49 THE INTERPLANETARY PLASMA AND THE HELIOSPHERE
(Plasma Interplanetaire et l'Heliosphere)

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INTRODUCTION

The Commission is intended to study the origin of the solar wind, the heliosphere, i.e., the region dominated by the supersonic solar wind, and the heliospheric interface with the interstellar medium. The activities of the Commission cover both theoretical and observational aspects of these three regions.

This report covers work on large scale phenomena in the Heliosphere, and my thanks are due to Dr. S.T. Suess for providing the material.

LARGE SCALE PHENOMENA IN THE HELIOSPHERE

Overview

This section deals with the detection, description and modelling of large-scale phenomena. A comprehensive understanding of these phenomena generally requires data from several souces in order to obtain a global view. Presently, continuing analysis of radio observations, of space-craft data from inside and outside the orbit of the earth and of lengthy data sets from earth-orbiting spacecraft are producing new discoveries. Recent discoveries include magnetic clouds, compositional changes associated with coronal streamers and the ability to track streamers to 1 AU using type III radio bursts. The interplanetary signature of coronal transients continues to be unclear, but some ideas have been advanced.

In the following three sections, spatial gradients, stream interaction and the propagation of transient disturbances are discussed in A, the heliospheric current sheet in B and the interplanetary signature of coronal expansion and transients in C. Many of the results and associated theoretical developments are in reviews or summaries of recent research by Burlaga (1983), Cuperman (1983), Schwartz (1981), Schwenn (1983), Smith (1983) and Wu (1983). This research summary is not intended to be comprehensive. Several specific topics are highlighted, with representative references supplied for each.

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Spatial Gradients and Dynamic Interactions

Pioneer 10 is now beyond the orbit of Pluto. Data from this spacecraft, together with data from Voyagers 1 and 2, Pioneer 11, Helios 1 and 2, IMP 6, 7 and 8, Explorers 34 and 35, and ISEE 3 are being used to define radial gradients of solar wind properties. Smith and Barnes (1983) review the spatial dependences of the solar wind plasma and magnetic field between 1 and 20 AU using the Pioneer data and compare the measurements with both the Parker theory for radial, azimuthally symmetric flow and the Goldstein-Jokipii theory including stream interaction. The observed radial gradients are consistent with the Parker model, except for the non-adiabatic temperature gradient. The field strength was found to decrease with distance from the heliospheric current sheet. No effects of the interstellar gas, e.g., mass loading, were detected. Gazis and Lazarus (1982) reported on a similar analysis of Voyager observations of the solar wind proton temperature between 1 and 10 AU, in comparison to IMP 8 results in Earth orbit. Again, the temperature gradient was observed to be sub-adiabatic. A detailed analysis of solar wind stream structure showed that the implied heating was occurring at the interface between high and low speed streams. Again, no effect of interstellar gas was reported.

Solar wind speeds between 1 and 15 AU were analyzed in more detail by Collard, Mihalov and Wolfe (1982). Pioneer 10 and 11 measurements were compared with IMP 6, 7 and 8 measurements made near the earth for six radial alignment periods between 1973 and 1978. The mean solar wind speed appeared to vary little with radius, but there were significant long-term temporal changes and changes with heliographic latitude. Changes in speed across streams decreased with distance and were extrapolated to almost disappear by 30-40 AU. Helios 1 and 2 data between 1974 and 1977 and between 0.3 and 1.0 AU were analyzed by Geranios (1982b), to show that the slow solar wind first increases its speed with distance, and then becomes more or less constant. The variation of solar wind speed with solar activity was also analyzed. The detailed complexity of the solar wind velocity structure was reported by Rhodes and Smith (1981). Using data from Explorers 34 and 35 and Mariner 5 during 1967, the existence of large, temporary, local north-south velocity gradients ranging up to 60 km/s/deg were implied. The momentum flux in the solar wind is the subject of a study by Steinitz (1983). He reports on Helios 2 data to show that the momentum flux does not depend on flowspeed nor on distance verifying the previously established invariance of momentum flux density. It is furthermore suggested that the momentum flux density carried by the solar wind may be constant over the solar cycle.

Considerable attention is being paid to solar wind composition due to better data from the new instruments. Marsch, et al (1982) have surveyed the radial variations of solar wind helium properties between 0.3 and 1 AU, using Helios 1 and 2 data. They reported extensively on the helium ion velocity distribuitons and derived parameters and placed strong restrictions on models of the interaction between solar wind protons and helium.

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Further general studies of helium abundance variations are reported by Borrini, et al, 1983, using data from IMP 6, 7 and 8, from 1971 through 1978. Low and average values of helium abundance are identified with different characteristic plasma 'states'. Helium enhancements are identified with high magnetic field intensities and low proton temperatures. In another paper, Borrini, et al, (1982) report on an analysis of shock wave disturbances from the same spacecraft and time period. Helium enrichments are observed in association with 46% of the shocks, and those with helium enhancements tend to be the srongest shocks observed.

Results on large-scale variations in the interplanetary magnetic field between 1 and 5 AU were reported by Burlaga, et al, (1982), using Voyager 1 and 2 observations, for the years 1977 to 1979. During this interval, there were notable deviations from the Parker theory configuration. These were attributed to temporal fluctuations and to field fluctuations in the radial direction. Transverse fluctuations in the IMF were reported to decrease in amplitude with distance and to be consistent with the presence of undamped Alfven waves. In a more detailed study, Slavin, Smith and Thomas (1984) report on large-scale temporal and radial gradients in the IMF using Helio 1, 2, ISEE 3 and Pioneer 10, 11 data. In addition to specific temporal variations, the authors report a more rapid decrease in the IMF intensity with radius than predicted by classical Parker theory. The cause of this result is suggested to be meridional transport due either to MHD processes or stream interaction.

Remote observations of solar wind velocity using interplanetary scintillation observations over extended periods were reported by Sime and Rickett (1981) and reviewed by Sime (1983). A global view of the solar wind and its evolution throughout the solar cycle has been derived. The potential for sensing the morphology of propagating disturbances associated with eruptive solar phenomena has been demonstrated. Recent developments using spacecraft transmitters now permit analysis of the solar wind inside 50 solar radii.

Perhaps the most important consequence of these cumulative data on spatial gradients is that they are now providing new conditons that must be satisfied by models of the solar wind acceleration region. These observational constraints on solar wind acceleration mechanisms are reviewed and summarized by Neugebauer (1983). The theory for ordinary, spherical, symmetric flow has developed along predictable lines in recent years, with few surprises (see reviews by Schwarz, 1981; Cuperman, 1983; Leer, Holzer and Fla, 1982). One new aspect is the suggestion that standing shock waves of various types may exist near the sun. Whang (1982) infers that MHD slow shocks can exist in the vicinity of the sun as a consequence of nonradial outflow from coronal holes. Habbal and Tsinganos (1983) look at the possibility of ordinary shock transitions in the presence of extended momentum deposition. Several experiments are now being planned to look for these shocks and their consequences on the state of the solar wind.

Several specific analyses have been made of corotating features in the solar wind. Urlaga, Schwenn and Rosenbauer (1983) analyzed the dynamical evolution of interplanetary magnetic fields and flows, between 0.3 AU and 8.5 AU using data from Helios 1 and Voyager 1 during 1980.

Voyager 1 observed two streams which had little fine structure. The corresponding flows observed by Helios 1 were much more complex. The suggestion is that most of the fine-scale features were swept up and 'entrained' by the large-scale flow. Burlaga (1983) further reported on the detection of corotating pressure waves without fast streams in the solar wind. Voyager 1 and 2 data observed this phenomenon between 2 and 4 AU and it is suggested that the development of large-scale, nonlinear pressure waves at the expense of part of the kinetic energy of streams produces a qualitative change in the solar wind in the outer heliosphere. A very interesting new technique for mapping corotating events using radio data from ISEE 3 was described by Fainberg, Bougeret and Stone (1983). Type III radio storms are observed out to 0.5 -0.8 AU, at a rate of 2 to 3 storms per solar rotation near solar maximum. These storms correlate with type I and III radio storms close to the sun and are associated with an almost continuous injection of suprathermal electrons into the interplanetary medium. The storms are most likely the extension of streamers into the interplanetary medium, thereby permitting the identification of stream structure with the corresponding features on the sun.

Another application of ISEE 3 radio data has related type II solar radio events observed in the interplanetary medium to propagating interplanetary shock waves (Cane, et al., 1982). Type II events are thought to be produced in the vicinity of shock waves, and have long been used to estimate shock speed in the corona. With the extended frequency range available in space, type II bursts have been followed almost to 1 AU. The general topic of observation of interplanetary shocks is reviewed by Smith (1983).

Several authors reported on developments in the theory of stream interaction (see review by Wu, 1983). A kinematic model of stream interaction, together with superimposed kinetic distortions simulating transient disturbances, was developed by Hakamada and Akasofu (1982) and Akasofu and Hakamada (1983). Sakurai (1983) reported an application of an analytical method of characteristics to the azimuthally dependent solar wind. Wu, Dryer and Han (1983) describe a numerical model that, although intended for simulating propagating disturbances, can also be applied to corotating structures. This is an MHD model that incorporates a meridonal component of the magnetic field and flow vector. Pizzo (1982) also describes an MHD model of corotating streams - this being a completely three dimensional model.

In an application of MHD modelling, Pizzo (1981) demonstrated the use of numerical models in inverse mapping of solar wind flow structures from point of observation back to the sun. This exercise illustrated the strengths and limitations of such mapping in terms of the amount of steeping the stream front has undergone when observed and whether or not a shockhas formed at the interface.

In two separate articles (Sarris and Krimigis, 1982; Geranios 1982a) evidence is presented for the presence of magnetically closed regions in the solar wind. Geranios has analyzed Helios 1, 2 and IMP 8 data taken in 1974 and 1976 to identify 85 cases in which the proton temperature was very low.

In 50 of these cases, the IMF showed characteristics favourable for closed structures. Sarris and Krimigis present data on energetic particles injected by solar flares and infer that these particles are bouncing between two magnetic mirrors. They obtain estimates of the extent of these loops to distances of 3.5 AU from the sun. A related, and perhaps identical structure is described as 'magnetic clouds' by Klein and Burlaga (1982). A magnetic cloud is a structure with a radial dimension of about 1/4 AU in which the magnetic field strength is high and the magnetic field direction changes appreciably by rotation of one component parallel to a plane. Forty -five clouds were observed near the earth between 1967 and 1978, with at least one passing the earth every three months. Clouds have also been identified at Voyagers 1 and 2, between 2 and 4 AU, (Burlaga and Behannon, 1982). The relationship of these clouds to solar phenomena is discussed in section C.

Heliospheric Current Sheet

A great deal of effort has been expended on interplanetary observations of the current sheet and on comparing the observed sector structure and geometry of the current sheet with that which is expected from solar observations. Data on solar coronal structure exists in the form of coronagraph observations (Roselot and Fulconis, 1983; Wilcox and Hundhausen 1983), green line coronal intensity (Tyagun, 1983) and potential magnetic field models using photospheric data (Wilcox and Hundhausen, 1983), Burlaga Hundhausen and Zhao (1981), using Helios 1 and 2 data from 1976, identify the sector pattern with the maximum brightness curves in K coronameter data at 1.5 solar radii. Bruno, Burlaga and Hundhausen (1982) continue this approach into 1977, adding IMP 8 data and claim that the latitudinal extent of the current sheet is consistent with that suggested in the coronal brightness data. Villante and Bruno examine the Helio 2 data from 1976 to learn the local orientation of the current sheet. They find the boundaries to be at a large angle with respect to the ecliptic plane. Villante, Mariani and Francia (1982) examine the entire period from 1974 to 1978 to deduce how the sector pattern seems to evolve with time and heliographic latitude.

It is shown that the structure of the current sheet as predicted from the maximum coronal brightness data is quite similar to that predicted from potential magnetic field models of the corona (Wilcox and Hundhausen, 1983). The potential field models are now extended to a major portion of the solar cycle by Hoeksema, et al, 1982, 1983), and the structure of the heliospheric current sheet from 1974 to 1982 is thereby reconstructed. The structure and dynamics of the current sheet in the interplanetary medium is analysed in two very different papers by Thomas and Smith (1981) and Niedner (1982). Thomas and Smith show the interplanetary deformation of the current sheet as it is entrained by overtaking high speed streams. Niedner uses 'disconnection events' in the comet tails to directly map the three-dimensional properties of the current sheet.

Behannon, Burlaga and Hundhausen (1983) apply a minimum variance analysis to magnetic field data during current sheet passages to compute a local normal to the current sheet and compare the result to the inclination measure contrasts with the global measure determined with multiple spacecraft comparisons or with comet tails utilized in most of the above analyses.

Interplanetary Signature of Coronal Processes

A generalization of analyzing the heliospheric current sheet in comparison to what it is believed to be like near the sun is to study the total dynamics of coronal expansion in the context of interplanetary observations. Because the current sheet is a direct reflection of the largest scale coronal processes, an obvious first approach is to sort solar wind data in reference to the location of the current sheet. This approach has been used by Borrini, et al., (1981) to carefully document a solar velocity minimum, high plasma density, nearly identical proton and helium bulk velocities and low proton and helium kinetic temperatures at the current sheet. Several relatedand preceding studies have closely related the current sheet to coronal streamers (Gosling, et al., 1981; Sime and Rickett, 1981; Feldman, et al., 1981; and other, earlier studies). Therefore the pattern demonstrated by Borrini et al., is indicative of the 'signal' of a coronal streamer at 1 AU. Their results provide important constraints on models of helium dynamics in coronal streamers and the low speed solar wind.

Models of coronal streamers presently fall into two classes. The first, and most closely related to observations, is the use of potential field models described above in association with predictions of the topology of the heliospheric current sheet. The second class is true MHD models. Two advances in this type of model have been reported by Robertson (1983) and Steinolfson, Suess and Wu, (1982). Robertson incorporated the effects of thermal conduction into the approach used several years ago by Pneuman and Kopp (1971). Steinolfson, et al., described treating the solution for the steady state as an initial-boundary value problem and quoted results for a wide variety of magnetic field strengths in an axisymmetric model.

Acceptance of the relationship between coronal streamers, potential field models of the corona and the character of the interplanetary medium has led to more extensive efforts to sort interplanetary data using these relationships. Zhao and Hundhausen (1983) used interplanetary scintillation data from 1976 to show the minimum in solar wind speed at the current sheet and also an increase in the average solar wind speed with angular displacement from the current sheet. However, angular displacement from the current sheet is not a unique parameter for ordering the solar wind, in that the solar wind speed can be just as low far from the current sheet as at the current sheet. Suess, et al., (1984) added information on the strength of the magnetic field at the source surface in potential field models of the corona to improve the correlation between coronal structure and the character of the solar wind. There it was shown that strong field regions on the source surface were the sources of high speed solar wind.

A much more elusive question has been the interplanetary signature of coronal transients. Coronal transients have been studied for more than a decade, with only moderate success in relating them to interplanetary phenomena. A related question has been the origin at the sun of magnetic clouds, which were first reported by Klein and Burlaga (1982). One of the most striking results has been the observation of a head-on, or halo coronal transient (Howard, et al., (1982). This observation was made with an orbiting coronagraph and showed that at least some coronal transients were more bubble-shaped than loop-shaped. Schwenn (1983) has reviewed an analysis of Helios 1 and 2 data in comparison with data from the same orbiting coronagraph to show that interplanetary shock waves can often be associated with coronal transients. In contrast, Burlaga and Klein (1982) and Wilson and Hildner (1984) ask the question of whether magnetic clouds are manifestations of coronal transients. The answer seems to be yes, but better statistics are needed for a positive identification.

A different aspect of propagating interplanetary disturbances is composition anomolies associated with coronal processes. The work reported earlier by Borrini, et al., (1982), showing an association between strong shock waves and helium enrichments, was used to infer that coronal ejacta origina in solar regions where the field strength is strongest. The helium enrichment is often thought to be material from prominences or low levels in the corona in which helium has been enriched due to gravitation separation.

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