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The scientific objectives of the International Solar Polar Mission

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The International Solar Polar Mission (I.S.P.M.), originally known as the Out-of-Ecliptic Mission, will be the first spacecraft mission to explore the third dimension of the heliosphere within a few astronomical units of the Sun and to view the Sun over the full range of heliographic latitudes. Its main objectives are to investigate, as a function of solar latitude, the properties of the interplanetary medium and the solar corona. The I.S.P.M. is a two spacecraft venture jointly conducted by E.S.A. and N.A.S.A. The two spacecraft will be injected into elliptical heliocentric orbits approximately at right angles to the ecliptic plane, by using the Jupiter gravity assist method, one northwards and the other southwards. After passing nearly above the poles of the Sun, each spacecraft crosses the ecliptic plane and passes over the other solar pole. The complete mission time from launch, foreseen for February 1983, to the second polar passage is approximately $4\frac{2}{3}$ years.

This paper summarizes the main scientific objectives of the instruments to be carried on this exploratory mission. It concludes with an outline of the payload, the spacecraft, the trajectory and the mission schedule.

Introduction

The dual spacecraft International Solar Polar Mission (I.S.P.M.) will be the first mission to explore the heliosphere and to view the Sun over the full range of heliographic latitudes. Of all interplanetary missions flown so far, none has gone beyond a narrow region around the solar equatorial plane. Pioneer 11 made the furthest excursion from this plane to a maximum heliographic latitude of 16° N. There is clear evidence that interplanetary conditions vary strongly with solar latitude. (A recent review of the three-dimensional structure of the interplanetary medium has been given by Axford (1977).) The I.S.P.M. will explore for the first time the physical characteristics of the interplanetary medium in its third dimension and relate them to processes occurring on the Sun. It will also open up a completely new perspective of solar features.

The scientific need for an out-of-ecliptic mission has been under discussion for about two decades (see, for example, Simpson *et al.* 1959; Page 1975; Fisk & Axford 1976 and references therein). The I.S.P.M. has now been approved on both sides of the Atlantic as a cooperative project between the European Space Agency (E.S.A.) and the U.S. National Aeronautics and Space Administration (N.A.S.A.) for launch in February 1983.

The I.S.P.M. is multidisciplinary. It involves many areas of interplanetary physics as well as solar and cosmic ray physics. Its primary objectives are to investigate, as a function of heliographic latitude, the properties of the solar corona, the solar wind, the structure of the Sun–wind interface, the heliospheric magnetic field, solar radio bursts and plasma waves, solar and galactic cosmic rays, and interplanetary/interstellar neutral dust and gas, and to locate the sources of cosmic γ-ray bursts. Secondary objectives include interplanetary physics investigations during the initial Earth–Jupiter phase and measurements in the Jovian magnetosphere during the Jupiter fly-by phase.

It is the purpose of this paper to present an overview of the main scientific objectives of the investigations performed by the I.S.P.M. The paper concludes with an outline of the payload and the spacecraft characteristics as well as a summary of the mission trajectory and schedule.

SCIENTIFIC AIMS

Physics of the inner and outer corona

One of the basic scientific goals of the I.S.P.M. is to observe the solar atmosphere over a wide range of heights from the unique perspective of high solar latitudes. The instrumentation to do this is a white light coronagraph and an X-ray/x.u.v. telescope. These will provide images of the solar atmosphere from the chromosphere (in x.u.v.) through the lower corona (in both x.u.v. and X-rays) to the outer corona (in white light). The ultimate scientific objectives to be pursued with such observations involve the quantitative understanding of physical processes in the extended solar atmosphere.

A specific example of an investigation to be performed is the study of the large-scale three-dimensional structure of the solar corona. The I.S.P.M. will offer a view of equatorial structures not available from near Earth. It will make it possible to follow the temporal evolution of large-scale features (such as coronal transients and active regions) throughout the complete solar rotation. Such observations reveal the evolution of the magnetic field governed not only by coronal, but also by subsurface processes (in the convection zone) determining the photospheric and coronal magnetic field. The I.S.P.M. observations – when combined with near-Earth measurements – will provide simultaneous observations of the corona along two essentially orthogonal lines of sight and will thus provide unique data for the three-dimensional modelling of the solar corona.

Another topic is the study of the relation between the solar atmosphere and the interplanetary medium. The usefulness of X-ray, x.u.v. and white light coronal data combined with field and particle observations has been strikingly demonstrated by the Skylab studies of coronal holes, solar wind streams and interplanetary magnetic sectors (see, for example, Hundhausen 1977; Hundhausen & Holzer, this symposium). The I.S.P.M. will provide such data over the full range of solar latitudes and, for example, will permit studies of the formation of the solar wind and its flow with respect to the interplanetary magnetic field structure.

A subject of particular interest in astrophysics is the transport of angular momentum by the solar wind. Direct measurements of the angular momentum are difficult to make. The measurements of the small deviations from radial solar wind flow suggest an angular momentum loss sufficient to despin the Sun in its main sequence lifetime. The coronagraph, from its perspective over the solar poles, can measure the radius at which coronal structures begin to show departures from co-rotation. It is this radial distance that determines the angular momentum that is imparted to the solar wind.

Physics of the heliospheric magnetic field

Many aspects of the propagation of energetic particles in the heliosphere, either cosmic rays or Sun-ejected, cannot be understood without a detailed knowledge of the overall three-dimensional topology of the heliospheric magnetic field and its time variations. It is therefore one of the main goals of the I.S.P.M. to determine the large-scale structure of the interplanetary medium. A specific example is the three-dimensional relation between interplanetary sector boundaries and the photospheric and coronal fields.

Several instruments, providing remote sensing and *in situ* measurements, will contribute to this aim. The coronagraph will provide the data base for the correlative studies of the relation between coronal structures (e.g. coronal holes, streamers) and interplanetary phenomena (solar wind streams). The magnetometers will provide the *in situ* measurements. These will be complemented by directional observations of type III radio bursts from both I.S.P.M. spacecraft that will permit the mapping of the interplanetary magnetic field lines from about 10 solar radii to about 5 AU from the Sun.

Other objectives related to the interplanetary magnetic field include the measurement of the field fluctuation spectra as a function of solar latitude and the determination of solar pole field strength and flux. It should be emphasized that the dual spacecraft concept with four polar passes permits two *simultaneous* flux estimates at *both* poles. These measurements are an essential boundary condition to any extension of the theories on the cause of the solar dynamo.

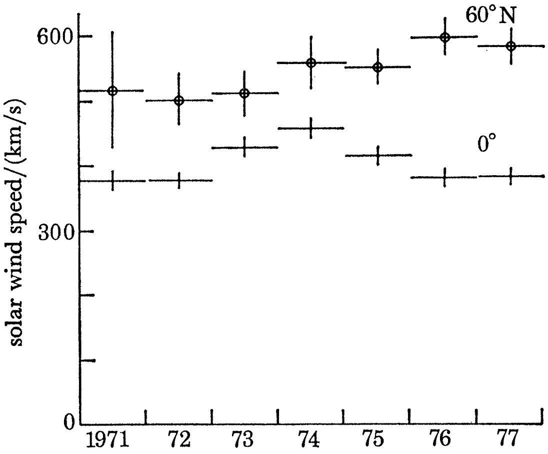

FIGURE 1. Average solar winds speed from interplanetary scintillation observations in latitudes 0° ± 10° and 60° N ± 10° for each year from 1971 to 1977. The vertical bars are plus and minus twice the standard deviation in the estimated mean speed (from Sime & Rickett 1978).

Physics of the solar wind

Intimately coupled to the structure of the solar and heliospheric magnetic fields is the flow of the solar wind plasma. We know from interplanetary scintillation studies that the solar wind speed increases at higher latitudes (figure 1) (Sime & Rickett 1978). Near the ecliptic plane the solar wind flow is dominated by interaction processes of slow and fast streams, mainly as a result of the longitudinal variations in the underlying solar corona. A completely different picture is expected above the solar poles. Here the solar wind will originate from the polar coronal hole with its open field lines. The field direction is expected to be radial, making the solar wind flow essentially parallel to the field at all altitudes. This flow is expected to be of a high velocity (600–800 km/s) and to have quite uniform properties in terms of density, temperature and composition. The conditions of the solar wind over the solar poles will therefore resemble much more the picture of a 'quiet' (but fast) solar wind than the conditions at lower latitudes.

The I.S.P.M. then will permit studies to be made of the properties of the solar wind plasma under simpler (or at least different) conditions than has been possible so far and will thus greatly contribute to improve our understanding of the physics of the solar wind. These studies involve, on both spacecraft, detailed measurements of the internal dynamics, the flow properties and distribution functions of solar wind ions and electrons as well as measurements of field and wave properties revealing the plasma microscale behaviour.

The I.S.P.M. observations will also include detailed measurements of the solar wind ion composition. These measurements will give us information on the source regions of the solar wind. Knowledge of the charge (ionization) states of solar wind ions provides a measure of the electron temperature in the corona where the observed ions are accelerated (Feldman 1977).

Another important objective of the magnetic field and plasma investigations is the determination of the three-dimensional configuration of corotating shocks. It is known from Pioneer 10/11 measurements that corotating shock pairs begin to develop by the interaction of long-lived solar wind streams around 1.5 AU and that at 5 AU almost all fast solar wind streams are associated with shocks (Smith & Wolfe 1977). The I.S.P.M. will extend these observations to high latitudes and, by making simultaneous measurements in the two hemispheres, will establish the general shape and possible large-scale distortion of the shocks. Theoretical calculations predict (Siscoe 1976) that the heliocentric distance at which co-rotating shocks form will increase rapidly above *ca.* 60° latitude and that shocks will not occur at all over the poles. Shock studies are of fundamental importance since acceleration at shocks is a possible mechanism for generating high-energy particles in gaseous envelopes of all stellar objects.

Physics of cosmic rays and solar particles

Comprehensive measurements of energetic particles over a wide range of energies and species as a function of heliographic latitude are another prime objective of the I.S.P.M. Such observations will give new information on processes that govern energetic particle propagation in the heliospheric magnetic field and will permit studies of many phenomena related – in a wider sense – to the propagation and acceleration of charged particles in an astrophysical plasma. The changing configuration and structure of the heliospheric magnetic field with latitude will give rise to different priorities for the various processes whose mixture we observe near the ecliptic plane. As with the solar wind, the I.S.P.M. will thus offer the chance to study the particle behaviour in a variety of different plasma conditions. Several sophisticated instruments on both spacecraft, providing detailed measurements of the chemical and isotopic composition and of anisotropies, will contribute to these investigations.

Low-energy (below a few hundred megaelectronvolts per nucleon) galactic cosmic rays are modulated on penetrating into the interplanetary medium as a result of their interaction with magnetic field irregularities carried by the solar wind. The particles observed near Earth enter the heliosphere at higher energies and are decelerated in the solar wind. The small gradients observed by Pioneer 10/11 in fact argue that near the ecliptic the modulation region could be many tens of astronomical units in dimension. There is compelling reason (see, for example, Völk 1976) to believe that the modulation is substantially reduced at high solar latitudes. Consequently, measurements of different species of cosmic rays as a function of latitude should help us to understand the modulation process much better than we do at present. Over the polar regions, observations of the elemental and isotopic composition of galactic cosmic rays with low energies in the interstellar medium should become available (Simpson 1978). These observations will provide insight into the origin and the propagation of cosmic rays that is not obtainable from measurements of their higher energy counterparts, and not obtainable in any other region accessible to us.

Another objective for investigation is the origin of the anomalous cosmic ray component appearing as an increase in the He, N, O and Ne fluxes below about 50 MeV/nucleon over the modulated galactic cosmic ray flux. The most promising current theory for the origin of this component suggests that it results from interplanetary acceleration of ionized interstellar neutrals (Fisk *et al.* 1974). Observations of the anomalous component on the I.S.P.M. should provide a definitive test of its origin. If the particles are galactic cosmic rays, their flux will increase towards the solar poles. If, on the other hand, the particles are accelerated in the solar wind, there is no reason for an increase. The component may even disappear at high latitudes where magnetosonic waves suggested as the source of the acceleration (Fisk 1976) become less abundant as a result of the expected radial nature of the field and the absence of stream–stream interactions.

A further example where we expect strong latitude variations is the appearance of shocks and their interaction with charged particles, in particular in the co-rotating interaction regions, discovered by the Pioneer 10/11, where particles are accelerated to energies of about 1 MeV/nucleon (Barnes & Simpson 1976; Pesses *et al.* 1978).

Observations of the variation in the Jovian electron flux with latitude will provide a direct measure of the cross-field diffusion of charged particles. These measurements should be more definitive than similar tests that use solar particles. The latter often yield ambiguous results since they can diffuse in the solar corona before they are injected into the heliosphere.

There are many objectives connected with the observations of solar particles. They can be used as probes of the conditions and physics in the solar corona, for studies of flare processes and for investigations of interplanetary propagation. The particle measurements on the I.S.P.M. will be complemented by simultaneous observations of directional, spectral and temporal properties of solar flare X-rays from which basic information on the acceleration, storage and escape processes of energetic electrons can be derived. The X-ray measurements from both spacecraft should determine unambiguously whether hard X-ray flare sources consist of a streaming electron population (non-thermal flare models) or an isotropic population (thermal models). Occultation measurements where the X-ray source is fully or partially occulted by the solar limb as viewed by one of the spacecraft will provide information on the location of the accelerating region, on the height distribution and the spatial extent of the source. In addition, comparison of the flare-site electron spectrum derived from the X-ray data with the spectrum observed *in situ* on the spacecraft can reveal information on coronal processes such as the velocity and rigidity dependence and the extent to which there is storage and secondary acceleration in the corona.

Physics of the heliospheric dust

Dust particles are important constituents of the solar system. It is therefore one of the objectives of the I.S.P.M. to study the origin and physics of heliospheric dust by measuring the three-dimensional spatial distribution and the physical properties of the interplanetary dust, including a possible interstellar component, as a function of latitude and heliocentric distance by both impact and optical methods. An impact detector will provide measurements *in situ* of dust properties. A zodiacal light experiment will provide multicolour observations (u.v. to i.r.) of the line-of-sight brightness and polarization over the sky resulting from sunlight scattered by the interplanetary dust cloud and from the diffuse astronomical background. The I.S.P.M. trajectory offers the unique opportunity to determine the scattering function (representing size, shape and material of the dust grains) that is measured along the line of sight from many different locations, thus allowing ultimately the determination of the brightness and polarization of the zodiacal light per unit volume of interplanetary space. These observations and results will define the three-dimensional extent and properties of the zodiacal cloud that are necessary to determine its origin, the processes by which it is maintained, and the mechanisms that tend to disperse it.

Table 1. Selected I.S.P.M. investigations

investigation	principal investigator	institute
	E.S.A. spacecraft	
magnetic field	P. C. Hedgecock	Imperial College, London
solar wind plasma	S. J. Bame	Los Alamos Sci. Lab.
solar wind ion composition	G. Gloeckler/J. Geiss	U. Maryland/U. Berne
low energy electrons and protons	L. Lanzerotti	Bell Laboratories
low energy ions	E. Keppler	M.P.I. Lindau
cosmic rays/solar particles	J. A. Simpson	U. Chicago
radio/plasma waves	R. G. Stone	N.A.S.A./G.S.F.C.
solar X-rays/cosmic gamma bursts	K. C. Hurley/M. Sommer	C.E.S.R. Toulouse/M.P.I. Garching
cosmic dust	E. Grün	M.P.I. Heidelberg
	N.A.S.A. spacecraft	
coronagraph/X-ray x.u.v. telescope	R. M. MacQueen	H.A.O. Boulder
magnetic field	M. H. Acuna	N.A.S.A./G.S.F.C.
solar wind plasma	H. Rosenbauer	M.P.I. Lindau
comprehensive particle analysis	E. C. Stone	California Institute of Technology
radio/plasma waves	R. G. Stone	N.A.S.A./G.S.F.C.
solar X-rays/cosmic gamma bursts	T. L. Cline	N.A.S.A./G.S.F.C.
zodiacal light	R. H. Giese	U. Bochum
interstellar gas	H. Rosenbauer	M.P.I. Lindau

Physics of neutral interplanetary/interstellar gas

Neutral interstellar gas (hydrogen, helium) is swept through the heliosphere as the solar system moves relative to the local interstellar medium. Properties of this gas, such as its three-dimensional distribution, velocity, density, temperature and H/He abundance, will be determined for the first time by an *in situ* measurement of neutral helium atoms and by optical methods. Two u.v. photometers/absorption cells will measure the neutral interplanetary gas by means of the resonantly scattered solar radiation (1216 Å, 584 Å†).

Cosmic gamma-ray bursts

Cosmic gamma-ray bursts remain, six years after their discovery, one of the outstanding puzzles in astrophysics. A simple technique for locating their sources is the use of a high-accuracy triangulation procedure in which the bursts are detected by three widely separated spacecraft, e.g. an Earth orbiter and two in deep space. The I.S.P.M. with its two widely separated spacecraft and identical detector systems on board will provide a unique baseline to perform these measurements. Indeed, the spacing between these spacecraft is sufficiently large that the location of gamma-ray burst sources may be determined to within less than 10″, more than an order of magnitude better than at present.

† 1 Å = 10^{-10} m = 10^{-1} nm.

Mission details

Instrumentation

Seventeen complex instruments have been chosen jointly by E.S.A. and N.A.S.A. to undertake the scientific investigations on this exploratory mission (table 1). Each spacecraft carries a core of instruments to provide the fundamental measurements of the solar wind, of energetic charged particles over a wide range of species and energies, of solar radio bursts, and of solar X-rays/cosmic gamma-ray bursts. Other instruments will be flown on one of the spacecraft only. The solar imaging instruments will be accommodated on the despun platform of the N.A.S.A. spacecraft. The scientific payload on each spacecraft weighs about 45 kg.

Besides these investigations with dedicated on-board hardware, radio science investigations have been selected that will make use of the spacecrafts radio systems for remote sensing plasma measurements in the inner solar corona during superior conjunction and – potentially – for the detection of gravitational waves. In addition, selected interdisciplinary and theoretical investigators will obtain early access to data from several experimental investigations to analyse specific problems in out-of-ecliptic science. In total, more than 200 investigators belonging to about 65 universities and research centres in 11 countries will participate in this mission.

Spacecraft

Both E.S.A. and N.A.S.A. will provide one spacecraft. The spacecraft will be spin-stabilized at a rate of approximately 5 rev/min about an axis pointing to Earth and be powered by radioisotope thermoelectric generators which can provide about 260 W. The telemetry system will operate in X-band (8 GHz) allowing the transmission of a few kbits/s. Each spacecraft will be tracked by the N.A.S.A. Deep Space Network for approximately 8 h per day. Since continuous data coverage is a prime scientific requirement, each spacecraft will have an on-board mass-storage device of at least 3×10^7 bits capacity. Average scientific data rates for times when there is no telemetry transmission will be about 500 bits/s. During periods of spacecraft tracking the real time data rate will be about 1 kbit/s. More details of the spacecraft configurations have been described by Eaton (1979).

Mission trajectory and schedule

The two I.S.P.M. spacecraft will be launched mated together with the Shuttle/three stage Inertial Upper Stage during a 10-day launch window of the February 1983 Jupiter launch opportunity. After separation of both spacecraft in orbit, their flight paths will be targeted to take them towards Jupiter with a spatial separation of approximately 0.01 AU allowing correlated observations from both spacecraft of small scale variations in the solar wind on a scale comparable to the spacecraft separation. The two spacecraft will arrive near Jupiter within about two days of each other in May 1984. By selecting the proper Jupiter encounter strategy (the two spacecraft will pass slightly south and north of the Jovian equator with a closest approach of about 6 Jovian radii), the gravitational field of the planet will then place both spacecraft into elliptical trajectories with high heliographic inclination which are essentially 'mirror images' of each other (figure 2).

Nearly $2\frac{1}{2}$ years after the Jupiter fly-by, the spacecraft will pass near simultaneously over the northern and southern solar poles, respectively, then cross the plane of the ecliptic and pass above the other solar pole before heading back towards Jupiter's orbit. Thus there will exist two periods during which the two spacecraft will view opposite poles of the Sun. Key dates in the mission time line are given in table 2. The nominal mission is constrained by financial considerations to end not later than 30 September 1987.

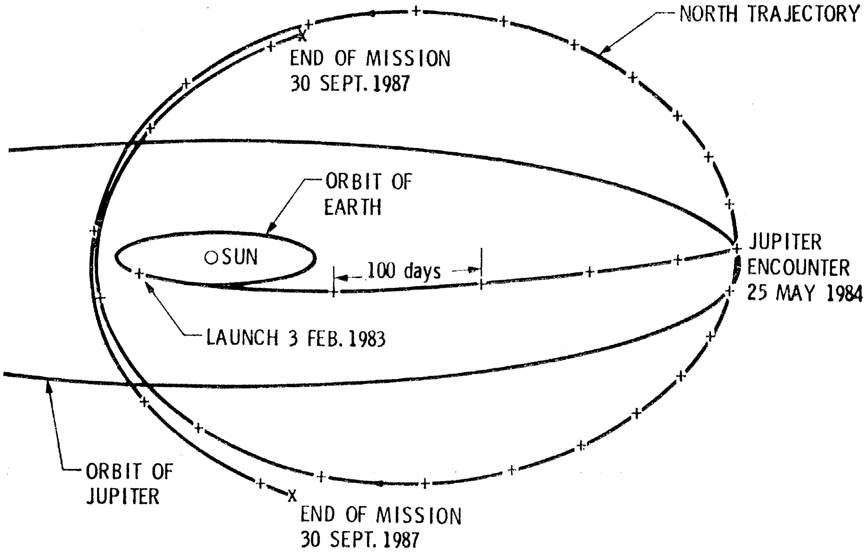

FIGURE 2. I.S.P.M. trajectory overview.

TABLE 2. I.S.P.M. MISSION TIME LINE

launch window	3–13 Feb. 83
superior conjunction	Dec. 83
Jupiter encounter	May 84
first polar pass	Oct. 86
ecliptic crossing	Mar. 87
second polar pass	Jul. 87
nominal end of mission	30 Sept. 87

TABLE 3. I.S.P.M. MISSION CHARACTERISTICS (NOMINAL MISSION, HIGH ENERGY LAUNCH)

	north s/c	south s/c
max. latitude:	89°	79°
days above 70°:		
first polar pass	119	85
second polar pass	118	103
heliocentric range/AU:		
first polar pass	1.98	1.83
second polar pass	1.98	2.01

The detailed mission design is still being evolved. The Science Working Team recommended that the total time spent by each spacecraft above 70° heliographic latitude be maximized, with the proviso that the arrival times of either spacecraft at maximum latitude lie within one solar rotation. There is also to be a minimum time overlap of 2 solar rotations above 70°. For thermal reasons the spacecraft shall not go closer to the Sun than 1 AU (at perihelion) and for scientific reasons the distance from the Sun at maximum latitude shall not exceed 2 AU. Table 3 lists some characteristics of the currently envisaged mission, but work on its optimization still continues. As it can be seen, each polar pass will provide for observation times of at least 3 solar rotations above 70°.

Summary

The I.S.P.M. is a logical next step in our exploration of the Sun and the heliosphere. It will provide, with two well instrumented spacecraft, a first look into a region never previously explored. It will replace our restricted two-dimensional outlook on the heliosphere by the three-dimensional reality. It will answer questions that have plagued solar and heliospheric physics for more than two decades and will undoubtedly discover new and unexpected phenomena. The scientific knowledge about the Sun and the heliosphere that the I.S.P.M. will gain will certainly have its impact on astrophysics on a wider scale.

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