COMMISSION 49: THE INTERPLANETARY PLASMA AND THE HELIOSPHERE (PLASMA INTERPLANETAIRE ET L'HELIOSPHERE)

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Introduction

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The area of interest to the Commission includes:

1. Solar wind composition and dynamics;
2. Interaction of solar wind with extended interplanetary sources of plasma and gases of non-solar origin;
3. Structure and dynamics of the three-dimensional heliosphere;
4. Interaction of heliosphere with the local interstellar medium.

The following reports summarize recent developments in the aforementioned fields.

Dynamic Phenomena in the Solar Wind

L.F. Burlaga

In this review a few topics have been selected which are being actively investigated and which are particularly important for understanding the heliosphere. The reader is also referred to the following reviews: Burlaga (1984, 1986, 1987a), Gosling (1986), Hundhausen (1985), Hundhausen *et al.* (1984), Kahler (1985), Klein (1987), Mihalov (1987), Pizzo (1985, 1986), Richter *et al.* (1985), Schwenn (1986) and Smith (1985).

LARGE-SCALE MAGNETIC FIELD AND PLASMA

Slavin *et al.* (1984) and Thomas *et al.* (1986) reported that at 10 AU the azimuthal component of the magnetic field is 25% lower than predicted by Parker. Klein *et al.* (1987), who considered the effect of temporal variations of the bulk speed, found from an analysis of Voyager data that the difference is only (10±7)% for the interval from 1977 to 1981. They found that the difference between the magnitude of the magnetic field observed at 10 AU and that predicted by Parker was less than 1% . Good agreement between observations and the predictions of Parker between 1 AU and 9.5 AU was also found by Burlaga *et al.* (1984).

Suess *et al.* (1985) and Nerney and Suess (1985) calculated that a 25% flux deficit might be produced in an axially symmetric solar wind as a result of the fact that the magnetic field is higher near the ecliptic than at higher latitudes. However, Pizzo and Goldstein (1987) point out that the solar wind conditions assumed by Suess are unrealistic. They show that a deficit of 10% can be produced by certain flow configurations which might be observed during the declining phase of solar activity, but they suggest that the deficit should be smaller when solar activity is increasing or high, which was the situation during which the radial variations discussed above were determined.

Thomas *et al.* (1987) report a significant meridional component of the magnetic field at 1 AU, corresponding to a flaring angle of 1.3°. Pizzo and Goldstein (1987) note that this implies a meridional flow speed of 10 km/s, for which there is no observational or theoretical basis.

The radial variation of the plasma parameters shows no surprises. The density falls of as R^{-2}, and $T_p \propto R^{-\alpha}$, where $\alpha = 0.5 \div 0.7$ (Gazis (1984)). There is no appreciable difference in the median values and distributions of the density, speed and temperature for two parts of the solar cycle at 10 AU (Barnes and Gazis, 1984). However, the distribution of dynamic pressure shows a larger tail when solar activity is high (Barnes and Gazis (1984)).

MAGNETIC CLOUDS, CMEs AND BIDIRECTIONAL ANISOTROPIES

Goldstein (1983) suggested that magnetic clouds are force-free configurations, but he did not present a specific solution. Marubashi (1987) computed magnetic field profile that might be observed by a spacecraft passing through a magnetic cloud with a force-free configuration, based on the arbitrary assumption that the pitch angle of the magnetic field increases as the square of the distance from the axis of the magnetic cloud. He found qualitative agreement between the model and the observations for two magnetic clouds. Woltjer's (1958) configuration of lowest energy force-free field with α = const gives magnetic field profiles which resemble those observed in magnetic clouds (Burlaga, 1987b).

A dynamical model of magnetic clouds was presented by Ivanov and Harshiladze (1984). Suess (1987) presented a model in which the magnetic field in a magnetic cloud is driven by an axial current as in the pinch effect.

Further evidence that magnetic clouds may be associated with disappearing filaments and coronal mass ejections was presented by Wilson and Hildner (1984, 1986) and Burlaga *et al.* (1987b). It is not likely that every coronal mass ejection is associated with a magnetic cloud. Magnetic clouds are associated with geomagnetic storms (Zhang and Burlaga, 1987; Wilson, 1987). Magnetic clouds which are associated with compound streams can produce relatively large geomagnetic storms (Burlaga *et al.* ,1987; Zhang and Burlaga, 1987), because the magnetic field is amplified in the interaction between a magnetic cloud and a stream or shock. A magnetic cloud has only small effect on galactic cosmic rays, unless it is preceded by a shock and a turbulent interaction region (Zhang and Burlaga, 1987).

Bidirectional anisotropies of energetic particles have been interpreted as evidence of closed magnetic loop structures. Gosling *et al.* (1986, 1987a) identified "bidirectional solar wind heat flux events" in ISEE-3 data, which they assume are signatures of coronal mass ejections. Gosling *et al.* (1987b) found that for such events there is a westward deflection of the flow just ahead of the event followed by an eastward deflection in the event itself. Some events are magnetic clouds, but many others do not show the rotation of the magnetic field which is characteristic of a magnetic cloud even though they typically have low temperature, low magnetic field variance, and high magnetic field intensity, which are characteristic of magnetic clouds. Marsden *et al.* (1987) identified bidirectional anisotropies in low energy protons. Some of their events are related to magnetic clouds. There does not appear to be a one to one relation between bidirectional solar wind heat flux events and bidirectional anisotropies in the protons.

SHOCKS AND FLOWS IN THE INNER HELIOSPHERE

MHD models of transient flows and shocks associated with coronal transients and flare ejecta in the corona were developed by Dryer and Smart (1984) and Dryer *et al.* (1984). Three-dimensional flows within 1 AU were modeled by Dryer *et al.* (1986). A kinematic model of interplanetary disturbances associated with shocks produced by flares was further discussed by Akasofu *et al.* (1985a, 1985b), Olmsted (1985, 1986) and Hakamada (1987). Smart and Shea (1985) discussed a method of "timing" a solar flare, based on the assumption that a shock moves at constant speed out to some distance and thereafter moves at a speed proportional to $R^{-1/2}$. An improved method for calculating shock normals was developed by Vinas and Scudder (1986).

Interplanetary shocks observed at 1 AU in association with Type II radio bursts (Cane, 1984) are relatively fast and are almost always associated with a solar flare (Cane and Stone, 1984) and a long duration solar X-ray event (Cane, 1985). Shocks related to solar filament eruptions outside active regions are not associated with Type II bursts, move relatively slowly, and are accompanied by only weak soft X-ray bursts (Cane *et al.*, 1986). The shocks are spherical over a wide range of longitudes (Cane *et al.*, 1987). The three-dimensional geometry of shocks associated with coronal mass ejections was discussed by Schwenn (1986).

A slow forward shock wave was observed at 0.3 AU by Richter *et al.* (1985). Whang (1987) has shown that a slow shock can transform into a fast shock as it moves away from the sun.

SHOCKS AND INTERACTION REGIONS IN THE OUTER HELIOSPHERE

Near the sun, isolated streams are the dominant dynamical feature (see, e.g., Richter and Luttrell, 1986), whereas far from the sun large pressure waves unaccompanied by streams are dominant (Burlaga, 1984).

At intermediate distances (1 to ~10 AU) fast streams overtake slower streams to form "compound streams", and their separate interaction regions coalesce to form "merged interaction regions" (Burlaga *et al.*, 1985a). This process of "entrainment" was modeled by Burlaga *et al.* (1985b) and Whang and Burlaga (1985a,b). Burlaga *et al.* (1986a) showed one case in which five streams and interaction regions at 1 AU coalesced to form one compound stream and two merged interaction regions at 6.5 AU, when an unusually fast stream entrained the flows ahead. Whang and Burlaga (1986) showed that the two merged interaction regions themselves coalesced between 6.5 AU and 9.5 AU.

Whereas a shock wave at 1 AU is usually driven by a stream, a shock wave far from the sun may be detached from the stream which originally produced it or the stream may damp out, leaving the shock to propagate alone. Two forward shocks or two reverse shocks may coalesce to form a single forward shock or reverse shock, respectively; and a forward shock may interact with a reverse shock, in which case both shocks emerge from the collision weaker than they were initially (Whang and Burlaga, 1985a,b). Shocks may form as far as 7 AU from the sun (Gazis *et al.*, 1985). Shocks and transient streams are observed out to at least 29 AU (Kayser, 1985; Kayser *et al.*, 1984). However, shocks associated with flares are less frequent, slower, and weaker far from the sun than those close to the sun (Mihalov, 1985). The topological configurations of corotating shocks in the outer heliosphere for the case of one or two corotating streams at 1 AU were computed by Burlaga and Klein (1986).

To determine the structure of the solar wind on a scale of 30 AU one must examine data over an interval of the order of 120 days. During such an interval one typically sees at least several interaction regions and the variations of the magnetic field and plasma parameters appear as "large-scale fluctuations" (Burlaga, 1984). Burlaga *et al.* (1984) showed that the characteristic period of the large-scale fluctuations in the magnetic field intensity apparently increased with distance from the sun between 1 AU and 9.5 AU, which they attributed to entrainment. This was confirmed by Burlaga and Mish (1987) using simultaneous data from ISEE-3 and Voyager. Burlaga and Goldstein (1984) found that the radial evolution of the spectra of the magnetic field strength may be different for systems of corotating flows and systems of transient flows. Evidence for period-doubling in the solar wind was found by Burlaga and Lazarus (1987), who showed that Voyager 2 observed recurrent interaction regions with a period of 25 days at ~15 AU when IMP-8 observed recurrent interaction regions with a period of 12.5 days relative to a fixed frame at 1 AU. This behavior is contrary to predictions for strictly periodic flows (Smith *et al.*, 1985), but such behavior is observed in driven damped nonlinear oscillators.

REFERENCES

(JGR = Journal of Geophysical Research)
Akasofu, S.I. et al.: 1985a, JGR **90**, p 8193; Akasofu, S.-I. et al.: 1985b, JGR **90**, p 4439; Barnes, A., Gazis, P.R.: 1984, *Uranus and Neptune*, ed. J.T. Bergstralh, *NASA-CP 2330*, NASA, Washington DC, p 527; Burlaga, L.F.: 1984, Space Sci. Rev. **39**, p 255; 1986, *The Sun and the Heliosphere in Three Dimensions*, ed. R.G. Marsden, D. Reidel, Dordrecht, p 191; 1987a, *Solar Wind VI*, submitted; 1987b, JGR, submitted; Burlaga, L.F., Goldstein, M.L.: 1984, JGR **89**, p 6813; Burlaga, L.F., Klein, L.W.: 1986, JGR **91**, p 8975; Burlaga, L.F., Lazarus, A.J.: 1987, JGR; Burlaga, L.F., Mish, W.H.: 1987, JGR **92**, p 1261; Burlaga, L.F. et al.: 1984, JGR **89**, p 10659; Burlaga, L.F. et al.: 1985a, JGR **90**, p 12127; Burlaga, L.F. et al.: 1985b, JGR **90**, p 7377; Burlaga, L.F. et al.: 1986a, JGR **91**, p 13331; Burlaga, L.F. et al.: 1986b, JGR **91**, p 2917; Burlaga, L.F. et al.: 1987b, JGR **92**, p 5725; Cane, H. V.: 1984, Astron. Astrophys. **140**, p 205; 1985, JGR **90**, p 191; Cane, H. V., Stone, R.G.: 1984, Astrophys. J. **282**, p 339; Cane, H. V. et al.: 1986, JGR **91**, p 13321; Cane, H. V. et al.: 1987, JGR, in press; Dryer, M.S., Smart, D.F.: 1984, Adv. Space Res. **4**, p 291; Dryer, M.S. et al.: 1984, Astrophys. Space Sci. **105**, p 187; Dryer, M.S. et al.: 1986, *The Sun and the Heliosphere in Three Dimensions*, ed. R.G. Marsden, D. Reidel, Dordrecht, p 135; Gazis, P.R.: 1984, JGR **89**, p 775; 1987, JGR **92**, p 2231; Gazis, P.R. et al.:1985, JGR **90**, p 9454; Goldstein, H.: 1983, *Solar Wind V*, ed. M. Neugebauer, *NASA Conf. Proc. SP 2280*, p 731; Goldstein, M.L. et al.: 1984, JGR **89**, p 3747; Gosling, J.T.: 1986, *Magnetospheric Phenomena in Astrophysics*, eds. R.I. Epstein and W.C. Feldman, American Institute of Physics, N.Y., N.Y., p 124; Gosling, J.T., McComas, D.J.: 1987, Geophys. Res. Lett. **14**, p 355; Gosling, J.T. et al.: 1986, JGR **91**, p 352; Gosling, J.T. et al.: 1987a, JGR **92**, p 8519; Gosling, J.T. et al.: 1987b, JGR, in press; Hakamada, K.: 1987, JGR **92**, p 4339; Hundhausen, A.J.: 1985, *Collisionless shocks in the Heliosphere*, eds. R.G. Stone and B.T. Tsurutani, *AGU Geophysical Monograph* **34**, p 37; Hundhausen, A.J. et al.: 1984, eds. D.M. Butler and K. Papadopulous. *NASA Ref. Publ.* **1120**, pp 6.1-6.32; Ivanov, K.G., Harshiladze, A.F.: 1984, Solar Phys. **92**, p 351; Kahler, S.: 1987, *U.S. National Report to International Union of Geodesy and Geophys. 1983-1986*, American Geophysical Union, Washington D.C., p 663; Kayser, S.E.: 1985, JGR **90**, p 3967; Kayser, S. E. et al.: 1984, Astrophys. J. **285**, p 339; Klein, L.: 1987, *Solar Wind VI*; Klein, L.W. et al.: 1987, JGR, in press; Marsden, R.G. et al.: 1987, JGR; Marubashi, K.: 1987, Adv. Space Sci.; Mihalov, J.D. 1985, JGR **90**, 210; 1987, *U.S. National Report to International Union of Geodesy and Geophys. 1983-1986*, American Geophysical Union, Washington D.C., p 697; Nerney, S.F., Suess, S.T.: 1985, Astrophys. J. **296**, p 259; Olmsted, C., Akasofu, S.-I.: 1985, Planet. Space Sci. **33**, p 831; 1986, JGR **91**, p 13689; Pizzo, V.J.: 1985, *Collisionless Shocks in the Heliosphere: Reviews of Current Research*, eds. B.T. Tsurutani and R.G. Stone, *Geophysical Monograph* **35**, American Geophysical Union, Washington D.C., p 51; 1986, Adv. Space Res. **6**(1), p 353; Pizzo, V.J., Goldstein, B.E.: 1987, JGR **92**, p 7241; Richter, A.K., Luttrell, A.H.: 1986, JGR **91**, p 5873; Richter, A.K. et al.: 1985, *Collisionless Shocks in the Heliosphere: Reviews of Current Research*, eds. B.T. Tsurutani and R.G. Stone, *Geophysical Monograph* **35**, American Geophysical Union, Washington D.C., p 33; Richter, A.K. et al.: 1985, JGR **90**, p 7581; Schwenn, R.: 1986, Space Sci. Rev. **44**, p 139; Slavin, J.A. et al.: 1984, Geophys. Res. Lett. **11**, p 279; Smart, D.F., Shea, M.A.: 1985, JGR **90**, p 183; Smith, E.J., 1985, *Collisionless Shocks in the Heliosphere: Reviews of Current Research*, eds. B.T. Tsurutani and R.G. Stone, *Geophysical Monograph* **35**, American Geophysical Union, Washington D.C., p 69; Smith, Z.K. et al.: 1985, JGR **90**, p 217; Suess, S.T.: 1987, JGR, in press; Suess, S.T. et al.:

1985, JGR 90, p 4378; Thomas, B.T. et al.: 1986, JGR 91, p 6760; Vinas, A.F., Scudder, J.D.: 1986, JGR 91, p 39; Whang, Y.C.: 1984, JGR 89, p 7367; 1987, JGR, in press; Whang, Y.C., Burlaga, L.F.: 1985a, JGR 90, p 10765; 1985b, JGR 90, p 221; 1986, JGR 91, p 13341; Wilson, R.M., Hildner, E.: 1984, Solar Phys. 91, p 168; 1986, JGR 91, p 5867; Wilson, R.M.: 1987, Planet. Space Sci. 35, p 329; Woltjer, L.: 1958, *Proceedings of the National Academy of Sciences* **44** No 5, p 489; Zhang, G., Burlaga, L.F.: 1987, JGR, submitted

Minor Ions in the Solar Wind

Peter Bochsler

It has been recently recognized that the presence of ions heavier than hydrogen determines to a large extent the dynamics of the expanding solar corona. In the following I shall give a brief account of the most recent results related to minor ions (i.e. ^{3}He and ions heavier than helium).

ELEMENTAL ABUNDANCES

Table 1 gives elemental abundances as obtained by in situ measurements.

Table 1

Abundances relative to oxygen

	Solar Wind		Solar Energetic Particles		Solar System	
H	1900±400	[1]	---		1400	[11]
He	75±20	[2]	72±3	[8]	108	[11]
^{3}He/^{4}He	$(4.9\pm0.5)\cdot10^{-4}$	[3]	---			
C	0.43±0.02	[4]	0.435±0.040	[9]	0.60	[11]
N	0.15±0.06	[4]	0.124±0.010	[9]	0.12	[11]
O	≡1		≡1		≡1	
Ne	0.17±0.2	[2,5]	0.142±0.014	[9]	0.14	[12]
^{20}Ne/^{22}Ne	13.7±0.3	[5]	$9.2^{+1.9}_{-2.2}$	[10]		
Si	0.22±0.07	[6]	0.161±0.009	[9]	0.050	[10]
Ar	$(4.0\pm1.0)\cdot10^{-8}$	[5]	$(3.3\pm0.6)\cdot10^{-8}$	[9]	0.0048	[12]
Fe	0.19±0.07	[7]	0.154±0.015	[9]	0.045	[10]

[1] - Bame *et al.*, 1975
[2] - Bochsler *et al.*, 1986
[3] - Coplan *et al.*, 1984
[4] - Gloeckler *et al.*, 1986
[5] - Geiss *et al.*, 1972
[6] - Bochsler, 1987
[7] - Schmid *et al.*,1987
[8] - Cook *et al.*, 1984
[9] - Brenemann, Stone, 1985
[10] - Mewaldt *et al.*, 1984
[11] - Anders, Ebihara, 1982
[12] - Meyer, 1985

These data remain incomplete since they do not include information on isotopic compositions except for helium and neon. Isotopic compositions of several additional elements, mostly noble gases, are available from the analysis of lunar soils. Recently, Wieler and co-workers (1986) have shown that lunar soil contains a surface implanted component with a ^{20}Ne/^{22}Ne ratio of 11.3±0.3 which they ascribe to Solar Energetic Particles (SEP). This result confirms the difference of the solar wind isotopic ^{20}Ne/^{22}Ne ratio (=13.7±0.3 - Geiss *et al.*, 1972) from SEP and it supports evidence for a secular decrease of the flux ratio of SEP to solar wind.

The ISEE 3/ICI (K.W. Ogilvie, P.I.) results have established strong correlations of the fluxes of the heavier elements with helium fluxes over time scales of several years. Undoubtedly there exist strong variations of these fluxes and their respective ratios as is well known for the case of