49. THE INTERPLANETARY PLASMA AND THE HELIOSPHERE

(PLASMA INTERPLANÉTAIRE ET DE L'HÉLIOSPHÈRE)

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1. ORIGIN AND PHYSICAL PROCESSES IN THE SOLAR WIND (S. Cuperman)

A. Introduction

It is now generally recognized that the solar wind represents that part of the solar corona which is not confined by the solar magnetic field, and therefore escapes into interplanetary space. The escaping gas is heated by sources of solar origin (presumably low frequency waves) to about 2×10^6 K within a distance less than (1/20) R from the sun's surface; although the solar wind temperature decreases thereafter, heating sources may continue to act through 1 a.u. heliocentric distance. A transition from subsonic to supersonic flow occurs within a few solar radii of the sun's surface, heat conduction representing the principal energy supply for the acceleration of the solar wind. However, additional accelerating processes may also be active.

In the following, a brief summary of highlights and problems during the last three years concerning the origin and physical processes in the solar wind will be presented.

B. Origin

Significant progress in the clarification of the nature of the plasma-emitting solar regions (M-region) was achieved from a coordinate analysis of Skylab/ATM data taken during 1973 and 1974, together with coinciding ground-based observations and *in situ* solar wind measurements (Zirker, 1). The physical model emerging from the correlative study was given by Hundhausen (2) (See also Cuperman and Dryer, 3). Relating coronal holes (solar regions of low density and temperature) to open magnetic regions in the corona, for the Skylab epoch, the model emplies a dominant influence by a dipole component of the solar magnetic field, with interplanetary sector boundaries related to the tilting, warping and distortion of a neutral sheet encircling the sun within $\sim 30^\circ$ of its equator. High speed solar wind emanates from the polar regions of the sun and from any large coronal holes; low speed wind occurs in a "belt" $\sim 50^\circ$ wide, centered on the neutral sheet. The 700-750 km sec^{-1} solar wind speeds observed in the ecliptic plane in 1973 and 1974 (the declining phase of solar cycle 20), likewise those observed by Mariner 2 in 1962 (the declining phase of solar cycle 19) may be more typical of global solar wind conditions than that observed within the low speed belt during the intervening decade.

A number of open questions still exist. Our present knowledge of the coronal expansion is based on measurements made solely within the ecliptic plane; the identity of coronal holes with open magnetic structures may not be consistent with observed magnetic fluxes in coronal holes; it is not clear whether all the high speed flows originate in holes, etc. Clarification of questions such as these could modify the above picture.

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C. Physical Processes

The observed features of the solar wind show it to be a warm, almost collisionless magnetized plasma consisting mainly of electrons, protons and alpha particles which can be described by different non-Maxwellian particle distribution functions. The solar wind is accompanied by plasma waves which indicate plasma instabilities of solar and interplanetary origin. These waves act on the solar wind particles and produce a (non-collisional) coupling between them and consequently anomalous transport processes. Nevertheless, the combined collisional and non-collisional coupling between the plasma components of the solar wind is relatively weak. Each particle species behaves almost independently; moreover, particle groups of various energy within the same species have rather different behaviour. More exactly, particles belonging to different energy range within the same species and particles belonging to different species are reciprocally affected by wave-particle interaction as well as by Coulomb collisions.

The basic processes to be considered here are: acceleration, heating, isotropisation and iso-thermalisation. Their elucidation should explain the macroscopic features of the solar wind and the detailed shape of the velocity particle distribution functions. Thus in the following we discuss separately the electrons, protons and the α-particles in the solar wind.

ELECTRONS. Comparison of the solutions of solar wind fluid models using collisional electron thermal conductivity and observations, indicated too-large predicted electron temperatures and especially too large electron heat fluxes (by a factor of about 50) at 1 a.u.. When anomalous (low) coefficients of thermal conductivity were used in the model equations, satisfactory agreement with observations was obtained (Hundhausen, 4 and Cuperman, 5). Consequently, kinetic models providing "reduced" electron thermal conductivity have been suggested.

Recently (6, 7, 8, 9) detailed plasma measurements revealed shapes of electron distribution function which strongly support a kinetic theory advanced by Forslund (10) (See also 11). Thus, below several keV energy, solar wind electron velocity distributions can be separated into two relatively convecting, distinct components, f_C and f_H (C-cold, H-hot). Heat is carried primarily by electrons with energy greater than about 60 eV (i.e. the f_H component) which move away from the sun relative to the solar wind rest frame with drift speed ΔV_H. Simultaneously, the cold electrons move opposite to ΔV_H with relative drift speed, ΔV_C, in such a way that the net electrical current is zero (in order to prevent a monotonic charge build up on the sun). The solar wind heat flux, q_e, is observed to be proportional to both ΔV_C and ΔV_H. Consequently, any kinetic mechanism capable of limiting either ΔV_C or ΔV_H will also limit q_e.

Recently, Feldman et al. (8) brought new evidence suggesting that ΔV_C and/or ΔV_H are limited by the local Alfven speed V_A, near 1 a.u. Not only do variations in ΔV_H and ΔV_C follow variations in V_A, but the average magnitudes of ΔV_C and V_A are nearly equal. Next, if ΔV_C is ever larger than about V_A one of several microinstabilities may develop depending on the values of the various plasma parameters. Assuming model velocity distributions consisting of two relatively convecting electron bi-Maxwellian and one proton bi-Maxwellian, the most important instabilities involve <u>Alfven</u>, <u>magnetosonic</u> and <u>whistler</u> modes. Whereas the Alfven mode is driven unstable by the relative motion between the <u>cold</u> electrons and the ions, the other two are driven unstable by the relative motion between the <u>hot</u> electrons and the ions. The effect of these instabilities must be to reduce continuously both ΔV_C and ΔV_H in order to maintain a marginally stable state. If the instability interacts strongly with the cold electrons thus reducing ΔV_C, then the interplanetary electrostatic potential must increase sufficiently to reduce ΔV_H (and hence q_e) in order to maintain zero electrical current. If the instability interacts strongly with the hot electrons, it reduces both ΔV_H and the heat flux directly (12). As the entire plasma expands away from the sun, solar wind electrons traverse regions of ever decreasing Alfven speed so that at some location, ΔV_C and/or ΔV_H become sufficiently large compared to V_A that one or more of the heat flux instabilities become active.

The heat flux driven whistler mode has been identified in the solar wind data, primarily in the low speed solar wind when the hot component anisotropy is small and f_H can be adequately characterized as a single convecting component. The correlation between ΔV_C and V_A found under the stated conditions is then consistent with the prediction of the linear theory of the whistler heat flux instability (13).

Most recently, Gurnett and Frank (14), using plasma wave measurements on the solar-orbiting Helios spacecraft and on earth-orbiting Imp 6 and 8 spacecraft suggested that the measured waves are short-wavelength ion-acoustic waves at frequencies $\omega \lesssim \omega_p$, which are Doppler-shifted upward in frequency by the motion of the solar wind. Moreover, since enhanced ion acoustic wave intensities have been associated with abrupt increases in the electron to proton temperature ratio, the authors proposed that the ion acoustic waves detected by Helios far from the earth are produced by an electron heat flux instability. Indeed, the ion-acoustic mode becomes unstable when the drift velocity ΔV_C in the distribution function described above is sufficiently large. Thus, if $T_e >> T_p$ the threshold drift velocity for instability is approximately $(\Delta V_C)_{threshold} \simeq (kT_p/m_p)^{\frac{1}{2}}$; for $T_p \simeq 4 \times 10^4$ °K the threshold value is 18 km s^{-1}. For solar wind states with relatively large electron temperatures drift velocity values $\Delta V_C > 18$ km s^{-1} may occur.

Further investigations by Gurnett and Frank based on comparison with the Imp 6 and 8 revealed that a substantial fraction, 50-70% of the ion acoustic wave turbulence detected in the solar wind near the earth is caused by supra-thermal protons streaming into the solar wind from the earth's bowshock. These upstream electrostatic waves, are indistinguishable from the ion acoustic waves detected by Helios. The upstreaming protons must cause a shift in the velocity of the core electrons with respect to the solar wind protons in order to maintain zero net current. If this shift is enough to produce instability, ion acoustic waves identical to the interplanetary ones are produced. It should be noted that, while the hot (halo) electrons streaming away from the sun and sunward streaming protons both contribute in some way to the current imbalance, because the intensities of the upstreaming protons are relatively small, a more complex (than a simple Maxwellian) distribution function for the cold (core) electrons is required.

An interesting theory for the electrons in the solar wind has been proposed by Scudder and Olbert (15). This approach starts with the Boltzman equation and retains the effects of Coulomb collisions via the Krook collision operator without recourse to wave-particle effects. Such an approach is based on the realization that thermal electrons (energies < kT) in the solar wind undergo 10-20 Coulomb collisions en route to the observer at 1 a.u.; this population is more removed from the properties of coronal electrons than are the "supra-thermal electrons (E > kT). This latter group contains a strong memory of coronal conditions since they have undergone only a few momentum transfer collisions. The thermal population is most nearly in collisional contact with the local dynamics of the solar wind. The suprathermal portion is determined by Coulomb collisional interactions with the radially changing solar wind material on a radial scale comparable to the Heliopause itself; therefore, this electron subpopulation is responsive to the consequences of the global dynamics of the solar wind (it is an attenuated vestige of collisional population deep in the corona, between 1.03 and 10 $R_\odot$, which has been redistributed via Coulomb multiple pitch angle scattering on magnetically open field lines). The suprathermal particles moving towards the sun are computed to be observed as a result of Coulomb collision induced backscattering at larger heliocentric distance (i.e., 1-10 a.u.) than that of the observer. Thus, the local form of collisional transport laws and equation of state (e.g., $q = -\kappa \nabla T$, $p = nkT$)

are replaced with global relations that explicitely depend on the relative position of the observer to the boundaries of the system. The authors were able to obtain numerical solutions of their model which predict the partition of thermal and suprathermal phase density, the break in the velocity distribution function and the magnitude of the skewness (heat flux density) in agreement to those typically observed at 1 a.u.

Further progress on solar wind electrons requires first, consideration of the actual velocity distribution functions which are more complex than those assumed in the theoretical analyses mentioned above (resonant instabilities are very sensitive to the details of the distribution function). Second, the theory should consider simultaneously all possible unstable interactions in the solar wind. Third, a fully non-linear treatment providing the observed state of the solar wind is needed. Fourth, an inhomogeneous theory in which particles and waves affect each other and adjust to changing conditions as the solar wind convects away from the sun is required.

PROTONS. The existence of significant discrepancies between the observed proton characteristics and the original fluid theoretical predictions at 1 a.u. represented an indication that certain physical processes were missing in the model equations. More specifically, the theory predicted too-low bulk speeds and temperatures (a factor of about ten!), as well as too-large thermal anisotropies, $T_{p,\parallel}/T_{p,\perp}$ ($\parallel$, $\perp$ indicate the radial and transverse directions, respectively). Although a number of dynamical processes could be invoked in order to explain (at least in part) the observed proton features, it appeared that the consideration of basic kinetic processes involving wave-particle interactions and plasma instabilities was indispensable for that purpose. It was found that magnetohydrodynamic waves of solar origin could both accelerate and heat the solar wind protons above the values predicted by simple theoretical models; alternatively, it was suggested, the proton heating is due to the interaction of the solar wind protons and electrons via the waves produced by electron instabilities, the result being an enhanced energy transfer from electrons to protons. As for the relatively low thermal anisotropy observed, it was suggested that this is a result of anisotropy produced instabilities which extract energy from the $\parallel$ temperature component and transfer it into the $\perp$ temperature component and constitute, therefore, a self-regulating mechanism. These aspects have been extensively covered in the review papers presented by Scarf (16), Hollweg (17) and Barnes (18); See also Gary et al. (19).

The theoretical studies just mentioned assumed that the solar wind proton velocity distributions could be adequately characterized by Maxwellian ($T_\perp = T_\parallel$) or bi-Maxwellian ($T_\perp \neq T_\parallel$) distribution functions. Recently, more detailed measurements of the solar wind protons have shown that most of the time the proton distribution functions are complex and better described in terms of two relatively convecting components than in terms of a simple bi-Maxwellian (20, 21). Rosenbauer et al. (22) reported indications of resonant wave particle interaction in fast stream solar wind ion distributions. Thus, an understanding of the radial evolution of the internal state of the solar wind protons requires the consideration of ion beam (more general, two-stream) driven instabilities, in addition to the anisotropy driven instabilities discussed above.

Because of this, the ion beam driven instabilities were recently given increased attention, both in a general context and with application to the solar wind (e.g. 23, 24, 25, 26). In these works, the starting point was the observation (not yet fully understood) in the interplanetary space of interpenetrating proton streams. Thus, the proton distribution function can be described by $f_p = f_M + f_B$, the subscripts M and B referring to main and beam proton components, respectively; f_M could be satisfactorily represented by bi-Maxwellians or bi-Lorentzians. Since the solar wind expansion sets up conditions such that V_A decreases with increasing helicentric distance, the relative velocity between interpenetrating proton streams

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should at some distance become comparable to V_A. Then, one of the three possible modes will be driven unstable depending on the value of the parallel β of the main proton component, β_M (β is the ratio of thermal to magnetic energies). If $\beta_M \lesssim 0.35$, then an obliquely propagating ion cyclotron instability will have the lowest threshold. The instability becomes more field aligned as $T_{\perp,M}/T_{\parallel,M}$ increases. If $0.35 \lesssim \beta_M \lesssim 0.45$, an oblique magnetosonic instability has the lowest threshold and above $\beta_M \simeq 0.45$ a field aligned magnetosonic instability has the lowest threshold. However, the prediction of a strong ion-cyclotron instability was inconsistent with the persistence of observed proton (and alpha) particle distributions in the high speed solar wind. This discrepancy was resolved by Abraham-Shrauner and Feldman (27) who showed that when a non-linear treatment of the kinetic equation is followed, the strong ion-cyclotron wave instability predicted by the linear theory is removed.

In these instabilities, free energy is carried by virtue of the relative streaming between beam and main proton component; thus, ion beam driven instabilities should also cause perpendicular heating at the expense of relative convective energy and consequently increase the ratio $(T_\perp/T_\parallel)_p$, which is in the direction of the observations.

The requirements on the theory for further progress in the understanding of the physical processes indicated for the solar wind electrons hold as well as for the solar wind protons (and alpha particles, to be discussed in the next section).

ALPHA PARTICLES. Spacecraft observations indicate three rather unexpected gross features of the alpha particles in the quiet solar wind at 1 a.u., namely: (i) the ratio of the α-particle to proton streaming velocities, V_α/V_p is equal to or larger than Unity; (ii) the long-term average of the α/proton density ratio is about 0.035, which is definitely lower than the lowest value obtained for the solar surface; and (iii) the distribution of the α/proton temperature ratios indicates a mean of approximately four. Except for values $V_\alpha/V_p > 1$, the other features mentioned above could be predicted by three-fluid models with phenomenologically shaped anomalous transport coefficients and adequate boundary conditions (i.e. relatively high α-temperatures) at the base of the corona. In these models, however, the collisional friction between the α-particles and protons was found to play an important role (28).

Hollweg and Turner (29) undertook a kinetic investigation of the alpha particles in the solar wind. In particular the authors tried to explain the occurrence of α-streaming velocities larger by up to 20% than proton streaming velocities. Specifically, Holweg and Turner investigated the combined effects of resonant and non-resonant acceleration of α-particles by left hand transverse waves. If only non-resonant interactions with parallel-propagating Alfven waves are considered, it is found that the accelerations given to α-particles and protons are different and that, at least when $dV_\alpha/dr = dV_p/dr + 0$, the Alfven waves tend to equalize V_α and V_p. When resonant wave-particle interactions are considered it is found that the acceleration of the α-particles to values $V_\alpha/V_p > 1$ is possible. Thus, to calculate the resonant acceleration of α-particles by Alfven waves Hollweg and Turner considered the resonant pitch-angle diffusion of charged particles moving in a spectrum of non-dispersive linearly polarized magnetic fluctuations. The pitch-angle diffusion coefficient was calculated to second-order in the resonant wave amplitudes and was combined with the Fokker-Planck equation in order to determine the average acceleration felt by the particles in the frame of the magnetic fluctuations. The α-particle distribution function in the frame of the magnetic fluctuations was taken to be a drifting Maxwellian. The numerical integration of the resulting expression indicates that the acceleration always tends to bring the particles to rest in the frame of the magnetic fluctuations; thus, the particles tend to be dragged by the waves. The particles are accelerated by the left-hand mode when the drift $V_D < 0$. Since the frame of the magnetic fluctuations is the same as the wave frame one has $V_D = V_\alpha - V_p - V_{ph}$. Since at 1 a.u. one observes $V_\alpha - V_p \cong V_A$ one may imply that outward-propagating left-hand waves with $\omega/k \cong V_A$ are present at the resonant frequencies. Finally, the theory requires the existence of a power-law index $n \cong 1.5$ in the wave power spectrum and effective wave phase speed at the sun greater than about 0.4 V_A; thus, inward-going or slowly propagatinv waves cannot produce consistent solutions at both 1 a.u. and at the sun.

2. LARGE SCALE STRUCTURE OF THE SOLAR WIND
(S.T. Suess)

A. Introduction

In describing structure of the solar wind, it is important to first identify the character of the solar wind. Feldman et al. (in White, 30) have done this by summarizing current knowledge of solar wind plasma and the interplanetary magnetic field (IMF) at 1 AU. This summary is a useful reference in describing any spatial or temporal gradient, average property, or statistical variance. Particular attention has been drawn to the result that the "structureless solar wind" is more likely to be observed at high speeds because this state appears to originate from large, uniform, open-field regions in the solar corona. Equally important is the publication of the "Interplanetary Medium Data Book" (31), a composite plasma and magnetic field data set from earth-orbiting spacecraft covering most of the period from 1963 through 1975 in 1 hour averages. The data are also available on a single magnetic tape.

Research highlights and problems in large scale solar wind structure are described in five sections - corresponding to a division into (i) radial and meridional gradients, (ii) high speed streams and coronal holes, (iii) the IMF geometry, (iv) propagating disturbances, and (v) other topics.

B. Radial and Meridional Gradients

Both *in situ* and remotely collected data on solar wind gradients continue to accumulate at a growing pace (32). Of particular importance has been the data collected by various spacecraft (Pioneer 10/11), Mariner 10, HELIOS 1/2) inwards to about 0.35 AU and outwards to more than 9 AU.

First, refinements have been made in the results stated in the previous report on outer solar system gradients in this series. It has now been established that the average solar wind velocity decreases by about 30 km/s between 1 and 5 AU, the proton flux decreases as r^{-2}, the proton density decreases more rapidly than r^{-2}, and although the proton temperature decreases, it decreases less rapidly than $r^{4/3}$ (33). The radial component and spiral angle of the IMF behave according to classical theory, whereas the azimuthal component decreases more rapidly than r^{-1} in quiet regions. In the Pioneer 10/11 data it was found that the azimuthal component of the IMF varies as r^{-1} between 3 and 4 AU, but falls off significantly faster beyond 4 AU. This effect has been attributed to rarifaction in quiet regions behind corotating interaction regions (CIRs) (33). Correlated fluctuations of solar wind quantities do not seem able to explain this phenomenon (34), although considerably more work could be done on this modeling problem. Behannon (35) has reviewed all the data on radial gradients of the IMF between 0.46 and 5 AU, reporting essentially the same conslusions as mentioned above, plus additional results on variances.

New information is available on radial gradients in the inner solar system from HELIOS 1/2, Mariner 10, and IPS observations. In the HELIOS observations (22) low speed plasma was found to expand nearly isothermally, whereas high speed plasma cools by 50% between 0.45 and 1.0 AU - which has been used to infer differing

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acceleration mechanisms for the fast and slow plasma. Concerning electrons, the HELIOS results imply 90% of the associated conductive energy supply available at 0.3 AU is converted into other forms of energy by 1.0 AU. A further HELIOS result is that the "medium energy electrons" are streaming away from the sun along magnetic field lines, presenting a feature known as a "strahl" in the electron distribution function. Other results for electrons come from Mariner 10, published by Ogilvie and Scudder (37) for gradients between 0.48 and 0.85 AU. In the core (thermal) - halo (suprathermal) division of the distribution function, they find a collisional core distribution coexisting with an approximately isothermal Coulomb collisionless halo distribution. Extrapolation indicates that this two-component distribution has a single temperature somewhere between 2 and 15 solar radii. The electron density, as with protons, decreases more rapidly than as r^{-2}. In an extension of the IPS technique, Woo (38) has used HELIOS 1/2 and Pioneer 10/11 as radio sources to find gradients near the sun, ranging from 1.7 to 180 solar radii. To a factor of 2.5, he finds the speed to be about 24 km/s at 1.7 solar radii. Assuming a mean density profile and a relationship between the rms density fluctuations and the density itself allows inferences to be made for the velocity and mass flux profiles in the acceleration regions, suggesting there was some convergent flow towards the equator in 1975/76.

The theory of radial gradients through spherically symmetric solar wind models has progressed slowly but steadily. Publications now include descriptions of the full solution space for two-fluid models and two-fluid models with thermal inhibition (39, 40), a fully self-consistent three-fluid model (41), and fluid models incorporating a great variety of internal processes through parameterization. These studies would not be expected to produce profound new predictions, but do make extremely important additions to understanding the structure of the solar wind equations, to solution techniques, and to the proper approach to approximating the internal processes (both known and unknown).

Meridional gradients can be determined near the ecliptic with spacecraft, out of the ecliptic with IPS and comet observations, and will be measured globally with the OOE/SPM. The IPS results, summarized by Coles (42) continue to show an increase in solar wind velocity with latitude. However, this disagrees both with comet tail observations which show no latitude effect, and with spacecraft data which show a much larger effect. Hundhausen (43) has suggested this discrepancy might be due to specific effects of longitudinal averaging. He states that "unless the solar wind spatial structure is simply organized above the solar equator, its presence is extremely difficult to infer in longitude averages unless the observations extend to very high solar latitudes. Thus the absence of semi-annual variations in ecliptic observations or the absence of large latitude gradients in IPS or comet tail results do not constitute evidence against the presence of strong spatial variations (or large spatial gradients)."

A final piece of data on meridional gradients comes from UV observations of the interstellar wind. Ajello et al. (44) deduce that the solar wind mass flux may have decreased with increasing latitude during late 1973 and early 1974. These observations, as well as the IPS techniques are developing in such a way as to make them valuable tools in model construction. However, a significant lessening in uncertainties will be necessary for qualitative model evaluation.

The problem of how to approach modelling meridional gradients poses many difficult questions. It may be necessary to construct a global stream-interaction model and then to compute azimuthal averages to find average meridional gradients. However, it may also be possible to utilize other approximations for some purposes. In one example, Suess and Feynman (45) calculate IMF sector boundary distortion using strictly radial flow with meridional gradients. To find meridional redistribution of fluxes, a more sophisticated treatment is needed. Suess (in Williams 46) reviews the MHD approaches and results from axisymmetric solar wind models, pointing out that the sophistication of anything but one-dimensional models of the solar wind, in terms of treating multi-fluid models, proper energetics, acceleration mechanisms, and internal processes remains extremely poor.

C. High Speed Streams and Coronal Holes

Due to a coordinated analysis of Skylab/ATM data taken during 1973 and 1974, together with coinciding ground-based observations and in situ solar wind measurements, a large improvement in the understanding of solar wind origin and structure has recently come about. Coronal holes, regions of low density and temperature, and of open magnetic field lines in the corona, are shown to be strongly associated with high speed streams and geomagnetic storms. Coronal holes have thus been identified as the long-sought "M-regions" postulated by Bartels. However, little is really known of the long-term behaviour and evolution of the holes, and added to this is a paucity of comprehensive models of the flows. The results of an intensive workshop on coronal holes and solar wind streams are described by Zirker (47) and collected together in (1), and models of coronal hole flows are reviewed by Suess (48). The main feature of present models is high flow speed and low density in the corona, and a suggestion of extended acceleration of the flow from holes. The main modeling need is for at least a single simple example of coronal dynamics including MHD effects, magnetically open and closed regions, and especially a respectable treatment of neergetics including extended acceleration. Structural questions include whether all the high speed flow originates in holes, how much of the low speed flow "leaks out" of seemingly magnetically closed coronal regions, and what is the behaviour of coronal holes, high speed streams, and the IMF over a solar cycle - especially out of the ecliptic. Synoptic coronal observations and model development are planned for the coming decade, so it can be anticipated that there will eventually be answers to some of the questions.

The evolution of stream interaction is now a much better understood process than it was a few years ago. Near 0.3 AU it has been found that streams can have extremely sharp boundaries (22). This is thought to be due to the coronal hole origin, and that these boundaries proceed to diffuse farther out. Portions of this process have been modeled using a fully three-dimensional non-MHD code developed by Pizzo (49). He also showed that nonradial flow can cause a slowing of dynamic stream front steepening. Beyond 1 AU, streams have been found to steepen dramatically into "corotating interaction regions" (CIRs) bounded by forward and reverse shock waves, and with large enhancements in density, temperature, field strength and fluctuation level in the region of initial positive velocity gradient (Smith and Wolfe, in 50). CIRs also appear to be associated with the acceleration of solar wind protons to MeV energies. It is possible to model CIRs using one-dimension plus time differencing codes with a magnetic field (51). This produces reasonable results, but future codes should be in two-dimensions and eventually include better treatment of energy flow.

D. The Interplanetary Magnetic Field Geometry

It has been shown statistically that the large scale coronal magnetic field organizes the flow of the solar wind so that the IMF sector structure is clearly associated with the general pattern of coronal holes of a given magnetic polarity. Given this result, it has then been possible to crudely follow the relative evolution of coronal holes, high speed streams and sectors for several years using such data as geomagnetic activity, H-alpha synoptic charts and the like. The IMF strength has been shown to not vary significantly in magnitude over a solar cycle (30), but the topology of sector boundaries is believed to very markedly - accounting for many observable consequences. This relationship is leading to a unified view of the magnetic field structure between the photosphere and the outer solar system (see Hundhausen in (1)), sector boundaries in the interplanetary medium (1, 45) and long-term variations of this system (30). A further extension

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of this work is leading to connections between solar dynamo thery, the solar cycle and the external unified field models (see Gilman in (1)). A particular result is that the sector boundaries extend only to moderate (about 16°) latitudes at least during some portions of the solar cycle (52).

The main consequence of this combination of data, statistical analyses, and empirical models has been a coherent hypothesis of the IMF globally and in time. This hypothesis is not testable in detail from the ecliptic, but will be severely tested at one instant in time by the OOE/SPM spacecraft. Analytical models are, as yet, either crude or limited to specific simple examples. IMF and sector boundary prediction awaits the same development of a comprehensive MHD model of coronal expansion as the problem of correctly treating the relationship between coronal holes and high speed streams. Potential field maps of coronal magnetic fields have been developed to high levels of sophistication, contributing greatly to the statistical relationship between the large scale coronal field and sector structure. However, it is probably true that quantitative modeling and prediction await a dynamic theory.

E. Propagating Disturbances

The analysis and modeling of propagating disturbances has benefited from coordinated studies of specific events and phenomena - aided by the establishment of the Study of Travelling Interplanetary Phenomena (STIP) in 1973. The best example of this is the August 1972 series of solar foare-generated disturbances. Observations and data are described in a collection of papers edited by Dryer (53), where use of widely distributed spacecraft and IPS measurements has led to a global picture of the structure and evolution of the complex series of shock waves generated by the flares. An important consequence of this collection has been the ability to test MHD numerical models of shock propagation throughout the solar system (see, e.g. 54). These codes, being similar in structure, are at a similar stage of development as the stream interaction codes and thus also have similar weaknesses and developmental needs.

One interesting possibility deduced from the August 1972 events and using Pioneer 10 data was that some flare-produced shock waves disappear beyond 1 AU due to self-interactions or interactions with corotating interaction regions (see Smith and Wolfe, in 50). This is especially true in the case of reverse shocks. Unfortunately, not enough flare induced shocks have been analyzed with Pioneer 10 and 11 to result in any statistically significant result on how often this occurs for forward shocks. Beyond a few AU, the interplanetary medium is dominated by the shock waves associated with corotating interaction regions so flare produced shocks will become relatively less important in any case.

A particular phenomenon that has received much attention recently is the coronal transient (see Gosling, in 46). This attention was stimulated by the Skylab/ATM observations of apparent "mass ejection events" in the corona which were not necessarily associated with flares. In fact, the interplanetary signature of the coronal mass ejection has been difficult to identify (55, 56). In modeling transients, numerical limitations have generally required that the calculation be divided between dynamics in the corona and dynamics in the interplanetary medium. Nevertheless, models of transient phenomena in the corona have become quite sophisticated during the past three years typified, for example, by those described by Wu et al. (57) and Steinolfson et al. (58). These models are usually limited to two-dimensional, time-dependent flow, but include magnetic fields and a sufficiently dense integration grid to resolve quite small spatial details. As with all coronal models, improvements are needed at least in treating the energetics of the flow and in adding the third dimension so that transverse waves may be considered.

F. Other Topics

There are many additional topics that could be noted here - I will mention only two. These are heavy ions in the solar wind and long term variations.

Observations of heavy ions (i.e. anything other than protons) in the solar wind continue to be very sparse. Hopefully, this condition will not persist for ever, but even the most recent experiments on ISEE-C, the spacecraft placed at the Lagrangian node between the earth and the sun, will not produce significantly better information on the composition of the solar wind plasma than previous experiments. Proposals have been made to place other satellites near the present orbit of ISEE-C during the next decade - and these would contain instruments capable of detailed composition measurements. Furthermore, OOE/SPM will have some capability to measure composition. The value of these measurements lies in understanding acceleration of the solar wind in the corona and in diagnosing the processes occurring in stream interaction regions. The theory of multi-ion flow is progressing at a steady pace demonstrated, for example, by the three-fluid analysis by Metzler and Dryer (41) and the multi-component coronal hole flow model by Joselyn and Holzer (59). It is expected that progress in theory will easily be able to keep up with developments in global modeling of coronal and solar wind structure. Therefore, the limitation will mainly lie in data collection for the next several years.

Long term variations of solar wind and IMF properties are becoming of great interest for the purpose of explaining several solar-terrestrial relationships and even some other observations such as that of correlated varying brightness of Neptune and Titan (60). Historical questions also arise under this topic, as in the question of the properties of the solar wind during the Maunder Minimum. Variations are described in some detail in (30). It can be expected that any modeling advances made in describing or predicting solar wind large scale structure will also be useful in predicting long term variations. This would be especially true if the model were to use fundamental low-corona parameters as a boundary condition.

3. THE NEARBY INTERSTELLAR MATTER AND THE DISTANT SOLAR WIND (H.U. Keller)

The general picture of the flow of neutral interstellar matter (ISM) through the solar system has now been generally accepted. A series of new observations and theoretical interpretations have tried to improve our knowledge of the basic paramaters of the hydrogen and helium atoms. The ISM moves through the solar system with a velocity between 10 and 25 km s^{-1} from the direction right ascension $\alpha = 252^o$ and declination $\delta = -15^o$ ($\pm 5^o$) some 50^o off the solar apex. The undisturbed densities of hydrogen and helium are $0.02 \lesssim n_H \lesssim 0.2$ cm^{-3} and $0.004 \lesssim n_{He} \lesssim 0.02$ cm^{-3}, respectively.

The first simultaneous hydrogen L_α 121.6 nm and He 58.4 nm observations were achieved by a spectrometer on board Mariner 10 in late 1973, early 1974. The interpretation (62, 63) of the four sky maps yielded densities for hydrogen and for helium at the lower end of the above mentioned parameter range. The upwind direction (64) was confirmed. However, small systematic differences of the L_α emission and the models using a spherically symmetric solar emission remained.

The fit of the model calculation could be improved by considering the 27 d periodic changes of the solar L_α emission which distort the longitudinal symmetry. The observed enhancement of the L_α backscatter above the sun's poles suggests a decrease of the solar wind flux at high latitudes (65, 66). An increase in solar wind speed at higher solar latitudes as found by inter planetary scintillation measurements (67) 2.1 km s^{-1} per degree) causing a decreasing charge exchange cross section is not sufficient to explain the observed asymmetry. In addition, a flux decrease of 15% is necessary (68). Enhanced solar L_α emission above the poles

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would yield a stronger backscatter, however, also increase the repulsive solar radiation pressure and therefore decrease the hydrogen density. Both effects tend to cancel each other. Rather low helium densities were also found from recent satellite (69) and rocket (70) observations. The interpretation of OSO 8 observations (71) based on the "hot gas" model yielded a helium density in the upper range, only marginally in agreement with the previously mentioned results. The emission line profiles of L_α and He 58.4 nm are calculated (72) from velocity and density distributions distorted from the original Maxwellian distribution by solar gravitational attraction. In the downwind direction corrections only for the mean Doppler shift relative to the solar line ("modified cold gas" models (64, 73)) are not sufficient.

The intensity for any looking direction generally depends on all three parameters: the velocity, temperature, and density of the interstellar atoms. Therefore the determination of their values is ambiguous. The use of hydrogen absorption cells allows to scan the emission line (74). Making use of the change in velocity of an interplanetary spacecraft yields the complete emission line (75). A temperature of $8.8 \pm 1 \times 10^3$ K was determined from the line width rather independent of all other parameters (76). Because of the low brightness (a few Rayleighs) He absorption cells are much more difficult to employ.

The high resolution spectrometer on board Copernicus was able to separate the L_α emission profile of the upwind direction from the geocoronal emission (77). The wavelength shift yielded a heliocentric speed of 22 km s^{-1} independent of other parameters of the ISM. Such a direct determination of the speed should be repeated.

A weak absorption feature on the long wave side of the solar L_α emission line was identified (78) and interpreted (79) to be produced by interstellar hydrogen between the sun and earth. Such an absorption was not expected since it requires a longer hydrogen lifetime than is consistent with current sky background measurements. More observations are needed to verify that the absorption feature moves from the red to the blue side of the solar line as the earth moves in its orbit from upwind to downwind. However, the solar line profiles of L_α and He 58.4 nm would suffer considerable absorption at distances of the outer planets (80).

The ISM is influenced by the solar radiation and solar wind. The improved accuracy of the observations has now lead to a discussion of these effects. The lifetime of the hydrogen atoms is limited by the charge exchange with solar wind protons while photoionization yields only a minor contribution. For helium the situation is inverted.

The size of the elongated cavity of hydrogen atoms around the sun due to ionization of the atoms seems to vary. The upwind cavity radius has likely decreased from the first measurements during the previous solar maximum (1967-71) to the Mariner 10 results during 1974 (at minimum conditions). A decrease of the radiation pressure is not sufficient as explanation but rather the hydrogen ionization rate (at 1 au heliocentric distance) seemed to have decreased from about 8×10^{-7} s^{-1} to below 4×10^{-7} s^{-1}. Even a strong variation of the ionizing solar UV flux cannot explain this decrease. The observations imply that the solar wind flux has decreased by about 50% from solar maximum conditions in the opposite sense to that observed in situ (81). However, the solar wind conditions near the ecliptic plane may not be representative for the large scale three-dimensional interaction with the instreaming interstellar matter. More correlative studies are necessary and a finite answer may only be given by the International Solar Polar Mission.

The importance of heating of the ISM by elastic collisions with the solar wind protons (and helium ions) remains a matter of controversy, basically because of different collision cross sections. Under favourable circumstances the hydrogen and helium atoms may gain temperatures of several thousand K within the earth's

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orbit and the conventional density determinations may seriously underestimate the helium abundance in the vicinity of the sun (82). With a smaller (by a factor 4) cross section heating may be negligible (83). Heating by solar wind electrons is only of minor improtance (84).

The possible influence of the collisions on the orbits of the interstellar atoms has not yet been investigated (85). Multiple scattering particularly of the L_α quanta seems to be important (85) and could influence the interpretation of the observations. This effect should be considered more rigorously in future modeling.

The comprehensive reviews of Holzer (1977) (83) and Thomas (1978) (86) discuss the above mentioned topics in detail. A recent paper of Weller and Meier (1979) (71) reviews the helium observations critically and defines a range of probable parameters of the ISM.

The local hydrogen densities are in reasonable agreement with values inferred from interstellar absorption line measurements to nearby stars (88, 89) yielding $n_H \approx 0.1$ cm^{-3} averaged over distances of several parsecs.

While the observed low densities and high temperatures place the solar system into a hot "intercloud" interstellar gas environment and encounter of the sun with dense clouds has been discussed repeatedly (90). The suggestion (91) of a nearby dense cloud (at about 0.03 pc in direction of Scorpius-O-hiuchus) has been refuted (92) based on absorption line observations towards 12 nearby stars. These observations are in good agreement with the local hydrogen density and the local velocity of the ISM. However, an encounter with a sufficiently dense ($n_H > 10^2$ cm^{-3}) interstellar cloud could confine the solar wind inside the earth's orbit (93) and lead to climatic changes on the earth (94).

The so-called "anomalous" component of the cosmic rays, an enhancement of certain ions, in quiet time spectra may well originate from the ISM (95). Neutral interstellar atoms with high ionization potentials can intrude far into the heliosphere before they are ionized and then accelerated to energies of a few MeV per nucleon. Although other sources such as novae (96) or galactic origin (97) have been discussed, the observed spectra of He, O, N, and Ne could be explained by calculations (98) based on a model (99) describing the acceleration of ions stemming from the interstellar matter.

The interaction between the solar wind and interstellar matter also changes the properties of the solar wind itself. The solar wind is slowed down and will finally be completely neutralized by charge exchange with the ISM atoms. Inside the heliosphere the neutral hydrogen atoms (former solar wind protons) are too fast (~ 400 km s^{-1}) to scatter the solar L_α line. However the former interstellar hydrogen atoms are picked up by the solar wind after ionization and form a highly non-thermal component which may be observable upwind outside of 10 au (100). Outside the heliosphere (50-100 au) the solar wind is slowed down sufficiently to be a source of hydrogen atoms with velocities of 20 to 200 km s^{-1}. These relatively fast H atoms penetrate into the inner heliosphere and may contribute up to 10% of the observed L_α background (101). In this subsonic region around the heliosphere an appreciable part of the in-streaming interstellar H atoms could already be ionized before even reaching the heliosphere (102).

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