SOLAR AND INTERPLANETARY DYNAMICS
(Symposium Summary)

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Solar and interplanetary dynamics comprises dynamic and plasma-physical phenomena in the solar atmosphere, the corona and the interplanetary medium in the broadest sense. In this symposium, however, one has essentially tried to restrict the subject matter to the study of the propagation of a disturbance, produced in the solar atmosphere, through the corona and the interplanetary medium. In studying solar and interplanetary dynamical phenomena we find ourselves in the unique position, with respect to other astrophysical disciplines, to be able to relate solar observations obtained with the highest possible spectral, spatial and time resolution with in situ measurements made in the interplanetary medium. It has now turned out that the two fundamental questions to be answered are:

a) How does the medium in between the sun and the earth and beyond the earth's orbit, the socalled *heliosphere*, look like? Does a basic undisturbed heliosphere actually exist, and is one able to model its observed magnetic structures and plasma motions with their spatial and temporal variations?

b) How and where in the solar atmosphere are the disturbances generated and what are the characteristic time scales, geometries and energies involved?

In trying to answer the above mentioned complex of basic questions one is invariably confronted with three outstanding problems in solar physics:

i) What causes solar magnetic fields to appear at the solar surface and how do they extend into the overlying atmosphere?

ii) How is the strongly magnetically structured corona produced and heated?

iii) What is the mechanism of solar eruptions such as flares and erupting prominences?

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1. CORONAL AND INTERPLANETARY STRUCTURE

As to the first problem the magnetic configuration in the photosphere is largely determined by the circulation in the subphotospheric layers. Conversely, the magnetic structures and their motion relative to the ambient photosphere can be used to get some insight in the rotation of the deeper layers. Once the magnetic structures, presumably present in the subphotospheric layers as flux tubes, have emerged, they must rather quickly evolve into one or the other of the two basic configurations: the open field structures and the closed field structures.

The open magnetic configurations, whose footpoints are grouped in large regions of essentially one polarity, are directly associated with the coronal holes, observed as persistent depressions in soft X-ray emission.

The coronal holes are the seats of the high speed solar wind. They are born in association with active regions and they grow as new active regions emerge and old regions disperse so as to form a new magnetic cell pattern. However, the lifetime of the open field structures is much longer than the lifetime of the individual active regions, which suggests that the active regions only produce minor changes in the large scale magnetic field pattern.

The closed magnetic configurations are observed in great concentration inside the active regions as loop structures visible in X-ray emission, the green coronal line, UV lines and in Hα. In between different active regions one frequently finds the interconnecting loops as convincing evidence that large scale magnetic reconnection must have taken place after the birth of active regions.

The closed magnetic regions bottle up part of the energy received as they show bright in X-ray emission, while the open regions dispose of their energy received by a high speed solar wind. It should be stressed here that no satisfactory theory of the heating of the corona for the holes as well as for the loop structures exist at this moment, though considerable progress is made on the propagation of Alfvén waves through an inhomogeneous corona. Only Alfvén waves seem to be able to transfer sufficient energy and momentum to great heights. In the lower transition layer and chromosphere acoustic shock waves are still undoubtedly the most likely source of heating.

The magnetic structure of the corona can be modelled in various ways. The simplest way is to assume a potential field with the photospheric field distribution as the boundary. Such a potential field appears indeed to be a reasonable approximation in many cases.

A still better approximation is a force free field distribution. Since β in the corona is much smaller than unity, this must be a good approximation for most of the coronal magnetic field. However, two critical remarks are appropriate:

Firstly: It is not at all certain that a force free field solution can be used as an equilibrium solution in the case that gas pressure is not negligible. Stable equilibrium solutions seem to be much more restricted than those of a zero pressure plasma ($\beta = 0$).

Secondly, the corona is not a static atmosphere and not even stationary. The lower boundary is in a state of continual motion while drastic field changes occur when new flux emerges. Moreover, several solar radii above the surface the magnetic Reynolds number is so large that all magnetic fields are stretched by the solar wind into interplanetary space. A force free field solution should be a bad approximation in this case and undoubtedly current sheets of different scales and geometries are present in the corona above an active region.

In the interplanetary medium the sector structure, with its sharp boundaries, is one of the most well established corner stones of the outer magnetic configuration.

Yet, it appears difficult to trace these sector boundaries back into the photospheric magnetic field or in any other solar phenomena. This is probably the result of the fact that the strong fields, which are the most pronounced, close rather low in the corona, while small though large-scale fields, which may remain unnoticed in the photosphere, are stretched outwards and thus constitute the important boundary condition for the magnetic structure of the "more or less undisturbed" outer interplanetary medium.

The sector structure is certainly related to the pattern of coronal holes of one polarity, which can frequently be interpreted as the extension of the polar coronal holes. The neutral sheet separating the north and south polar coronal holes encircles the sun like a "ballerina skirt". The large scale pattern of magnetic fields, clearly outlined by filaments, is only weakly affected by solar activity. However, when large scale magnetic fields of one polarity merge into that of the opposite polarity the filaments become distorted and disrupt.

Filaments always occur at neutral lines and are the inevitable evidence that reconnection of magnetic fields does take place on a large scale in the corona, thus giving rise to numerous kinds of disturbances.

The process of large scale reconnection in the corona is intimately associated with the formation of prominences and loop type structures. The whole dynamics of the corona and the interplanetary medium must be seen in the light of these facts: Large-scale long lasting open unipolar magnetic regions with, at their borders, the shorter-living and smaller bipolar active regions. At many places reconnection occurs at the borders of the unipolar magnetic regions as well as inside the bipolar regions.

2. CORONAL TRANSIENTS

A great deal of work has been reported on the study of the coronal and interplanetary responses to disturbances at various time scales. Long time scale variations of the heliosphere follow the evolution of solar activity and its influence on the large scale magnetic structure. Short time scale variations which are observed as coronal transients are associated with eruptive solar phenomena of various kinds in particular with flares and prominence eruptions.

Coronal transients have been extensively studied in white light, X, radio and, in most cases, they can be associated with mass ejections. Some of the transients are nothing else but the remnants of the transient producing agent. In particular transients observed in white light are mass ejection transients which are associated with Hα flares, X-ray events, eruptive prominences, sprays, surges and metric type II and type IV bursts. The mass ejections that have been identified have often a loop type appearance. They are strongly associated with flares and filament disappearances (Disparitions Brusques) and often occur when the surface fields are strong and complex. The correlation with flares and erupting filaments is particularly strong if one restricts attention to the large flares and filament eruptions only, evidently the energetic events. In these cases the correlation with soft X-ray events and metric radiobursts is very good. The correlation of coronal disturbances with erupting prominences is certainly better than with flares. The important conclusion that can be drawn from all this is that eruptive prominences and disparitions brusques must be the central phenomenon that produces a coronal transient. There is increasing evidence that a prominence eruption in an active region is to a large extent the solar flare. It is therefore of paramount importance to study the relation between prominence eruptions and solar flares and the cause of prominence eruptions that do not seem to be related to any flare. Detailed studies of preflare emissions and disturbances can possibly solve this outstanding problem in solar physics. The radio transients are in general associated with shock waves and particle acceleration except for the moving type IV which is direct evidence for a moving plasma cloud. Since particle acceleration is likely to be associated with magnetic reconnection , any form of magnetic reconnection may give rise to a radio transient. In the very powerful cases mass ejection may well result from reconnection and so-called current sheet rupture. It is of interest to note that metric type III bursts increase in number prior to mass ejection transients. Their peak seems to correspond with the forerunners.

Theoretical work on the origin and nature of coronal transient falls in two categories. First there are the model calculations of coronal disturbances where the mechanism causing these disturbances has been unspecified but where one particularly concentrates on modelling the spreading and propagation of a magnetohydrodynamic perturbation. Such a perturbation can be either a temperature or pressure pulse caused by an as-yet unspecified impulsive heating mechanism in the lower atmosphere or a well defined magnetic perturbation at the lower boundary. Impulsive heating can give rise to mass ejections such as surges and spicules. To give full credit to all possible wave modes and interactions these calculations ought to be made in three dimensions using kinetic theory instead of the fluid approximation. Notwithstanding the restrictions one is forced to make, these numerical calculations give promising results, although the large variety of velocities of coronal transients already indicates that a pure wave mechanism certainly cannot explain the majority of white light transients. Instead real mass ejection has to be of central importance.

Secondly there are the models of evolving magnetic structures such as sheared fields, helical structures, loop type structures on the one hand and on the other hand the models of emerging magnetic fields creating large scale current sheets, where the process of magnetic reconnection is the major cause of magnetic reorientation and its dynamical consequences.

Both types of field configuration are used as model fields in flare theory and both types of field may actually occur in a flaring active region or in prominences. The extreme cases that are studied are the force free fields and the neutral sheets. I repeat the conjecture expressed earlier that hopefully force free fields can be used in a low β plasma when the boundary conditions change very slowly but it seems unrealistic to model the field this way when a fast disturbance occurs. The dynamic evolution of coronal flux tubes and arcades has recently come off the ground but none of the studies reported have considered the complicated boundary value and initial value problem in a fully consistent way.

Any magnetic configuration in a low β plasma that is in equilibrium must have the major component of the current density parallel to the magnetic field. Hence, the magnetic field is thus likely to be subject to MHD instabilities of the kink-mode as well as of the tearing mode type. On the resistive instabilities no work has been reported during this conference, while kink type structures in 3-dimensional non-linear calculations have been shown to occur under certain conditions during force free field evolution.

Large perpendicular current densities can only occur in neutral sheets, where $\beta \gg 1$ or they may be generated because of short time scale disturbances, e.g. at the boundaries. In that case the interchange instability may develop, increasing the rate of heating and possibly giving rise to detached plasma clouds. It should be emphasized that plasma turbulence may play an important role in the heating and dynamics of neutral sheets as well as in other configurations where magnetic reconnection occurs. Several attempts have been made to find the observable signatures of plasmaturbulence especially in radio waves. Radar measurements indicate that a high level of low frequency plasma waves is present above active regions, possibly giving a clue to the mechanism of the heating of the active solar corona. However, no satisfactory theory has been presented for the onset and maintenance of plasmaturbulence in coronal and interplanetary structures.

The presence of plasmaturbulence in the corona and heliosphere clearly indicates that the study of the propagation of a disturbance through the outer layers can only be treated correctly when a microscopic description is used. Only the microscopic description treats properly the processes of dissipation and wave-particle interactions.

The corona is not a fluid but a collisionless multicomponent plasma subject to perturbations of various time scales that sometimes can be surprisingly well approximated by a fluid.

I have tried to summarize the present state of knowledge and the trend of research in this field as it has come across during this symposium in a general sense without a discussion of any detailed work that has been presented.