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INTERPLANETARY PHYSICS LABORATORY (IPL)

A CONCEPT FOR AN INTERPLANETARY MISSION IN THE MID-EIGHTIES

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A Concept for an Interplanetary Mission in the Mid-Eighties

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ABSTRACT

A concept for a near-earth interplanetary mission in the mid-eighties is described. The primary scientific objectives would be to: 1) determine the composition of the interplanetary constituents and its dependence on source-conditions and 2) investigate energy and momentum transfer processes in the interplanetary medium. One needs a spacecraft which will carry at least eleven experiments with a combined mass of 70 or 80 kg, which will provide approximately 80 watts of power, and which will maintain a bit rate of at least 2 kb. sec^{-1}. The spacecraft must be sufficiently distant from the earth that it does not see particles and plasma waves associated with the earth, but close enough to maintain the moderate bit rate, e.g., at the earth's libration point. Such a mission would accomplish three important secondary objectives: 1) provide a baseline for deep space missions, 2) investigate variations of the solar wind with solar activity, and 3) provide input functions for magnetospheric studies. In addition, it is possible to intercept a comet (e.g., Halley, Giacobini-Zinner, Borrelly) with the spacecraft and investigate the interaction of the solar wind with a comet using eight of the eleven instruments which are recommended for the primary mission.

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I. INTRODUCTION

An Interplanetary Physics Working Group (IPWG), chaired by Dr. K. Anderson and appointed by Drs. Glaser and Timothy of NASA Headquarters is considering goals for interplanetary physics in the 80's and missions which will be needed to accomplish these objectives. The IPWG has identified two missions for high-priority consideration--an exploratory, "out-of-the-ecliptic" (OE) mission, and an intensive, "near-earth" mission. While the primary emphasis of the OE mission would of course be on discovery, the emphasis on the near-earth mission would be on understanding the interplanetary constituents that have been discovered during the last fifteen years. These constituents include the solar wind, suprathermal ions, electrons, neutral particles from the interstellar medium and their ionization products, energetic particles from the sun, and particles from the galaxy. The outstanding problems concern the composition of the ions and neutral particles, the sources of the particles and their acceleration mechanisms, and the mechanisms by which they interact with one another through electric and magnetic fields. This knowledge is of fundamental importance for solar system studies, it has applications to other astrophysical systems, and it is important to physics in general.

The purpose of this report is to discuss the scientific rationale for a near-earth interplanetary mission and to describe instruments and trajectories which are appropriate for this mission.

II. SCIENCE OBJECTIVES

The mission is designed to investigate the interplanetary constituents in the neighborhood of Earth. The primary objectives of this mission are the following:

1) a. Determine the particle's chemical, isotopic and charge-state composition;

   b. Identify their sources and the dependence of composition on source conditions.

2) Investigate the basic energy and momentum transfer processes.

The following important but secondary objectives can be accomplished with essentially no extra cost:

1). Provide a 1 AU baseline for deep space missions.

2). Investigate variations of the solar wind with solar activity.

3). Provide interplanetary input functions for magnetospheric studies.

There is also a mission option to investigate the interaction of the solar wind with a comet, since Giacobini-Zinner, Borrelly and Halley will pass near the spacecraft in the 1985 to 1987 period.

III. SCIENCE RATIONALE: PRIMARY OBJECTIVES

A. Composition and Sources of Interplanetary Constituents

1. Solar Wind

Several basic questions concerning the solar wind and the solar atmosphere remain unanswered:

a). How is the solar wind accelerated?

b). What are the sources of solar wind streams, jets, and quiet wind?

c). How do elemental abundances vary spatially and temporally in the solar atmosphere?

d). What is the composition of the undifferentiated solar atmosphere?

The solar wind acceleration problem is important in astrophysics because it is thought that stellar winds are of primary importance in angular momentum loss. One theory proposes that the acceleration takes place very close to the sun. Another theory proposes that the wind is accelerated by heat deposition in a region between ≈ 2 to 25 $R_\odot$. With charge composition measurements, one could determine the thermal state at the "freezing-in" height. Given density versus radial distance, one can determine the temperature at various heights and thus directly test the extended heating theory.

The sources of the solar wind are poorly understood. Some post-shock flows (jets) can be attributed to solar flares, but many such flows have been observed which cannot be related to flares. Some high-speed streams probably originate in coronal holes, but it is possible that many streams originate in open field regions that are not associated with holes. It has been suggested that low-speed wind might come from the edges of coronal holes, from the separatrices of active regions, or from the sites of coronal transient events, but none of these possibilities has been confirmed and other possibilities cannot be excluded. It is likely that the composition is different in the various sources listed above, so a measurement of the detailed composition of the solar wind is likely to aid in distinguishing among these sources.

The solar atmospheric abundances must be highly structured in some places and at some times, as indicated by variations of solar wind He abundance by a factor of 100 and variations of solar wind O, Si, and Fe abundances from 4 to 10 times. Continuous and more detailed measurements of the solar wind abundances will contribute significantly to our understanding of the spatial and temporal structure of the solar atmosphere and the fractionation that takes place there.

The composition of the undifferentiated solar atmosphere is of fundamental importance to theories of stellar interiors, nucleogenesis, and origin of the solar system. Although this mission cannot provide the final answers, one cannot arrive at an equivalent, undifferentiated solar atmosphere without understanding the spatial and temporal variations that exist; as described in the preceding paragraph, this mission can significantly contribute to that understanding.

<u>Measurements</u>. In order to accomplish the objectives discussed above, one should measure distribution of charged states of the dominant solar wind ions through Fe with 10 min time resolution under all solar wind conditions. One needs an instrument with $\Delta Q \leqslant 1$ for $Q < 20$ and $\Delta m/m \leqslant 0.05$.

The past and planned measurements of the solar wind are of two types--energy per charge measurements and energy per charge plus velocity selection measurements. The energy per charge measurements resolve only some of the charge states, and then only when the temperature (and hence the speed) is low. Thus, such measurements provide no information about coronal conditions responsible for accelerating the hot, high speed wind. The second type of measurement is inherently superior. Although good measurements of the oxygen charge states should be made by the composition experiment on ISEE, there remains a need for an instrument with higher charge resolution up through Fe which is capable of such measurements under all solar wind conditions.

2. Suprathermal Ions ($\approx$10 keV/n to $\approx$500 keV/n)

Suprathermal ions probably consist of a mixture of particles from at least two general sources--the sun and the interplanetary medium. The solar particles are perhaps accelerated in flares and active regions. The interplanetary particles are presumably accelerated locally, from the solar wind population, by phenomena such as shocks, magnetic merging and magnetic fluctuations. A major objective is to distinguish solar and interplanetary suprathermal ions. This can be accomplished by measuring the charge composition. The mix will change with time, so it is necessary to make continuous measurements of both the suprathermal particles and the solar wind. In order to identify particular sources (e.g., flares, shocks, merging regions) simultaneous measurements of the interplanetary magnetic field and plasma, and solar features are also needed.

A second objective is to identify the mechanisms which accelerate suprathermal particles. Several mechanisms have been proposed. Each mechanism affects the composition and spectrum in a different way. For example, an electric field accelerates particles proportional to eZ/m, whereas a Fermi mechanism accelerates particles proportional to rigidity. Thus by measuring the composition, one can make definitive choices among acceleration theories.

Measurements. One should determine the charge and mass composition of suprathermal particles through Fe with a time resolution of ≈ 1 min. For energies $\leqslant 100$ keV/n, one needs a charge resolution $\Delta Q/Q \leq 0.05$, a mass resolution $\Delta m/m \leq 0.15$, and a geometrical factor $\approx 10^{-3}$ cm^2 sr.

No charge composition measurements have been made or are planned for particles $\leqslant 100$ keV/n and $\geqslant 10$ keV/n.

3. Interplanetary Neutral Particles

The neutral atoms in the interplanetary medium are presumably primarily of interstellar origin. The presence of neutral H and He has been detected indirectly, but no direct *in situ* measurements have been made and there are no measurements of the heavier atoms. With measurements of these particles one can accomplish the following objectives:

a). Investigate the chemical composition, density, temperature, and speed of the nearby interstellar medium.

b). Investigate the formation and initial velocity distribution of singly charged ions from interstellar neutrals, the acceleration of such ions in the solar wind, and their contribution to heating the solar wind.

Measurements. One should determine the properties of neutral H, He, C, N, O, and Ne as a function of azimuthal angle in the ecliptic plane.

4. Energetic Solar Particles

Recent interplanetary measurements have identified two new types of events associated with small solar flares: He^3 rich events, and heavy ion rich events. In He^3 rich events the ratio of He^3/He^4 can exceed unity; in heavy ion rich events, the abundances of iron and oxygen are about equal. Little is known about these events, because of the lack of adequate sensitivity of current instruments. In particular, the reason for the anomalous composition is not known. It is not known, for example, whether the composition is due to processes such as spallation in the source region or to a selective acceleration process. Thus, a major objective is to determine the chemical, isotopic and charge composition of MeV particles from small flares, and investigate the mechanisms which produce the "anomalous" composition in small flares. A second objective is to investigate the composition of solar surface matter; and this can be done by measuring the isotopic composition of solar energetic particles heavier than He through Fe in the range 1-100 MeV/n.

Measurements. In order to determine chemical, isotopic, and charge state composition of MeV particles from small flares, one needs large area detectors ($\sim$100-500 cm^2 sr) with a mass resolution $\Delta m/m \leqslant 0.05$ and a time resolution of 1-5 hours. A separate instrument is needed for isotopic composition between He and Fe in the range 1 to 100 MeV. It is desirable to have simultaneous measurements of γ rays, since the presence of γ rays would unambiguously show the presence of nuclear reactions and could aid in investigating acceleration mechanisms in the flare site.

B. Energy and Momentum Transfer Processes

The solar wind near earth (1 AU) is a fully ionized, collisionless, magnetized plasma consisting primarily of electrons and protons. An understanding of the basic physical processes in this plasma is essential for developing models for the streams, shocks, and waves which relate solar and terrestrial (or planetary) activity. Since very similar plasmas occur in stellar winds, supernovae remnants, galactic nuclei, and perhaps other astrophysical systems, the solar wind truly serves as a laboratory for cosmic plasma physics. The following paragraphs discuss just some of the collisionless plasma processes that can be investigated with the IPL, viz., shocks and current sheets, waves and fluctuations, heat flux and related instabilities, ion driven waves and instabilities, and type III bursts and electron beam stability.

1. Shocks and Current Sheets - Shocks and current sheets are of special interest for plasma investigations for several reasons. Their thickness is on the order of a few proton gyroradii, so they must necessarily be described by plasma kinetic theory; they are sites of a variety of possible waves and instabilities, and they offer the great advantage of being localized with well defined geometries, thus presenting well-posed problems for theoretical studies. Interplanetary fast shocks are relatively weak compared to the earth's bow shock, so a study of their structure would complement studies of bow shock structure, which have been very fruitful. Slow shocks have been identified in the solar wind, but their structure has not been studied; they are of special interest, because their structure has never been investigated in earth laboratories or elsewhere. In the magnetic field, current sheets in which

the magnetic field intensity drops to zero have been identified. Some of these are associated with whistler-type waves, but the mechanism of wave generation cannot be determined, because plasma measurements have not been made with sufficient resolution. Other such current sheets have been shown to be sites of magnetic merging, but there is no information available about the plasma processes associated with them.

Specific objectives thus include the following: 1) investigate the structure of slow shocks and weak fast shocks; 2) determine the structure and stability of current sheets, and 3) investigate the plasma processes associated with magnetic merging in the solar wind. The measurements needed for these studies include 1) high resolution ($\leq$ 0.1 sec) measurements of the density temperature and speed, 2) high time resolution (0.05 sec) measurements of the magnetic field, and 3) measurements of the plasma wave spectrum.

2. Waves and Fluctuations - The solar wind contains a great variety of waves and fluctuations, most of which are poorly understood. Let us consider just two examples. Magnetic field measurements on the MVM S/C revealed the frequent occurrence of waves near the ion gyrofrequency; they could be ion cyclotron waves or perhaps whistler waves, but one needs simultaneous measurements of the complete ion distribution function to definitely identify them and to determine their cause. Interplanetary scintillation measurements provide a very valuable tool for remotely studying the solar wind out of the ecliptic and close to the sun, but there remains a controversy about the nature of the fluctuations that cause the scintillations; with sufficient time resolution of the plasma measurements one could end this controversy by determining whether

the fluctuations are a special class of waves with a scale on the order of a gyroradius, or whether they are much larger scale waves that are an extrapolation of the wave spectrum that has been observed at very low frequencies.

The basic objective is thus to identify the nature of the fluctuations near the ion gyrofrequency, determine their origin, and investigate their effects on particle velocity distributions. The measurements needed are the same as those described in Section B1.

3. Solar Wind Heat Flux - Electron heat conduction provides a major means of energy transport in collisionless plasmas. A thorough knowledge of the conduction process is therefore essential for understanding the behavior of physical systems containing hot plasmas. There is some disagreement as to how to describe the heat conduction process itself. In one view, heat near 1 AU is carried primarily by a "halo" of electrons $\gtrsim$ 60 eV which move away from the sun relative to the solar wind rest frame at a speed ΔV_H, accompanied by a return current of cold electrons with a drift speed ΔV_C. In another view, the core and halo electrons have the same convection speed, and heat conduction is the result of an asymmetry in the forward and backward moving halo electrons. In the first view, heat regulation occurs as the result of one of three possible instabilities which arise when ΔV_H and ΔV_C become sufficiently large compared to the Alfvèn speed. The regulation mechanisms in the second view of heat conduction have not yet been completely worked out. Some progress in understanding heat transport in a collisionless plasma can be made by searching for waves generated by the instabilities which are predicted to occur by linear plasma theory. It is likely that a basic understanding

of the physics of heat conduction in a collisionless plasma requires a fundamentally non-linear and inhomogeneous theory in which the particle distributions locally maintain an equilibrium with self-consistent wave fields.

Thus, the basic objective is to understand the nature of heat conduction and the processes which regulate heat conduction in a collisionless plasma. The measurements needed are high time and spectral resolution measurements of the 3-D electron distribution and the ion distribution, measurements of the magnetic field with comparable or higher time resolution, and a complete set of electric and electromagnetic wave diagnostic measurements.

4. Ion Beam Regulation - Generally, proton distributions in the solar wind are complex and better described in terms of two convecting components than in terms of a simple bi-Maxwellian, and generally the alpha particles move with a bulk speed different from that of the protons. Such relative motions can be unstable. An understanding of the internal state of the dominant solar wind ions thus seems to require at the least a knowledge of ion beam driven instabilities in a collisionless, magnetized, high β plasma. For example, it is possible that the relative speed between two interpenetrating proton streams should at some distance from the sun equal or exceed the Alfvén speed (which decreases with distance from the sun); at this point one of three possible electromagnetic modes will be driven unstable depending on the parallel β of the main proton component. Similarly, the relative motion between alpha particles and protons might generate waves (e.g., ion cyclotron waves) which could then damp and reduce or control the relative speed between the ions.

The general objective is thus to determine the relative streaming motions among ions in the solar wind and identify the plasma processes which regulate these motions. Progress towards the end requires high spectral resolution measurements of the proton, He^{++}, and electron distributions, high time resolution measurements of the plasma density, DC magnetic field measurements, and high quality plasma wave observations.

5. Type III Radio Emissions and Electron Beam Stability - Type III bursts consist of radio waves which drift in frequency from high values above 100 MHz to low values near about 10 kHz. It is now reasonably certain that they are excited at twice the local plasma frequency by solar generated electron beams with peak energy between 5 and 100 keV. These observations pose two basic theoretical questions: a) How does an electron beam in a low density plasma transfer energy to plasma oscillations without disrupting the beam?; and b) How are plasma waves converted to electromagnetic radio waves? The answers to these questions are essential for proper data interpretation in much of radio astrophysics.

The basic beam-plasma mechanism responsible for the production of longitudinal electrostatic plasma waves has been known for some time. However, subsequent interactions between the waves and the exciter beam, as well as among the waves, which lead both to beam disruption and electromagnetic radio waves, are not very well understood. For example, the most important non-linear mechanisms which couple a plasma wave to ion density fluctuations and to other plasma waves do not scatter the pump radiation out of resonance with the initial electron beam. This fact has two important consequences. First the insufficiently scattered plasma radiation will react back on the electron distribution in such a way as to remove the free energy which drives plasma waves initially unstable. A marginally stable state will therefore be quickly established. Second, excitation of electromagnetic radiation at twice the local plasma frequency is thought to require two plasma waves traveling in opposite directions. This process has been described by a non-linear one-dimensional theory. However, an alternative theory, based only on the linear growth phase of an instability shows that a three-dimensional calculation gives faster growing instabilities than the 1-D theory, but it does not produce oppositely propagating plasma waves.

A basic objective of this mission is to identify the mechanism(s) of exciting type III radio bursts. Since there are now several theories which make definite and distinctly different predictions about the waves that will be generated, it is reasonable to expect that this objective can be achieved, given the following measurements: high-time resolution ($\sim$ 1 msec time constants) measurements of the amplitude and k-vector orientation of the plasma waves, and simultaneous 3-dimensional measurements of 5 to 100 keV electrons.

6. In Situ Acceleration of Energetic Particle - Viewed from a distance, the heliosphere must appear like a source of energetic particles. Most of these particles are injected with high energy into interplanetary space by acceleration mechanisms in the lower solar atmosphere. However, several different experimental observations indicate that some of these particles are also accelerated by mechanisms in interplanetary space. An understanding of these mechanisms is of fundamental importance to astrophysics and plasma physics.

One of the many possible acceleration mechanisms involves the acceleration of interstellar neutral atoms which penetrate into the heliosphere and become singly ionized by either photoionization or charge exchange collisions. Subsequent to ionization, a small fraction of these particles get accelerated by the solar wind up to energies of about 10 MeV per nucleon.

In the following we concentrate on He^+ of interstellar origin because it is most abundant and should be representative of the heavier ions such as N^+, O^+, and Ne^+. The evolution of He^+ velocity distributions subsequent to photoionization is not known. The anisotropic distribution shapes which should evolve in the absence of wave-particle interactions have been shown to be unstable. Since initial time scales for wave growth are short compared to the solar wind expansion time scale, it has been postulated that He^+ ions become quickly incorporated into the solar wind. However, a non-linear analysis has not been made so that wave saturation levels and consequent energy and pitch angle diffusion times are not known. It is therefore theoretically possible that in addition to the above suggestion, the He^+ ions (2) evolve adiabatically, (3) become isotropized but not thermalized by subsequent wave-particle interactions, or (4) are accelerated by transit time damping of a spectrum of fast mode waves present in the outer solar wind. A comprehensive search of existing solar wind heavy ion spectra yielded only upper limits which were an order of magnitude lower than that expected if interstellar He^+ ions are quickly thermalized. Thus, although it is possible that occasional solar wind conditions can lead to complete assimilation, most often He^+ velocity distributions must remain diffuse. The first possible evolution sequence mentioned above can therefore not be dominant. On the other hand, an anomalous component of energetic ions has been observed in interplanetary space, and plausibly interpreted in terms of the acceleration of a small fraction (10^{-4}) of the initially low energy heavy ion population (including He^+) of interstellar origin. These observations seem to favor alternative 4. However, since the number fraction of the ions actually observed with high energy is exceedingly small, a firm decision cannot be made at present.

One objective of this mission is therefore to investigate the ionization of interstellar neutral particles, the acceleration of these ions, and the subsequent evolution of their distribution functions. To achieve this, one needs measurements of the interstellar neutral particles of the distribution functions of ions such as He^+, N^+, O^+ and Ne^+, and measurements of plasma waves which might be driven unstable by these distribution functions.

IV. SCIENCE RATIONALE: SECONDARY OBJECTIVES

A. 1 AU Baseline

A spacecraft will presumably be launched out of the ecliptic in the early 80's, and it is possible that the MJS S/C will continue to measure properties of the distant interplanetary medium at that time. In order to identify latitudinal and radial gradients using measurements from those S/C, it is essential to have baseline measurements at 1 AU, because the solar wind changes with time. In particular, a baseline is needed to measure large-scale gradients in the solar wind, the flux of galactic cosmic rays, the distribution of interstellar neutral particles and the flux of solar particles which are redistributed by propagation processes. The necessary measurements would be provided by some of the instruments needed to accomplish the primary objectives discussed above.

There are definite plans for a Jupiter orbiter in the early 80's. This spacecraft will remain within Jupiter's magnetosphere, and no provisions have been made for simultaneous interplanetary measurements. Jupiter's magnetosphere is highly variable, and it is possible that there are qualitatively different large-scale configurations of Jupiter's magnetosphere corresponding to different mesoscale configurations of the solar wind, so knowledge of the input function is essential for understanding Jupiter's magnetosphere. By the early 80's, it should be possible to calculate mesoscale solar wind conditions near Jupiter given suitable measurements at 1 AU, so the proposed near-earth mission could perhaps provide the input function needed for the JO studies.

B. Long-term Variations of the Interplanetary Medium

The global pattern of plasma characteristics in interplanetary space provides information concerning large scale patterns of whatever in the sun is responsible for driving a high speed coronal expansion. For example, synoptic observations of the solar wind speed between 1962 and 1975 showed that high speed flows evolved from preferred longitude regions which rotated rigidly with the sun. Furthermore, the pattern of observed high speed conditions became very stable and the amplitudes and widths of individual streams became very large just prior to the minimum of solar cycle number 20. This situation was also reflected in the observed pattern of enhanced geomagnetic activity. Perhaps these patterns indicate the presence of giant convection cells present below the photosphere but this is not known.

A search through past records of geomagnetic activity indicate that solar cycle number 20 was different from cycles 11 through 19. Although even and odd 11-year cycles are generally different, the second peak in geomagnetic activity during this past cycle was unusually high. To obtain a more representative picture of variations of interplanetary conditions associated with the solar activity cycle, it is necessary to measure characteristics of the sun and solar wind for at least one more 11-year period.

The record of the past solar cycle is incomplete. Some long periods are not covered at all; there are many gaps in the record corresponding to times when the medium was monitored by earth-orbiting spacecraft that were periodically shielded from the solar wind by the magnetosphere; and there are gaps due to failures of instruments. Furthermore, there has been a considerable evolution during the past decade in the types of measurements that are possible, due to the development of better instruments. Thus, it is desirable to continue to make measurements of the solar wind into the next solar cycle in order to study long-term and short-term variations that were missed during the last cycle. Furthermore, there is the possibility that the next cycle will be rather different from the last cycle.

C. Input for Magnetospheric Studies

Studies of the earth's magnetosphere will undoubtedly continue into the early 80's. Since magnetospheric activity is driven by interplanetary conditions, there will be a need for continuous measurements of the solar wind and magnetic field near the earth at that time. It is likely that magnetospheric research in the eighties will focus on composition studies and on plasma physics investigations. Clearly the proposed IPL would be complementary to and highly compatible with such studies. Although much could be achieved by simply making the results of the IPL available to the magnetosphere community on a timely basis, the scientific return would be greater if magnetosphere studies were carefully coordinated with the IPL mission.

V. COMET OPTION

Three comets are possible "targets of opportunity" for this mission. Giacobini-Zinner and Borrelly can be intercepted if the spacecraft is in a highly elliptical earth orbit. Alternatively, Comet Halley could be intercepted if the spacecraft moves near the earth in a slight inclined (few degrees), nearly circular solar orbit.

Several fundamental cometary problems can be solved with the instruments designed for the interplanetary objectives described above. These include the following:

1. Determine the nature and morphology of the solar wind-comet interaction.
2. Investigate the basic ionization mechanisms in the coma.
3. Investigate the structure, motion, composition, and magnetic fields in the coma and tail.

Solutions to all of these problems would be enhanced by coordinated, simultaneous observations from the ground. The viewing geometry and the time of intercept should be considered when the trajectory is chosen.

Basic features of the nature of the solar wind-comet interaction include the following: the position and structure of the transition region between interplanetary plasma and cometary plasma; the deceleration of solar wind plasma and production of energetic ions in the coma by charge exchange; the cooling of interplanetary electrons in and near the coma; the distortion of interplanetary magnetic fields near the coma by convection, magnetic diffusion, and instabilities, and the induction of magnetic fields by currents in the coma and tail; the existence, location, strength, and structure of a bow shock.

The instruments needed for these investigations are a solar wind plasma analyzer, a magnetometer, plasma wave detectors, a suprathermal electron analyzer and a mass spectrometer. A suprathermal ion detector is also applicable.

Although ions and radicals in the coma have been extensively studied for many years, it is not known how they are produced. At least three ionization mechanisms can be investigated by the IPL instruments: electron impact, charge exchange, and the critical velocity effect. Electrons with energies from a few ev to greater than a few hundred keV can ionize neutral molecules; they are present in the solar wind, and they can probably be accelerated in the bow shock and transition region surrounding the comet. Charge exchange is certainly taking place and is important in several respects. The critical velocity effect is an ionization process that has been observed in the laboratory when a collisionless, magnetized plasma interacts with a neutral gas; it is poorly understood, and its relative important in comets is not known.

In the coma, magnetic fields can possibly be produced by diffusion from the solar wind and by induced currents in the comet's ionosphere. Nothing is known about them, but they could be important in regard to the penetration of the solar wind into the comet. The motions of the coma material, the ionization processes, the fine structure of the coma, the morphology of the coma can be outlined, the motions of some constituents can be studied, and the composition of some ions can be identified by instruments carried on the IPL for interplanetary studies.

Of particular interest is the manner in which material is carried into the tail of the comet. This material, ionized molecules such as CO^+, OH^+, and H_2O^+, flows down the tail and eventually becomes part of the expanding solar-wind plasma. The motion of features in the ion tail can be interpreted as due to this outlow, but they can also be interpreted as wave motion. Considerable fine structure in the form of rays is found in the ion tail strongly implying the presence of a magnetic field generally aligned parallel to the tail axis. The morphology of streamer development strongly supports the idea that the magnetic field is captured from the solar wind and anchored in the cometary plasma surrounding the nucleus. The tail field can be estimated at $\gtrsim 10^2 \gamma$ (for a comet near 0.5 AU) and currents $\sim 10^8$ to 10^9 A. may flow along the tail. The overall orientation of the tail is known, on the average, to be determined by the local streaming direction of the solar-wind plasma. The precise orientation of the comet tail is important since it has been used to estimate the angular momentum flux carried by the solar wind. This mission would therefore provide a specific calibration of the technique utilizing comet tail orientations to estimate the rate of solar spin down.

The morphology of streamer evolution indicates a wrapping of magnetic field lines around the nucleus and a subsequent turning to the tail axis in a manner picturesquely described as a "folding umbrella". This means that fields of opposite polarity are constantly being pressed together in a neutral sheet which contains the tail axis. We may expect a wide variety of plasma phenomena to occur--possibly including reconnection of field lines and cross-tail currents. If any of these currents are discharged through the coma, they could provide the ionization process discussed below.

The cometary scientific objectives outlined above can be accomplished without special cometary instruments on the IPL. Conversely, most of the instruments which should be carried on the IPL to accomplish the primary objectives of the mission can be used with little or no change to make the cometary measurements discussed above (see Table 1). This fast-fly-by comet option would not replace a comet-dedicated mission, but would complement such a mission. For example, it could complement a Comet Halley investigation either by providing advance information to investigators mission planners from a Giacobinni-Zinner intercept several months prior to a Halley intercept or by intercepting Halley itself in a region not sampled by a Halley-dedicated spacecraft.

TABLE 1

Interplanetary	Mass (kg)	Power (watts)
* Solar Wind Composition Analyzer	15	10
* Suprathermal Ion Detector	10	6
* Neutral Interstellar and Cometary Particle Detector	5	4
* High Resolution Plasma Analyzer	12	6
* Energetic Electron Detector	6	5
* 3-D Solar Wind Spectrum Analyzer	6	5
* Plasma Wave Detector	10	9
* Magnetometer	3	5
Solar Energetic Particles	10	7
Galactic Cosmic Ray Detector	15	7
Radio Wave Detector	8	7
TOTALS†	100	71

* Applicable to comet intercept with essentially no modification.

† If the comet option is chosen, it would be necessary to include an ion mass spectrometer (7 kg and 10 watts) and it would be highly desirable to include a dust analyzer (6 kg, 4 watts).

VI. PAYLOAD

Table 1 lists the instruments needed to accomplish the scientific objectives discussed in the preceding sections. It is possible that some additional instruments of merit will be proposed, and some provision must be made to accommodate them. Many of the instruments listed in Table 1 are entirely new or significantly different from previously flown instruments, so it is difficult to accurately estimate the weight and power requirements. The numbers in Table 1 are thus rough estimates, but they are conservative. The instruments are arranged in two groups: The first consists of experiments that apply to both intensive interplanetary studies and to cometary studies; the second consists of experiments that apply to interplanetary studies only. Note that the comet-intercept option places a negligible constraint on the payload, and that conversely most of the "interplanetary" instruments can be used for comet studies.

VII. TRAJECTORIES

The scientific objectives discussed above put two constraints on the trajectory: 1) the spacecraft must be in the solar wind and far enough from the earth that it is undisturbed by particles and fields related to the earth and 2) it must be close enough to earth that moderate bit rates of 2 kbps can be maintained. At least three trajectories are consistent with these constraints: 1) a halo orbit around the sunward libration point similar to ISEE-C; 2) a circular orbit similar to the earth's, but inclined several degrees to the ecliptic. (In this orbit the spacecraft oscillates in a north-south direction relative to the earth with a period of 1 year thus allowing the study of latitudinal variations over $\approx 6^{o}$); 3) A high elliptical orbit about the earth with an apogee of ≈ 0.3 AU. The second of those options is compatible with an intercept of Comet Halley in December 1985, and the third is compatible with an intercept of Comet Giacobini-Zinner in September 1985. The selection of the trajectory need not be made within the next few years, but the two primary constraints given above cannot be relaxed if one is to achieve the scientific objectives discussed above.

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COMET GIACOBINI-ZINNER SUMMARY

Observational History: Giacobini-Zinner has been observed at nine apparitions since its discovery in 1900. Because of unfavorable orbital geometry it was poorly observed at two apparitions (1940, 1966) and missed completely in 1907, 1920, and 1953. However, numerous observations of its behavior near perihelion were obtained in 1946, 1959, and 1972 when it passed relatively close to the earth. Giacobini-Zinner is one of the brightest periodic comets when it is near perihelion. It is noteworthy that the absolute luminosity of this comet appears to be constant or even increasing with time. Irregular brightness variations over periods of a few days have been reported.

Nuclear Region and Coma: A well-defined nuclear condensation develops near perihelion. Observations in 1972 suggest that Giacobini-Zinner possesses an inner and outer coma. The observable diameter of the outer coma is $\sim 5 \times 10^4$ km, while the diameter of the inner coma is about 2×10^4 km. The spectrum of Giacobini-Zinner shows a strong continuum which indicates a large dust component. The abundances of CN and C_2 radicals have been compared with Encke, and it was found that while the abundance of CN was approximately equal in both comets, the abundance of C_2 was greater for Encke.

Tail: A narrow straight tail begins to develop about three months prior to perihelion. Near perihelion, the observed tail length is $\sim 5 \times 10^5$ km. A dust tail has also been reported.

Dust: Giacobini-Zinner is quite dusty for a short-period comet. Its dust density is estimated to be about 50 times greater than Encke's but is probably 1000 times smaller than Halley's. The Giacobinid (or Draconid) meteor showers that are associated with Giacobini-Zinner have probably been the most spectacular meteor displays of the present century. These showers were particularly strong in 1933 and 1946. Studies by Jacchia et al. [5] of the 1946 shower indicate that the Giacobinid meteors are abnormally fragile as compared with meteors from other showers.

Nongravitational Effects on Orbital Motion: A rigorous investigation by Yeomans[6] has shown that Giacobini-Zinner's nongravitational forces have increased with time over the 1900-1965 interval. (This unusual characteristic is shared with Biela's comet which disappeared in 1852). The orbital motion of Giacobini-Zinner is somewhat erratic as indicated by the 1972 observations which imply that the nongravitational forces have decreased or stopped altogether. An apparent discontinuity in the comet's motion between 1959 and 1965 should also be noted.

COMET BORRELLY SUMMARY

Observational History: Borrelly has been observed at nine apparitions since its discovery in 1904. Excellent orbital geometry during its first four apparitions (1905, 1911, 1918, 1925) produced a large number of observations. However, a perturbation by Jupiter in 1936 changed Borrelly's period, and the geometric conditions for near-perihelion observations have been poor ever since that time. Borrelly was not observed at all in 1939 and 1946. Fortunately, another perturbation by Jupiter in 1972 has again changed Borrelly's period so that favorable orbital geometry will be available in 1981 and 1987. From the numerous early observations, it has been well-established that Borrelly is quite active for a comet with a perihelion distance of about 1.4 AU.

Nuclear Region and Coma: A bright nuclear condensation has always been observed when favorable geometric conditions have existed. The observable coma diameter is $\sim 5 \times 10^4$ km. No spectroscopic observations have been reported.

Tail: A narrow bright tail has been observed during six of the apparitions, and generally persists for several months. Observed tail lengths are $\sim 5 \times 10^5$ km.

Dust: No data available.

Nongravitational Effects on Orbital Motion: The nongravitational forces affecting the motion of Borrelly have been investigated by Yeomans.[6] It was found that although Borrelly is affected by substantial nongravitational forces, the transverse component of the nongravitational acceleration has remained constant over the entire 70-year observational interval.

COMET HALLEY SUMMARY

Observational History: Halley's comet has been seen at every apparition since at least 86 B.C., making twenty-seven appearances in all. It is a spectacular object displaying physical characteristics of a typical long-period comet, and was observed extensively during its 1910 apparition. Its exceptional brightness is indicated by the fact that naked-eye observations were recorded over a four-month interval at this apparition. Brightness estimates taken from the 1910 data imply that Halley's absolute luminosity is nearly two magnitudes brighter after perihelion.

Nuclear Region and Coma: Halley's very bright nuclear region has been estimated to be several thousand kilometers in diameter. The failure to observe a solid nucleus when Halley transitted the sun on May 18, 1910 gives an upper bound of 50 km to any solid nucleus for this comet. Diameters for the visible coma near 1 AU in the post-perihelion phase are $\sim 5 \times 10^4$ km for the inner coma and $\sim 3 \times 10^5$ km for the outer coma. The spectrum of the coma region is almost entirely CN and C_2 superimposed on a continuous background. Jets and streamers invariably showed CN specta. A number of transient phenomena were observed in the inner coma region. Explosive activity was particularly well established in April, May, and June 1910. Temporary secondary nuclei were observed to coalesce with the primary nucleus after a few hours or days.

Tail: Two well-developed tails were seen in 1910. One was primarily gaseous (CO^+), and the other was mainly dust. Near its maximum, the observed tail length was ~ 0.35 AU. Several tail condensations ("knots") were also observed.

Dust: Halley is a very dusty comet. Dust densities are probably 1000 times greater than those found in dusty short-period comets.

Nongravitational Effects on Orbital Motion: A rigorous examination of Halley's nongravitational accelerations has not been completed as yet. However, it is known that the nongravitational effects amount to an average lengthening of Halley's period by 4.1 days at each apparition.

III. ACCELERATION AND ENERGY TRANSFER PROCESSES IN THE COLLISIONLESS INTERPLANETARY PLASMA

A. SHOCKS AND DISCONTINUITIES.

B. WAVES AND FLUCTUATIONS.

C. TYPE III BURSTS AND ELECTRON BEAM STABILITY.

D. HEAT FLUX INSTABILITIES.

E. ION DRIVEN WAVES AND INSTABILITIES.

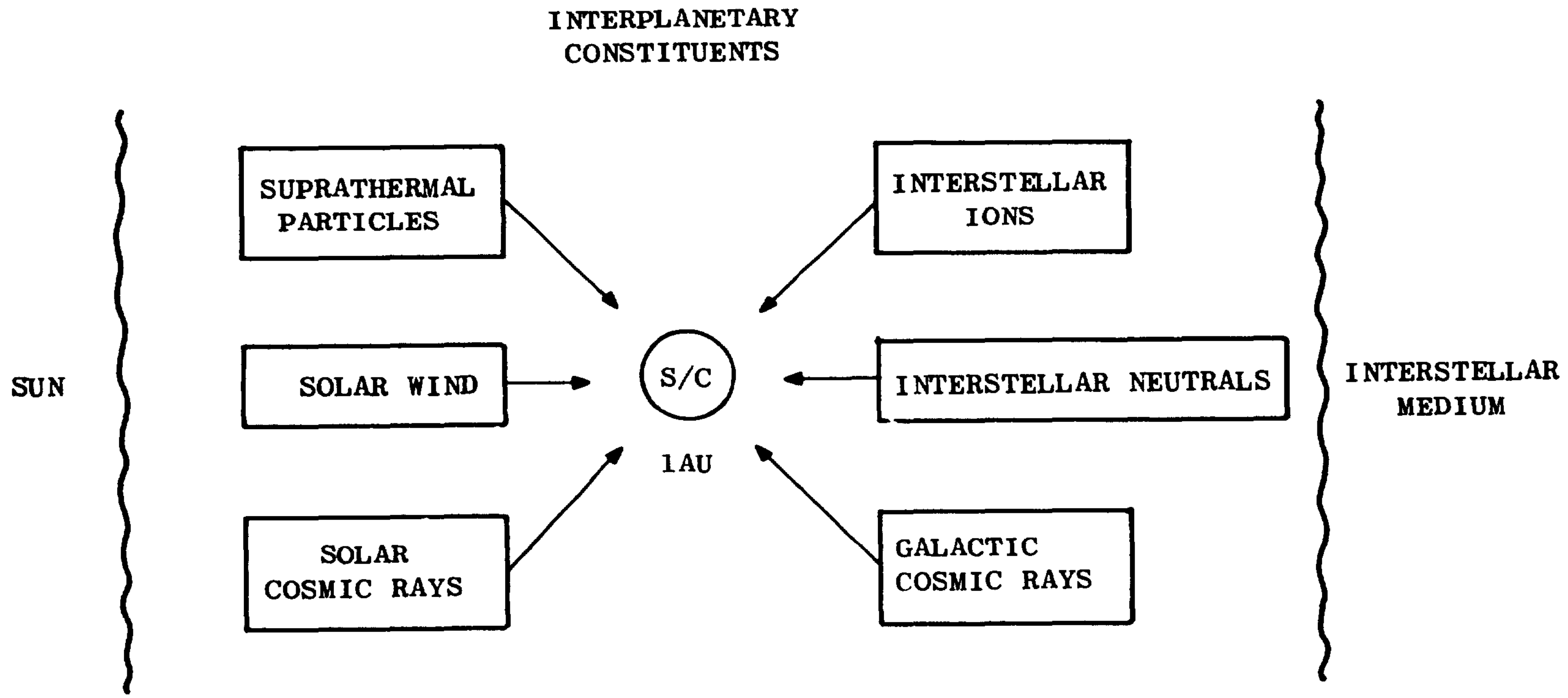
INTERPLANETARY
CONSTITUENTS
SUN
SUPRATHERMAL PARTICLES
SOLAR WIND
SOLAR COSMIC RAYS
S/C
1AU
INTERSTELLAR IONS
INTERSTELLAR NEUTRALS
GALACTIC COSMIC RAYS
INTERSTELLAR
MEDIUM

Figure 1