49: THE INTERPLANETARY PLASMA AND THE HELIOSPHERE

(PLASMA INTERPLANETAIRE ET L'HELIOSPHERE)

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I. INTRODUCTION

This commission is intended to study the following problems: (1) the solar corona, i.e. the region of the origin of the solar wind; (2) the heliosphere, i.e. the region dominated by the supersonic solar wind as it expands through the neutral component of the interstellar medium; (3) the heliospheric interface, i.e. the region in which the interaction between the two counterstreaming magnetized plasmas, the subsonic solar wind and the interstellar medium, takes place. The activities of this commission cover both theoretical and observational investigations of these three regions.

In the following presentation members of this commission will give status reports with concern to ongoing investigations in the aforementioned scientific fields of this commission.

II. BASIC RESULTS OBTAINED IN THE USSR DURING 1979-1981 WITH CONCERN TO COMMISSION 49 (INTERPLANETARY SPACE)

(A.Z. Dolginov)

A. Solar Wind Plasma Studies

The study of the solar wind plasma via measurements performed in 1979-1981 by means of broad-angle instruments on board the Earth satellites Prognoz 4 and 6 was continued. Physical processes in interplanetary space connected with the propagation of the shock waves generated by the solar flare on January 1, 1978 were investigated by means of complex measurements of plasma, magnetic field and energetic particles performed aboard the Soviet space probe Prognoz 6 and the West German space probes Helios 1 and 2 at three different points in the solar system. The interplanetary shock wave was observed as a "piston wave" on Helios 1 and as a "blast wave" on Helios 2 and Prognoz 6. This result demonstrated the absence of a direct relation between the characteristics of the interplanetary shock wave and the time of energy release on the Sun. It seems that there are no pure "blast waves" at all. Such waves are registered only if the point of observation is inappropriately connected by the magnetic lines with the point of the flare.

The possibility of proton acceleration up to the energy of several MeV in the oblique shock waves during the time of the order of 1 min (shock-spike) was shown. An essential increase of proton flux with the energy 1,4 - 5,8 MeV observed aboard the Prognoz 6 satellite in the vicinity of the oblique shock wave front is evidence for an acceleration process in such waves. There is up to now no theoretical explanation for this effect. The study of plasma characteristics and electron spectra at energies of about 1 MeV with Prognoz 4 shows that the source of electrons in the region near the magnetopause is the same as considered by Meng and Anderson (1970). The essential difference of the electron flux behaviour in different magnetospheric regions shows that the source of electrons is the outer radiation belt on the dayside of the magnetosphere.

A model of the system of currents in the vicinity of Venus is proposed. It is based on the measurements of plasma and electron fluxes performed aboard the Venus satellites Venera 9 and 10.

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B. Solar Cosmic Rays

A study of solar cosmic rays was continued in 1979-1980 by the Prognoz satellites and the Venera space probes. Proton acceleration has been shown to take place in all cases where the electrons are also accelerated, even in the faintest flares at a small total energy release in the absence of a second acceleration stage in the shock wave. The energy loss by particles during their propagation in interplanetary space, resulting in a falloff of the spectrum in the low energy range, has been studied. The inclusion of such a loss has made it possible to derive the same altitude of generation for protons as for electrons.

The gamma ray emission from solar flares has been studied theoretically. The nuclear reactions of the flare-accelerated heavy nuclei have been shown to contribute much to the gamma ray flux. For example, if particles are accelerated in a flare up to rather small energies below 10 MeV/nucleon, then all the gamma rays will be produced in the nuclear reactions of heavy nuclei.

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C. Solar Wind Plasma Turbulence

A method to map the interplanetary plasma turbulence based on the scintillation index for more than 150 sources per day was elaborated. The following results have been obtained in observations carried out in 1975-79: a) the polar regions of the interplanetary plasma are essentially perturbed during the solar activity cycle (in the years of the activity solar maximum the structure of the interplanetary plasma has a quasi-spherical symmetry, in the years of the activity minimum it is elongated in the equatorial direction); b) there exists a strong correlation (the correlation coefficient reaches 0,75) between the scintillation index averaged over all sources and the geomagnetic A_p index.

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D. Radio Scintillations

A theory of nebular radio source scintillations was elaborated. The statistics of scintillations indicates the discontinuity structure of the solar wind which consists of many jets. The velocity distribution of the interplanetary plasma was obtained. The possibility of geomagnetic activity predictions using scintillation data has been considered.

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E. Particle Acceleration

A theoretical analysis of solar cosmic ray propagation and acceleration by shock waves in the interplanetary medium was developed. The explanation of the temporary and spectral features of cosmic ray observation was put forward.

Charged particle adiabatic invariants for an oblique shock wave field have been considered on the basis of the Krylov-Bogolubov asymptotic method. The energy gain of fast particles has been calculated.

A theory of cosmic ray acceleration by weak solar flares was developed. The abundance anomaly (He^3 and heavy elements) was explained. A general consideration of events which accompany the events in radio, X-ray and optical bands was performed.

A theory of MHD waves in an inhomogeneous and moving medium has been developed. Nonlinear effects and destruction of the waves have been considered. The theory has been applied to the MHD wave evolution in the interplanetary medium.

Some abrupt interplanetary magnetic field intensity variations observed aboard the spacecrafts at the heliocentric distance from 0.3 to 2.2 AU are explained by the heliographic longitudinal dependence of solar wind flow. An analysis of the observational results proves the existence of a large extension of the corotating streams. The discrepancy of the magnetic field intensities, obtained at various heliocentric distances, with those predicted by Parker's model is explained as a result of some solar magnetic field variation.

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III. FREE NEUTRALS IN INTERPLANETARY SPACE: SOURCES AND COUPLING TO THE SOLAR WIND PLASMA

(S. Grzedzielski)

A. Introductory Remarks

This report deals with the problems related to the presence of free neutral atoms (molecules) in interplanetary space. The scope of the subject was substantially broadened in recent years as in situ measurements based on direct counting of energetic neutrals or on indirect analysis of plasma signature variations ascribed to neutrals (and dust) began to supplement the classical optical (UV) detection methods. The new important Voyager results are discussed in somewhat greater detail.

The point sources of neutral gases in the Solar System include terrestrial planets, comets, Jupiter (Io), Saturn (Titan), and as a possible candidate (although not confirmed as yet) the Sun. The extended sources consist of the all-pervading neutral interstellar wind and, possibly, the interplanetary dust. Excluded from the present report are the terrestrial planets and the comets. Although, at least in the case of Venus, copious fluxes of neutrals seem to penetrate into the solar wind well ahead of the planet, in both of these types of objects the emission of neutrals is intimately linked with the structure of their ionospheres/exospheres. Neutral fluxes ahead of even the bow shock may also be a typical feature of active comets at heliocentric distances $\lesssim$ 3 AU. This issue will hopefully be elucidated during the planned missions to the Halley comet (encounter in March 1986).

B. Jupiter and Saturn as Sources of Neutrals

The Pioneer and Voyager data together with the Earth-based (visual) and Earth-orbiting (mainly UV; Copernicus, IUE) spectroscopic observations indicate that the systems of Jupiter and Saturn may leak free neutrals to the interplanetary space. With the energy per particle less than 0.01 eV in the atmospheres of Jupiter and Saturn no direct escape seems possible (Trafton, 1981). However, the energetics of escape from Io and (possibly) Titan looks much more promising (Cheng, 1980; Dessler, 1980; Eviatar and Siscoe, 1980; Pollack and Witteborn, 1980; Shemansky, 1980; Smyth, 1981; Trafton, 1981). Enhanced sputtering rates for the icy satellites (Johnson et al., 1981) may also contribute to the production of neutrals.

The neutral H cloud associated with Titan (Barker et al., 1980; Broadfoot et al., 1981a; Clarke et al., 1981; Judge et al., 1980; Sittler et al., 1981) extends probably from 8 to 25 Saturn radii and may contain up to 2 x 10^{34} neutral H atoms (Broadfoot et al., 1981a). Also dust and neutrals seem to be present in the E-ring region (Sittler et al., 1981). For most of the time the Titan torus is probably contained within the magnetosphere of Saturn (Bridge et al., 1981), and the H atoms, if ionized by (mainly) electron impact, will have little chance of escaping. On the other hand, charge exchange with the radiation belt protons may lead to high energy neutrals. During the approach of Voyager 1 to Saturn such neutrals (of energy exceeding 40 keV) seem indeed to have been observed (Kirsch et al., 1981b; also Stone and Miner, 1981). The estimated loss rate is $\sim 10^{24}$ neutrals/s.

At times of enhanced solar wind pressure part of the cloud may extend out of the magnetosphere (Pioneer 11 flyby, Wolfe et al., 1980; also Sittler et al., 1981) and H may charge-exchange with the solar wind magnetosheath. If, for instance, Titan happened to be exposed to the magnetosheath protons for 1/4 of its orbit (= 3.4 x 10^5 s), $\sim 10^{30}$ neutral H atoms of $\sim$1 keV energy could be produced (rate 3 x 10^{24} at./s).

Io can be a much stronger and permanent source of neutrals. Several escape mechanisms from the Io surface/atmosphere were proposed: volcanic activity (plumes), Jeans' escape (also via the Lagrange point), exobase exposure to the Jupiter magnetospheric plasma, sputtering of surface and/or atmosphere (Pollack and Witteborn, 1980; also Cheng, 1980; McElroy and Young, 1975; Smith et al., 1979; Haff et al., 1981). Loss rates spanning 5 orders of magnitude, up to 10^3 g/s (=10^{30} SO_2 molecules/s) are being suggested (Cheng, 1980; also Haff and Watson, 1981), although the estimates (of eventual ion supply) based on mass loading of the Io plasma torus point towards rather lower values of 10^{28} ions/s, and the (model dependent) estimates inferred from the intensity of the observed O and S emission lines yield 10^{27} ions/s (Shemansky, 1980; Broadfoot et al., 1981b; Brown and Ip, 1981).

The escaping neutrals (SO_2, SO and then S and O) move in the Io torus with the Keplerian velocity (17 km/s) and are upon ionization (mostly by the low energy electrons) picked up by the $\vec{v} \times \vec{B}$ electric field of the corotating Jovian magnetosphere (corotation speed = 74 km/s at Io). Hence they acquire cyclotron gyration energies of up to 90 eV/nucleon. A subsequent charge exchange of such an ion with a torus neutral creates neutral atoms of energies ranging up to 1.5 keV for the O atoms. Such energization associated with the intramagnetopause rather than with the bow shock phenomena is also suggested by the Voyager 1 and 2 observations of heavy ions (Zwickl et al., 1980). Dissociative attachment of < 10 keV electrons on SO_2 may even lead to higher energies: the reaction products (S and O atoms) are left with a small additional energy that allows them to climb ballistically up in the gravitational field of Jupiter. They may then charge exchange in regions with higher corotational velocities. Thus neutrals with energy ranges of tens-of-keV can be produced. Only a very tiny fraction of all Io neutrals may be involved in this last process (Cheng, 1980). Such very energetic neutrals (14 - 61 keV) could have possibly been detected by Voyager 1 during the approach to Jupiter (230 - 100 Jovian radii from the planet, Kirsch et al., 1981a). The inferred total neutral loss rate by Jupiter is (if isotropic) $\leq 10^{25}$ at./s. Since the bulk of Jovian neutrals will rather have energies < 1 keV, the reported neutral flux does not necessarily contradict the high loss rate ($\sim 10^{30}$ at./s) favoured by Cheng. Adopting this high rate both for O and S escaping isotropically with $\sim$80 km/s (at infinity) one obtains that the Io neutrals may dominate (by mass) over the neutrals of interstellar origin within 1/4 AU from the planet. In this case the mass loading of the solar wind by the Jovian neutrals (ionization time = 2.7×10^7 s at Jupiter orbit) may slow down the solar wind by $\sim$1.5 km/s upon arriving at 60 Jovian radii from the planet (expected solar wind ion temperature increase $\lesssim$ 3000 K). The production of neutrals, if depending on the volcanoes, may also be a strongly time-dependent phenomenon (Cheng, 1980). In any case variations in the Io torus are observed (Sandel et al., 1979; Warwick et al., 1979).

C. Outgassing from the Interplanetary Dust

For an interplanetary grain saturated with the solar wind particles, which seems to be the case for the inner solar system, the desorption of neutrals will keep pace with the impinging ion flux (Holzer, 1977). Beyond a few AU from the Sun the amount of dust seems to be too small (Stanley et al., 1979) to yield a measurable effect unless there exist in these regions some unknown sources of fine dust grains. One such possibility was recently put forward by Mendis et al. (1981): beyond 5 AU from the Sun submicron grains can be electrostatically levitated and removed from the cometary nuclei, yielding a dust blow-off rate comparable to that observed in medium bright comets during perihelion passage between 3 AU and 0.5 AU.

However, the best known and most promising dust source is the outer part ($r > 4$ solar radii) of the circumsolar dust cloud (Leinert et al., 1978; Beard, 1979; Mukai and Yamamoto, 1979) in which the sublimation rate may still be low enough to enable the magnetite dust to survive (Mukai and Schwehm, 1981). The production of neutrals by dust outgassing in that region was investigated by Fahr et al. (1981) for a model distribution of dust grains based on the Helios data (Leinert et al., 1978). The erosion rate seems to be sufficiently small to virtually ensure all hydrogen to desorb as H_2, 5% of which is subsequently dissociated into H atoms. However, desorption as SiH or CH with an 80% recovery of atomic H by subsequent dissociation is also under discussion (Fahr et al., 1982). Helium will appear in atomic form. As the thermal speeds of the dust-generated neutrals are small compared to the (circular) orbital velocities of the parent grains, the resulting density of neutrals will essentially be determined by the local (very fast) ionization rate compensating the local production of neutrals. For a plausible value of the dust density parameter $\Gamma = 2 \times 10^{-19}$ cm^{-1} Fahr et al. (1981) obtain $n_H \simeq 10^{-2}$ at./cm^3 ($n_{He} \simeq 10^{-3}$ at./cm^3) at 4 solar radii. Charge exchange of the outgassed neutrals with the solar wind protons will constitute a source of 1 keV H atoms and also (after "pick up") of keV/nucleon He^+ and H^+ ions that do not exist in the primary solar wind. The dust-generated neutral cloud should shine in the resonantly scattered solar Ly-α and He-584 A lines. These emissions could be within the reach of observational capabilities for look angles close to the Sun (<6°) if the above value for Γ is realistic (Fahr et al., 1981). However, Γ could as well be much smaller and the intensity varies directly with Γ. Also complicated dust grain dynamics (Morfill and Grün, 1979) could alter the calculated intensity spectra.

D. Neutrals of Interstellar Origin

The external local interstellar medium constitutes by far the strongest source of neutrals to the interplanetary space. Assuming a 100 AU heliosphere radius, a 20 km/s inflow velocity, and 0.05 atoms/cm^3 neutral external density, the source strength is $\sim 7 \times 10^{35}$ at./s. Almost all information on these neutrals is obtained by analyzing the scattered solar H I Ly-α and He I λ 584 A lines. Recently, first H I Ly-β measurements were reported (Shemansky et al., 1979); also the reality of a previously reported absorption feature in the solar spectrum and attributed to neutral H was assessed (negative conclusion, Meier, 1979; Artzner et al., 1981).

The general picture is rather well understood (Fahr, 1974; Holzer, 1977; Thomas, 1978). In recent years the data are interpreted in terms of the so-called "hot" (Meier, 1977; Wu and Judge, 1980) model which describes how an initially isotropic and Maxwellian velocity distribution of neutrals changes when it is convected towards and then "falls" into the gravitational well of the Sun (Danby and Camm, 1957) with a net loss of particles due to ionization (Meier, 1977; Fahr, 1978). The salient features of the distribution of neutrals are a large cavity for H and a smaller one for He accompanied by a very long island of increased He density as a result of gravitational focusing. Recent successes in the investigation of interplanetary resonance radiation at 1216 A and at 584 A are reviewed in the contribution following this report.

E. Coupling of the Newly Ionized Particles to the Solar Plasma

The ionization processes do not practically alter the momentum of a neutral atom undergoing ionization. The newly ionized particles (new ions) inherit the velocity distribution function characteristic for the parent neutrals. Two problems arise: (1) will (and on what time scale) the velocity distribution function of the new ions "relax" to the distribution function of the background plasma?, and (2) if yes, will this then significantly affect the general state of the solar wind?

A positive answer to (1) was given almost a decade ago for δ-type distribution functions of the neutrals in a series of papers by R.C. Davidson, R.E. Hartle and C.S. Wu. The time scales were short compared to the flow time scales of the solar wind. Recently the problem was discussed again by Curtis (in the context of the Venus exosphere, 1981) and Grzedzielski and Rozmus (1982) for a more realistic case of finite temperatures of the new ions. Again the time scales proved to be short: for an equilibrium situation (production of new ions by ionization compensated by their loss through particle - unstable wave interaction) the relaxation time scales on a linear theory are between 10^2 s (at ~ 1 AU) and 10^5 s (at ~ 100 AU) both for hydrogen and helium. The number density of the "unrelaxed" new ion population is then between $\sim 10^{-6}$ and $\sim 10^{-9}$ cm^{-3}. The theoretical short time scales may possibly be in conflict with an observational datum on the He^+ ions: as shown by Paresce et al. (1981) an upper limit for the interplanetary He II λ 304 A emission can be used to set a lower limit of 10^9 s for the decrease of the suprathermal He^+ velocity towards the bulk solar wind speed. The rare occurrences of the He^+ ions being detected in the interplanetary shock waves are attributed to traces of "cold" chromospheric plasma carried away by the flare ejecta (Schwenn et al., 1980; Gosling et al., 1980).

If the short time scales do apply, one can treat (2) in terms of fluid dynamics (in any case the mass loading in a direction perpendicular to the magnetic field is rather beyond doubt). The dust-generated neutrals do not significantly affect the solar wind flow (Ripken and Fahr, 1980; Fahr et al., 1981). A measurable effect, even at moderate solar distances, can probably result from the solar wind being slightly decelerated, heated-up and deflected by the downwind helium island (Grzedzielski, 1980). However, the solar wind can be influenced by the mass loading of neutrals, especially at large heliocentric distances, and the predicted deceleration and heating of the solar wind plasma can in the future be tested against the measurements: as estimated by Błeszynski and Grzedzielski (1982), the expected solar wind velocity gradient at the positions of Pioneer 10 in 1986 and Voyager 1 in 1989 will be 5 km/s per 10 AU.

Petelski et al. (1980a, 1980b) have discussed the fluid-like interaction of the solar wind with the interstellar neutrals (on the stagnation line only) when the ionization rate is increased by the so-called critical velocity effect (observed in the laboratory when the energy of the bulk motion of the neutrals relative to the background plasma exceeds the ionization energy). By scaling up the laboratory results to the interplanetary conditions, a significant enhancement of ionization is obtained for heliocentric distances $\gtrsim$ 10 AU. However, the exceedingly long growth time scale for the "turbulent heating" of the ionizing electrons may raise doubts as to the legitimacy of the scaling over so vast a gap of values. Assuming the approach to be valid, Petelski et al. obtain a much more rapid deceleration of the solar wind, and the terminating shock becomes very weak or non-existent (cf. also Petelski, 1981) with the heliosphere radius significantly diminished.

The neutral interstellar atoms were also suggested to be the source of the so-called "anomalous" component of the cosmic rays (enhanced He, N, O, Ne at $\sim$10 MeV/nucleon, Fisk et al., 1974; Fisk, 1976). These atoms, upon ionization in the solar cavity, may then be swept back to the outer heliosphere and accelerated on the way to $\sim$10 MeV/nucleon. Then, having high rigidities now (single ionization!) they easily diffuse back again into the inner heliosphere. The recent intercomparison of the Helios 1 and 2 and Pioneer 10 cosmic ray data (McDonald et al., 1981) indicates that near solar maximum most of the modulation must occur beyond 23 AU, and that the "anomalous" and galactic cosmic ray helium intensities are well correlated. This suggests that the required interplanetary acceleration of the "anomalous" component probably occurs beyond the modulation region. The discussion of the modulation data (especially for the high energy particles) is hindered by the poorly understood role of large-scale drifts (Fisk, 1981) and the dependence of modulation on the changes of "waviness" of the interplanetary current sheet (Jokipii and Thomas, 1981).

F. Neutral Species and the Boundary of the Heliosphere

If one assumes that the temperature of the ionized component of LISM (local interstellar medium) is $\sim 10^4$ °K as deduced from the analysis of neutral gases, then the Mach number M of the interstellar gas flow past the heliosphere is $\gtrsim 1$. The heliosphere then must be compressed in the upwind direction, with the ionized component deflected around the flanks and the neutral component going (almost) directly inside. Even in the simplest case of a fluid-like description of the solar wind plasma ramming against the interstellar plasma, the problem is difficult. The boundary values have to be stated on surfaces (inner shock, tangential discontinuity, outer shock) that depend on the solutions themselves. This difficulty was circumvented by Baranov et al. (1979) by finding the stationary solution as an asymptotic case of the non-stationary ones. Knowing the plasma flow between the surfaces, Baranov et al. are able to estimate the relative number of the primary interstellar H atoms that go through unaffected by charge exchange with the deflected interstellar plasma (the analysis was also extended to the case when the force upon the deflected flow due to momentum transfer from LISM by charge exchange with interstellar neutral hydrogen is taken into account, Baranov et al., 1981).

These results bear on the discussion of the intriguing question of the anomalous observed H/He ratio (cf. Part IV). Assuming that the standard ratio 10 holds in LISM, two (extreme) views can be proposed: (a) the observed ratio is ∿5 instead of 10 because H in LISM is ∿50% thermally ionized while He stays neutral. This agrees nicely with the ∿15 000 K temperature deduced from the Mariner 10 data as shown by Blum et al. (1980, 1981); (b) ∿50% of the neutral H from (predominantly neutral) LISM is retained by charge exchange in the transition layer while the neutral He atoms go through, in view of the very small charge exchange cross section with the protons. However, in case (b) the population of neutral H atoms inside the heliosphere may significantly be affected by the H atoms that charge-exchanged in the shocked interstellar gas. This effect was as yet not evaluated. Other complications will result if the LISM magnetic field is strong enough to influence the structure (i.e. destroy the axial symmetry) of the discussed boundary layers or if it reconnects with the interplanetary magnetic field of solar origin (Akasofu and Covey, 1980; Ahluwalia, 1981).

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IV. EXTRAPOLATION TO THE NEARBY INTERSTELLAR MATTER

(F. Paresce)

A. Observational Access to the Local Interstellar Medium

Two basic and complementary perspectives can be adopted in order to determine the correct ISM parameters at or near the heliopause. The first is that of the ISM gas residing in the inner solar system that has already transited through the solar wind - ISM boundary region and the second is that of the gas residing at distances of 1-10 pcs from the sun that has yet to flow past the sun but will do so in the next 10^4-10^5 yrs. A comparison of the two sets of measurements should yield valuable information on the boundary conditions and, conversely, on their effect on the ISM conditions. It will, of course, also be assumed that the gas is uniform over distances of ≃1 pc or less.

B. The "Inside" Aspect of the LISM

As a matter of fact, the relatively high speed of the neutral ISM gas with respect to the sun (≃20 km/s^{-1}) allows its deep penetration into the solar system before it can be appreciably ionized. Most ISM particles can be found at ≃90% of their undisturbed interstellar density values within a region of 1-5 AU of the sun. Within this region can also be found the highest densities of ions resulting from the ionization of the ISM neutrals. This proximity of the ISM to the sun can be conveniently exploited by observers in or near the earth. A careful analysis of the solar ultraviolet spectrum (see for example, White, 1977) shows that there are a number of intense emission lines that could, in principle, resonate with ISM particles or their derivatives. These include the prominent CII, 1336; OI, 1304; HI, 1216; NII, 1085; HI, 1025; OII, 834; He I, 584; He II, 304 A chromospheric emission features. Due to experimental limitations, only the HI, 1216 and the He I, 584 A lines amongst these can be used effectively for this purpose. Very recently the He II, 304 A line emission structure has been explored to a limited extent (Paresce et al., 1981; Lay et al., 1980). Recently first HI Ly-β measurements were reported (Shemansky et al., 1979).

Recent observations of the resonantly scattered hydrogen Lyman-α and He I, 584 A interplanetary emissions have been extremely useful in confirming, extending and appreciably narrowing the earlier range of acceptable ISM parameters (Thomas and Krassa, 1971; Bertaux and Blamont, 1971; Paresce et al., 1973). A wide variety of techniques and observing platforms have been exploited, including low spatial and spectral resolution (Weller and Meier, 1976, 1979, 1981), low spatial and high spectral resolution (Freeman et al., 1976, 1980; Fahr et al., 1978; Lay et al., 1980), high spatial and low spectral resolution (Freeman et al., 1977, 1979), high spatial and spectral resolution (Adams and Frisch, 1977) detectors from earth orbit and a similar mixture of measurements from interplanetary probes (Broadfoot and Kumar, 1978; Ajello, 1978; Bertaux et al., 1976, 1977; Ajello et al., 1979).

Since the ISM parameters are not measurable directly by any of these techniques because they are too intimately interrelated, they are obtained only as a result of comparisons with theoretical models with free adjustable parameters. A vigorous effort has been expended on the development of suitable and accurate models. These now take into account, in one way or another and with varying success, the effects of non zero gas temperatures, multiple scattering and electron and proton heating enhanced ionization by nonthermal and thermal electron impact (Meier, 1977; Thomas, 1978; Wallis and Wallis, 1979; Wu and Judge, 1978, 1979, 1980; Wallis and Hassan, 1978; Fahr, 1978; Keller et al., 1981; Petelski et al., 1980). Other special effects such as solar variability (Thomas, 1976), galactic emission (Thomas and Blamont, 1976), solar line shape uncertainties, solar wind and radiation anisotropies (Witt et al., 1979; Kumar and Broadfoot, 1978), neutralization of solar wind H^+, He^{++}, and He^+ by zodiacal dust (Holzer, 1977; Fahr et al., 1981) penetration of interstellar dust (Bertaux and Blamont, 1976), enhanced solar wind - ISM interaction due to electron impact ionization of hydrogen (Petelski et al., 1980) have been considered but it is not yet clear what their contributions to the overall uncertainties of the experimental determinations are.

In a recent workshop organized by the Max Planck Institut für Aeronomie in Lindau, West Germany in 1980, a number of observers and theoreticians have attempted to reach a consensus on the appropriate values of the ISM gas parameters deduced by these techniques. Because of the considerable experimental and theoretical difficulties it is not too surprising that there exists a rather discomfitingly wide range of possible physical parameters. This state of affairs is also due, in part, to the undeniable fact that the scattered intensities are not always very sensitive to any one particular parameter. The rather diffuse character of the very few features observable in the backscattered radiation pattern at 1216 and 584 A represents a substantial obstacle to the goal of acquiring accurate values of the ISM parameters. The distant hydrogen density n_H should be in the range of $0.04 \leq n_H \leq 0.08$ cm^{-3}, the helium density between $0.008 \leq n_{He} \leq 0.015$ cm^{-3}, temperature between $6000 \leq T \leq 14\,000$ ^{o}K, the LSR velocity vector of modulus $15 \leq |V| \leq 20$ km/s^{-1} oriented along the direction $250 \leq l \leq 315^{o}$, $-25 \leq b \leq -2^{o}$.

Although the scatter of the measurements within the cited ranges seems fairly uniform, there is a slight tendency that cannot, at present, be ignored or conclusively ascribed to observational error, for the helium observations to yield higher gas temperatures than the hydrogen observations by a few thousand ^{o}K and a slightly different flow direction by $\simeq$15-20^{o}. The accuracy of measurement will have to be increased substantially to confirm this surprising effect. Nevertheless, it seems to be clearly established that the gas is in a lukewarm phase, slightly ionized and possessing an inherent motion originating roughly from the direction of the Scorpius-Centaurus region of the galaxy.

A serious problem that is often overlooked concerns the validity of the assumption that the ISM conditions obtained by probing its structure out to, at most, a few tens of AU from the sun are at all appropriate for the gas at a few hundred or a few thousand AU at or near the solar bowshock and heliopause. As was mentioned before, because of our ignorance of the precise physical characteristics therein, it is difficult to assess the magnitude of this effect. Conventional wisdom has it that helium will flow through undisturbed due to the smallish or negligible cross sections for the relevant interactions while hydrogen will have a harder time, especially if the bulk velocity is low (Fahr, 1974; Wallis, 1978; Ripken and Fahr, 1982). Thus, it should always be kept in mind that there is a far from negligible probability that the quoted value of n_H at least is lower, perhaps substantially lower, than the appropriate value at large distances from the interaction region. One might even be tempted to attribute the putative temperature and flow direction differences in the hydrogen and helium gases seen in the inner solar system to unspecified mechanisms operating near the solar wind - ISM boundary.

Two concepts that should be pursued vigorously in the near future are 1) direct in situ sampling of the interplanetary wind particles by means of a direct particle detector on an interplanetary probe and 2) high spectral resolution observations of the two most prominent lines. An instrument to carry out the former investigation was built for the forthcoming ESA solar-polar mission so that ISM neutrals will be measured out to $\simeq$ 5 AU and also at high ecliptic latitudes (Rosenbauer and Fahr, 1977). This technique should represent a considerable leap forward in measurement accuracy and has the fundamental advantage of being able to unravel the tight interdependencies between density, temperature, and velocity.

High spectral resolution is another high priority in this field both as a means of separating terrestrial from interplanetary emission (Adams and Frisch, 1977) and, even more important, to actually resolve the line. Preliminary low sensitivity measurements of this sort have been recently attempted on the He I, 584 A line using resonance gas cell methods and have yielded promising results (Freeman et al., 1976, 1980; Fahr et al., 1978; Lay et al., 1980). Spectral resolution and separation problems can best be overcome by the use of large earth-orbiting telescopes with high resolution spectrographs such as IUE or, better, the upcoming Space Telescope that could be used to observe the Lyman-α line to determine its Doppler shift with respect to the geocoronal line for various view directions and times of year.

Imprecise as these measurements may be, they are extremely useful for our understanding of the structure of interstellar matter. The fundamental aspect here is that they probably represent the most direct evidence for the existence of the lukewarm phase first postulated by Field et al., (1969) and whose presence was only otherwise inferred from HI 21 cm absorption and emission observations (Radhakrishnan, 1974; Baker, 1979 and references therein). Since this gas is very inconspicuous in optical and ultraviolet absorption line studies, some have even argued that it does not exist at all (Scott et al., 1977). It is now clear, however, that the very undeniable presence of a hot tenuous gas at $T \sim 10^5 - 10^6$K implied both by OVI absorption and soft X-ray and EUV diffuse background observations (Jenkins, 1978a,b; Tanaka and Bleeker, 1977; Cowie et al., 1979; Fried et al., 1980; Davelaar et al., 1980; Paresce and Stern, 1981) and the presence of cooler clouds absolutely requires a gas at an intermediate temperature. In this picture, the hot low density phase is maintained in these conditions by the repeated passage of supernova or stellar wind shock waves (McCray and Snow, 1979 and references therein) that also compress, accelerate and partially or totally evaporate the cool ($T \sim 10-100^\circ$K) gas clouds. Consequently, at the outer edge of these clouds, transition regions of intermediate temperature, density, and ionization structure represent the conductive interfaces between these two extreme phases (McKee and Ostriker, 1977). The ionization level of the resultant lukewarm ($\simeq 10^4$K) plasma is maintained in a precarious equilibrium by a complex and probably very spatially variable combination of cosmic ray, stellar and diffuse EUV radiation in the 50 - 1000 A range, the latter originating in the hot surrounding gas. Precise boundaries between the various phases are, of course, only useful schematizations of this complex and dynamic phenomenon.

C. Ionization Conditions in the ISM

The backscatter measurements of the ISM in the solar system can play a vital role in confirming or sharpening our understanding of this gas phase especially since it allows, in principle, a separation of the parameters that are often seriously interlocked in the interpretation of interstellar absorption lines. In fact, once the 50-3000 A radiation field near the sun is determined precisely, these observations should yield a complete and unique solution to the ionization structure and the heating mechanisms of the ISM. Specifically, assuming a normal cosmic H/He abundance ratio of 10 is valid, the degree of ionization of hydrogen implied by the backscatter measurements can be as high as ≃50% with an associated electron density $n_e \simeq 0.05$ cm^{-3}. To maintain this state of affairs in a gas at 10^4K in photoionization equilibrium requires an ionization rate $G = \alpha n_e^2/n_H \simeq 2.10^{-14} s^{-1}$ where α is the recombination coefficient at that temperature. Similar values were obtained by Meier (1980). Since, under these assumptions, $G = \int_0^\infty \sigma(\nu)F_\nu d\nu$ where $\sigma(\nu)$ is the photoionization cross section of hydrogen, G depends crucially on the radiation field intensity below 910 A impinging on the atom. Assuming F_ν to be constant in the region just below the ionization edge, the required photon flux near the edge corresponding to the computed G is of the order of 10-20 photons cm^{-2}s^{-1}A^{-1}. Ionization by EUV photons below ≃400 A will tend to decrease this number somewhat.

Several attempts have been made recently to measure the intensity of the diffuse EUV radiation field in the solar vicinity (Paresce and Bowyer, 1976; Sandel et al., 1979) or to estimate it semi-empirically (Grewing, 1975; Blum and Fahr, 1976). In practice all that is available presently are measurements of specific intensity in a few directions as opposed to a total flux F_ν that is necessary to compute G. Between 912 and ≃200 A, only upper limits several orders of magnitude above the required flux have been determined which, then, cannot be used to constrain the ISM model described. The semi-empirical models constructed to account for the observed ionization structure of ISM clouds are consistent with the data reported here as long as the radiation temperature is less than 10 000°K (Blum and Fahr, 1976) to avoid the very high values of electron density determined by Grewing (1975). It is clear that little progress can be made in this field until precise measurements of the radiation field in the EUV are carried out, hopefully, in the next few years with the launch of an EUV Explorer.

D. Large-Scale Diagnostics of the ISM

Independently of the question of how the warm ISM is maintained, it is interesting to determine its extent and structure in all directions around the sun. Interstellar hydrogen absorption of stellar spectra at 1216 A or of white dwarf emission in the EUV (Cash et al., 1979 and references therein) provides some information on this important question. Although the number of stars that can be observed in this way is dishearteningly small and the spatial coverage quite limited, it is rather clear that the very local hydrogen density of $\simeq 0.05\ \mathrm{cm}^{-3}$ is roughly maintained out to a distance of $\simeq 4$ pcs. A possibly higher density of $\simeq 0.1\ \mathrm{cm}^{-3}$ may be more appropriate in the range 1.3 - 3.5 pcs, so that the sun may be immersed in a slightly lower density region than the immediate surroundings. This result should be viewed with some skepticism, however, since the quoted difference may well be within experimental errors and/or due to the assumption of negligible interaction with the heliopause. Beyond $\simeq 11$ pcs, the density definitely drops to values oscillating between 0.01 and 0.1 cm^{-3} with most stars below 0.05 cm^{-3}. Beyond approximately 75 pc the density increases past 0.1 cm^{-3}. For distances out to $\simeq 500$ pc, the measured hydrogen column densities towards hot stars (Bohlin et al., 1978) show substantial variations from place to place in the sky, confirming the expected patchiness of the local ISM.

Thus, the presence of a tenuous cloud of gas just in front or surrounding the sun of total column density $2 - 5 \cdot 10^{18}\ \mathrm{cm}^2$ and diameter of $\simeq 5$ pc can be clearly inferred from these results. Since the column density remains roughly constant with distance beyond 10 pc out to $\simeq 75$ pc in many directions (HZ43 is the most notable example of this remarkable behaviour), the neutral hydrogen density must plummet to very low values beyond the edge of the cloud in which the sun is imbedded. This is logically interpreted as the rough boundary between the warm and the hot phase of the ISM and is consistent in general with the latest results of the EUV diffuse background observations (Paresce and Stern, 1981) that require a fixed slab of $\simeq 2.10^{18}\ \mathrm{cm}^{-2}$ of absorption in front of the hot plasma emission region that extends out to $\simeq 100$ pcs.

If McKee and Ostriker's (1977) model is to be taken literally, the weakly ionized lukewarm phase in which the sun is apparently immersed should be located on the periphery of a cool, dense cloud a pc or so away that is slowly evaporating into the hot ISM beyond. Vidal-Madjar et al., 1978 have suggested that such a cloud may be at a distance of ≥ 0.03 pc (2.10^4 AU) from the sun in the direction of the Sco-Cen association. This claim is based on the possible existence of a strong HI density gradient in the local ISM, of a far UV flux anisotropy and on differences in the D/H ratio in different lines of sight. These premises have been disputed, however (McClintock et al., 1978). Since most diffuse clouds in the ISM are found to be marshalled in sheets rather than spheres (McCray and Snow, 1979) and the McKee and Ostriker model does allow for the existence of small clouds ($R \simeq 0.5$ pc) without a core, its failure to be detected should not be unduly disturbing.

A final noteworthy although highly speculative point that has been discussed at some length recently concerns the effects on solar and planetary structure and evolution of an encounter or repeated encounters with a dense ($n_H \geq 10^2\ \mathrm{cm}^{-3}$) interstellar cloud (Talbot and Newman, 1977; McKay and Thomas, 1978; Butler et al., 1978; Fahr, 1980; Ripken and Fahr, 1982 and references therein). It is, in fact, very unlikely for the sun to have avoided dense clouds in its $\simeq 5.10^9$ yr. lifetime. Approximately 10^2 such encounters are expected, of which $\simeq 10$ could have involved clouds with n_H in excess of $10^3\ \mathrm{cm}^{-3}$. The practical consequences on the earth including the triggering of ice ages are of great significance and have been discussed in detail by McKay and Thomas (1978). As the hydrogen density at the heliopause increases, its position is shifted closer and closer to the sun. The crucial parameter here is the value of n_H for which the supersonic wind is confined by the ISM to a region whose radius is smaller than 1 AU in the case of the earth. Using the similar mass, momentum and energy continuity equations with interaction terms describing the present low density ISM - solar wind scenario, Ripken and Fahr (1982) have shown that this critical point is reached at $n_H \simeq 1.2 \cdot 10^2\ \mathrm{cm}^{-3}$. This surprisingly low value implies that the earth has probably resided many and long times in the undisturbed ISM and without its normal solar wind shield. Effects on the sun, however, should be minimal for even the densest ISM clouds cannot completely choke off the solar wind.

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