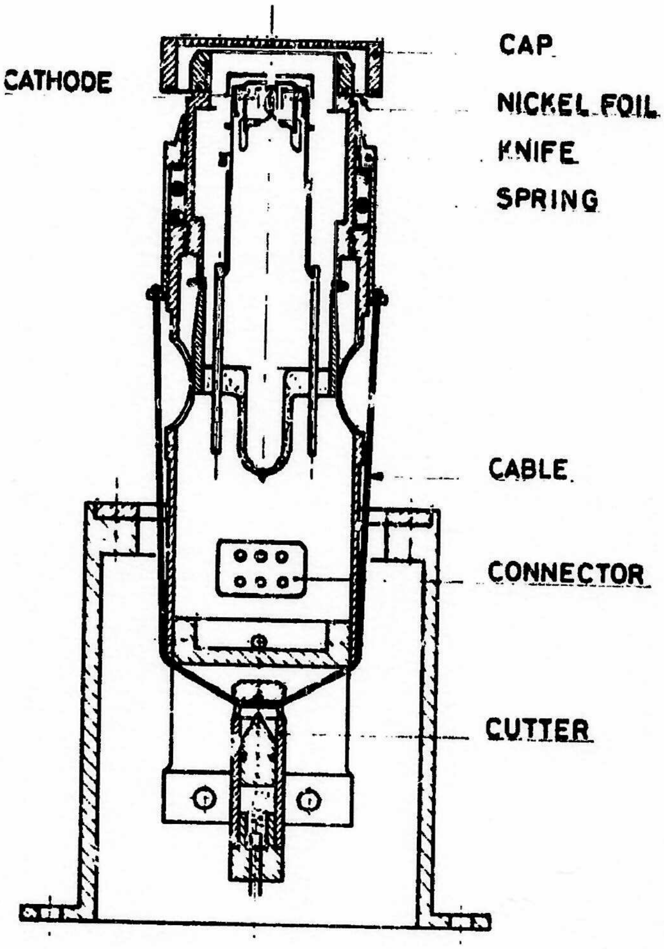

FIG.1 ELECTRON GUN STRUCTURE

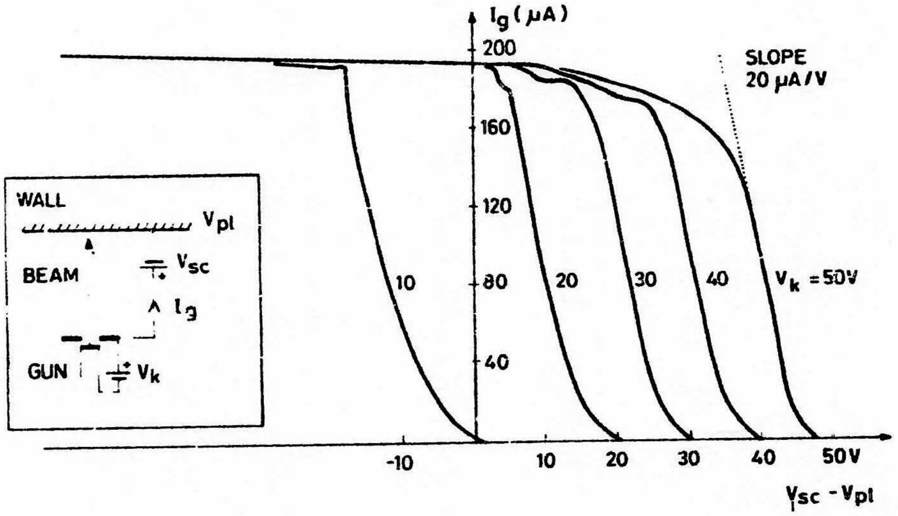

FIG.2 GUN TESTS

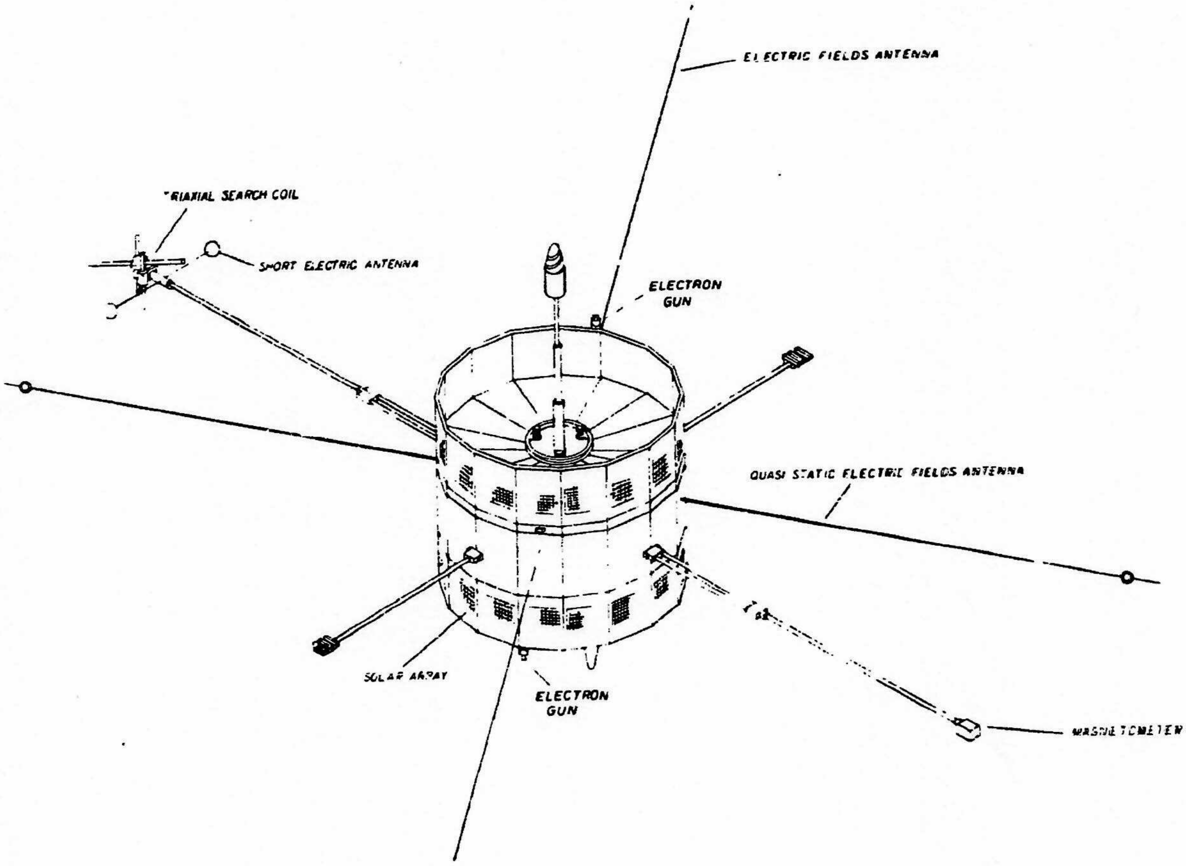

FIG.3 ISEE-1 SPACECRAFT CONFIGURATION

C-17

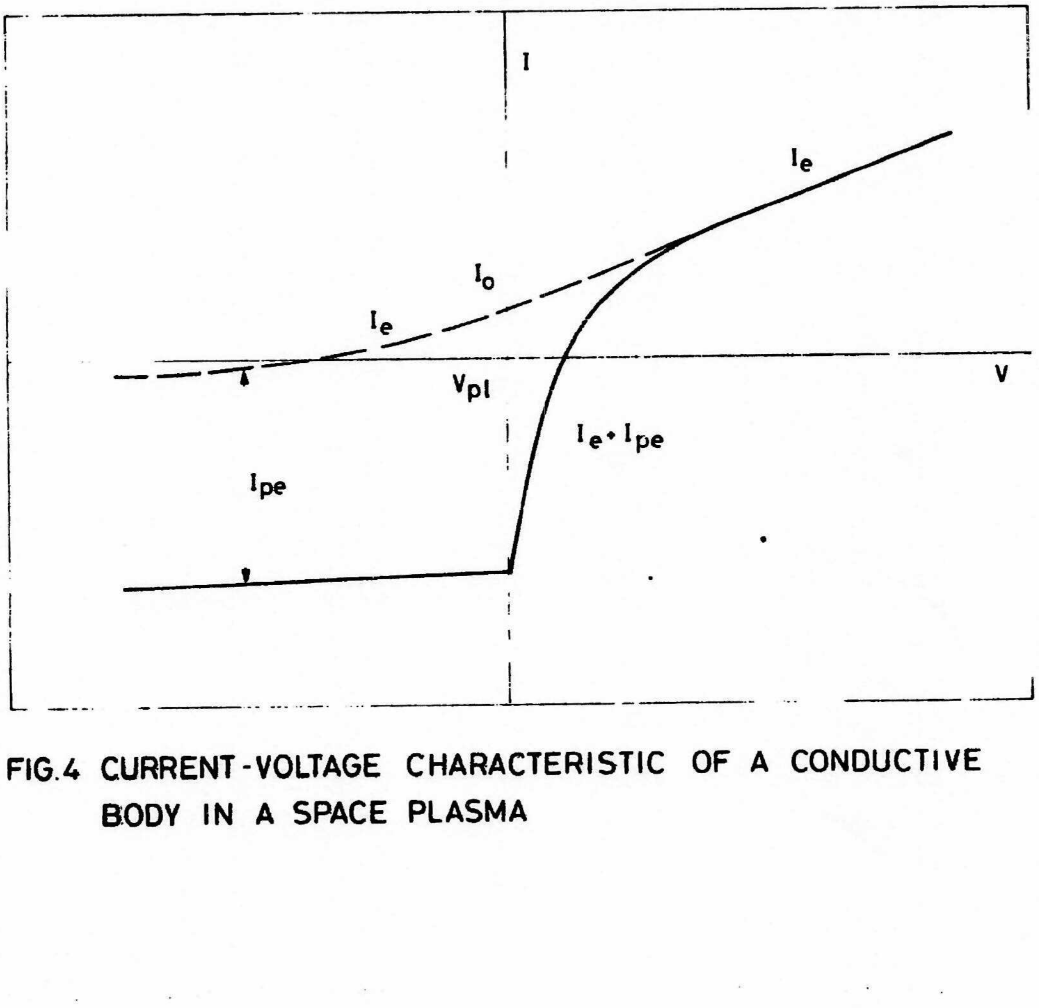

FIG.4 CURRENT-VOLTAGE CHARACTERISTIC OF A CONDUCTIVE BODY IN A SPACE PLASMA

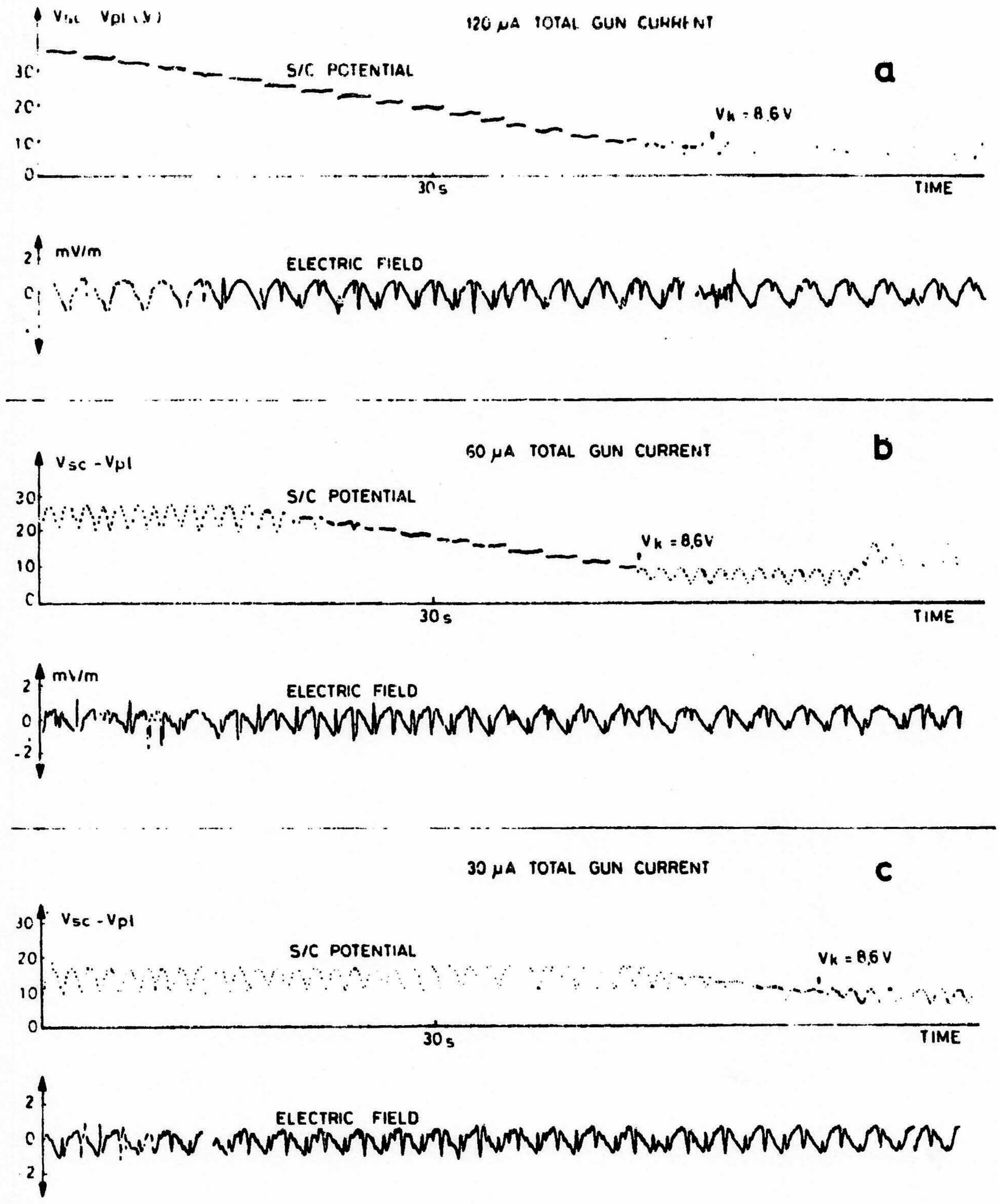

FIG.5 SPACECRAFT POTENTIAL AND ELECTRIC FIELD

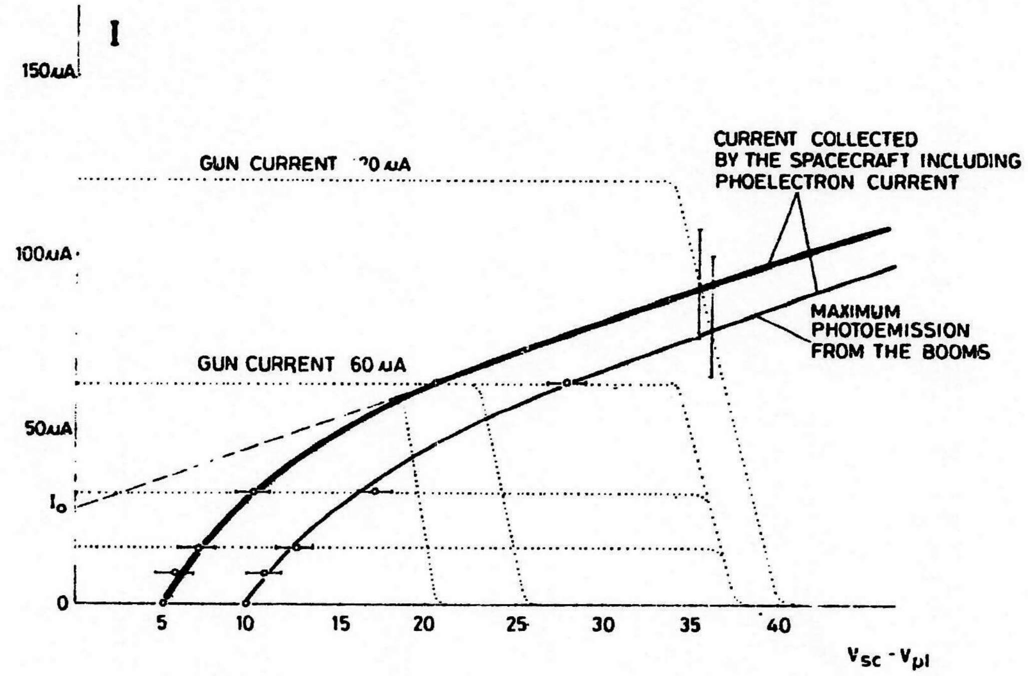

FIG.6 CURRENT - VOLTAGE CURVES

Post Launch
Mission Operation Report
No. S-862-77-01/02/03
September 11, 1979

TO: A/Administrator

FROM: S/Associate Administrator for Space Science

SUBJECT: International Sun-Earth Explorers-1, 2, & 3;
Post Launch Report #2

International Sun-Earth Explorers (ISEE) -1, 2, and 3 are adjudged successful based on results of the mission with respect to the prelaunch objectives.

The ISEE Program is an international cooperative effort between the National Aeronautics and Space Administration and the European Space Agency, focusing on solar-terrestrial relationships as a joint contribution to the International Magnetospheric Study. It employs three coordinated spacecraft to advance our knowledge of the magnetosphere, the solar wind, and the interactions between them.

ISEE-3 is in a halo orbit about the Sun-Earth libration point, about 1.5 million kilometers from the Earth on the Earth-Sun line. ISEE-3 samples the incoming solar wind one to two hours before it arrives in the Earth's magnetosphere, where its effects are determined in detail by ISEE-1 and -2, moving in similar, highly-eccentric orbits with variable separation. ISEE-1 and -2 are able, for the first time, to separate time and space variations and thus to measure motions and structures as the Earth's magnetosphere responds to the solar wind fluctuations noted by ISEE-3. These studies represent essential steps in understanding the processes that control Earth's near-space environment.

Some of the most important results achieved to date are as follows:

- The magnetopause is fairly steady when the plasma contains a north-directed magnetic field, but it moves erratically when this field is south-directed.
- When the plasma magnetic field is southward, violent reconnection of magnetic fields has been observed at the magnetopause. This process of "magnetic reconnection" has been theoretically postulated as a mechanism for transferring energy but has never before been observed in tenuous plasmas. This is important to general plasma physics and to applications of plasma physics to astrophysics.
- ISEE-3 has observed energetic particles accelerated outwards from the Earth's bow shock that probably originated from the solar wind. This acceleration process sheds light on the origin of cosmic rays at the lower end of the spectrum.
- The gamma ray burst detector on ISEE-3, together with those on other spacecraft, led to the first identification of a gamma ray burst source on March 5, 1979, using direction findings techniques. The object, in the supernova remnant of the large Magellanic cloud, provides important clues to the origin of these gamma ray bursts and the mechanisms that produce them.
- Successive passes of ISEE-1 and -2 through the plasmapause, magnetopause, and shock-front boundaries have enabled their dynamics to be studied. Both wavelike and piston-like motions have been found, with velocities up to 100 km/sec. Some of these were found to produce magnetic micropulsations that can be seen from the ground, but whose origin was not understood.

8/31/79

- The first energetic ion mass spectrometer measurements made in the distant magnetotail on ISEE-1 have found ions of ionospheric origin accelerated to fairly high energies. Previously, this region was believed populated by material of solar wind origin.

- The coordinated high resolution electric and magnetic field measurements, together with three-dimensional particle spectra are discovering new information on plasma flow and acceleration processes. These represent important steps in studying the energy flow from the Sun, the entry of solar particles and energy, and the energy balance of the Earth's near-space environment.

In addition, the detailed solar wind isotopic composition measurements are helping to increase our understanding of the processes that occur on the Sun. The solar wind and cosmic ray measurements made near Earth provide a baseline for comparing with measurements on planetary missions to investigate possible gradients and large scale structure of plasma and cosmic rays in the solar system.

The advance warning obtained from ISEE-3 of solar wind features that lead to later perturbations in the Earth's magnetosphere are becoming of great importance as these relationships are being increasingly understood. The Space Environment Services Center of the National Oceanic and Atmospheric Administration, located in Boulder, Colorado, has, therefore, requested real-time access to ISEE-3 for prediction purposes. An access link to the relevant data stream is expected to be on-line by early 1980.

In summary, ISEE-1, -2, and -3 are working well, have met their primary and secondary objectives, and have obtained new information on the dynamics of the magnetosphere, the transfer of energy from the solar wind and the energization of plasma in the magnetotail that will be needed to understand the overall energy balance in the Earth's near-space environment.

Thomas A. Mutch

MISSION OBJECTIVES FOR ISEE A/B AND C MISSION

The International Sun-Earth Explorers, ISEE/A, B and C represent a three-spacecraft project to investigate the detailed structure of the boundaries between the earth's magnetosphere and interplanetary space, to investigate the fluctuations in the solar wind, and the relations between these fluctuations and changes in the magnetosphere boundaries.

The primary mission objectives of ISEE A and B are to make detailed measurements of the structure of the magnetosphere boundaries and their fluctuations from two points in space, and to obtain sample near-earth measurements of the solar wind. The primary mission objective of ISEE-C is to obtain detailed measurements of the solar wind and its fluctuations. The maximum value of the ISEE project is obtained by simultaneous operation of all three spacecraft for several solar rotations.

H. Glaser
H. Glaser
Director
Solar Terrestrial Programs

Date: 9/20/77

Noel W. Hinners
Noel W. Hinners
Associate Administrator
for Space Science

Date: Sept. 25, 1977

Attachment 2
S-862-77-01/02/03

ASSESSMENT OF THE INTERNATIONAL SUN-EARTH EXPLORERS MISSIONS

Based upon a review of the assessed performance of the International Sun-Earth Explorers 1 and 2 launched on October 22, 1977, and ISEE-3 launched on August 12, 1978, this mission is adjudged successful with the prelaunch mission objectives stated above.

Harold Glaser

Harold Glaser
Director, Solar Terrestrial Division
Office of Space Science

Date: Sept 5, 1979

Thomas A. Mutch
Associate Administrator
for Space Science

Date: 9/9/79

NASA News

National Aeronautics and
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For Release:

Charles Redmond
Headquarters, Washington, D.C.
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September 14, 1987

Jim Elliott
Goddard Space Flight Center, Greenbelt, Md.
(Phone: 301/286-6256)

RELEASE: 87-137

TWO NASA SCIENTIFIC SPACECRAFT TO REENTER OVER SOUTH AMERICA

Two NASA scientific satellites are expected to create fireballs as they reenter Earth's atmosphere only 2 minutes apart over South America, September 26, officials at Goddard Space Flight Center, Greenbelt, Md., reported today.

The spacecraft, the International Sun-Earth Explorers (ISEE), will burn-up in the atmosphere in the early morning over Brazil according to Osvaldo Cuevas of Goddard's Flight Dynamics Facility.

ISEE-1 and ISEE-2 were launched on a single Delta rocket from Cape Canaveral Air Force Station, Fla., Oct. 22, 1977. The orbiting spacecraft, with identical instruments but separated by a distance of almost 500 miles, studied fluctuations in plasma waves, the magnetic field, proton and electron density, cosmic rays, gamma ray bursts and the solar wind in the near-Earth environment.

Dr. Keith Ogilvie, project scientist, indicated that investigations conducted with the satellites were very productive, resulting in a large number of scientific papers published over the past 10 years. Both spacecraft participated in the Polar Regions and Outer Magnetosphere International Study, a multi-satellite campaign last year, providing simultaneous measurements of Earth's magnetosphere dynamics.

At reentry, the spacecraft will have studied the near-Earth environment for almost 10 years, greatly surpassing their designed lifetime of 3 years. Reentries should occur on the spacecrafts' 1,518th Earth orbit, according to Robert O. Wales, ISEE mission manager.

- more -

The ISEE-1 spacecraft was designed, fabricated, assembled and tested at Goddard with its components made at Goddard or supplied by industry or universities.

A consortium of 10 European countries supervised construction of ISEE-2 under contract to the European Space Agency. The 10 countries were Belgium, Denmark, France, Germany, Italy, the Netherlands, Spain, Sweden, Switzerland and the United Kingdom. Dornier Systems in Germany led the contractor team.

- end -