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On the Flux and the Energy Spectrum of Interstellar Ions in the Solar System

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The flux density of ions created by ionization of interstellar neutral particles in the solar system and picked up by the solar wind is calculated as a function of the neutral particles. A very broad maximum occurs at an angle of 0 and a distance that depends on the density and speed of the neutral particles and on the ionization time but is typically in the general region of 10 AU. For atomic hydrogen the flux density is estimated to exceed 10^4 cm^{-2} s^{-1} over the distance range from a few to nearly 100 AU. The velocity space distribution of the interstellar ions is calculated under the assumption of no significant energy diffusion but with inclusion of adiabatic effects as well as a possible strong pitch angle diffusion. The energy spectrum is highly nonthermal and much broader than that of the solar wind ions; under the assumed conditions, interstellar protons are easily distinguishable from solar wind protons by their location in velocity space. If charge exchange is an important contributor to the ionization of hydrogen, the observed local intensity of interstellar protons should exhibit time variations correlated with the density changes of the solar wind stream structure.

INTRODUCTION

The solar wind interacts with the interstellar medium through the acceleration of ions created from the interstellar neutral particles in the solar system. The effect of this interaction on the solar wind has been considered by several authors [*Semar*, 1970; *Wallis*, 1971, 1972; *Fahr*, 1972; *Holzer*, 1972; *Holzer and Leer*, 1973] (see also *Axford* [1972] for a general review). For commonly assumed properties of the interstellar medium, appreciable effects on the solar wind are expected only beyond a distance of several tens of astronomical units from the sun, the possible exception being the solar wind temperature, which can significantly increase appreciably closer to the sun if thermalization of the newly created ions occurs. Since planned missions to the outer solar system will explore primarily the region out to 10 AU, it is possible that the effect of the interstellar medium on the solar wind will not be detected.

In this paper we turn our attention to the ions of interstellar origin to see if they can be detected directly, rather than indirectly, through their effect on the solar wind. We calculate as a function of position the expected flux density and, under the assumption of no thermalization, the velocity distribution of these ions. For the case of hydrogen we find that appreciable intensities occur inside 10 AU and that the new ions are well separated from the solar wind protons in velocity space. Thus the interstellar medium should be detectable inside 10 AU, either by direct observation of protons (and other ions) of interstellar origin if they are not thermalized or through heating of the solar wind if they are.

Throughout this paper, for convenience, we shall speak of 'interstellar ions' when we refer to ions created by ionization of the interstellar neutral particles within the heliosphere (not to be confused with ions that might be present in the interstellar medium itself).

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CALCULATION OF THE ION FLUX DENSITY

The distribution of interstellar neutral particles in the vicinity of the sun is governed primarily by the sun's gravitational attraction, radiation pressure, and removal by ionization. From *Fahr* [1968], *Blum and Fahr* [1969, 1970], *Semar* [1970], *Holzer and Axford* [1971], *Tinsley* [1971], *Holzer* [1972], *Axford* [1972], and *Feldman et al.* [1972*a*] the neutral particle number density $N(r, \theta)$ at a point P is given by

$$N = N_0 \frac{1}{\sin\theta}\left\{\frac{\partial b_1}{\partial r}\exp\left(-\frac{\lambda\theta}{b_1}\right) + \frac{\partial b_2}{\partial r}\exp\left(-\frac{\lambda(2\pi - \theta)}{b_2}\right)\right\} \quad (1)$$

where N_0 is the density at infinity; θ is the angle between the direction of the sun's motion relative to the neutral gas and the line connecting P to the sun; r is the heliocentric distance to P; b_1 and b_2 are the impact parameters for the two possible particle trajectories passing through P, given by

$$\begin{Bmatrix} b_1 \\ b_2 \end{Bmatrix} = \left[\left(\frac{1}{2} r \sin\theta\right)^2 + (1-\mu)\frac{GM}{V_0^2} r(1-\cos\theta)\right]^{1/2} \pm \frac{1}{2} r \sin\theta \quad (2)$$

and λ is a charcteristic distance

$$\lambda = a^2/V_0\tau_a \quad (3)$$

where V_0 is the speed of the sun relative to the neutral gas and τ_a is the ionization time at some reference distance a; GM/r^2 represents the net force of gravitational attraction and $\mu GM/r^2$ the repulsion by solar radiation pressure; for the case of hydrogen atoms it is commonly assumed that the two nearly cancel, so that $\mu \approx 1$. Equation (1) neglects the thermal spread in the velocities of the neutral particles.

The most important ionizing processes are photoionization and charge exchange with solar wind protons; if τ_{ph} and τ_{ex} are the corresponding ionization times, then

$$\frac{1}{\tau_a} = \left(\frac{1}{\tau_{ph}} + \frac{1}{\tau_{ex}}\right)_a \quad (4)$$

Under the assumption of a spherically symmetric and time-independent solar wind flow and solar radiation field, the ratio a^2/τ_a (and hence λ) is independent of the value of a to the extent that the attenuation of the photon flux and the accretion of interstellar protons can be ignored. Table 1 lists, for a number of atomic and molecular species, the values of τ_a^{-1} obtained by *Siscoe and Mukherjee* [1972] (who included the effects of photoionization, charge exchange with a solar wind proton flux density of 3×10^8 cm^{-2} s^{-1} at 1 AU, and ionization by electron and ion impact which turned out to be negligible in all cases) and the corresponding values of λ, with V_0 = 10 km s^{-1}, a commonly assumed value. In most of the cases, $\lambda \gg 1$ AU; the exceptions are He, Ne, and possibly N.

A newly created ion under the influence of the steady solar wind electric and magnetic fields executes a cycloidal trajectory with the guiding center moving at right angles to the magnetic field with the perpendicular component of the solar wind flow velocity. Sufficiently far from the sun, the interplanetary magnetic field is spiraled into a nearly circular pattern centered on the solar rotation axis; the characteristic length associated with the spiral pattern is $\lambda_s = V_{sw}/\Omega \sin \theta_s$, where V_{sw} is the solar wind speed, Ω is the angular speed of the sun's rotation, and θ_s is the polar angle measured from the solar rotation axis. For $r \gg \lambda_s$ the spirals closely approximate a circle with $\hat{\mathbf{B}} \perp \hat{\mathbf{r}}$; the guiding centers of the new ions are then carried in their cycloidal motion nearly radially away from the sun at the solar wind speed. Near the equatorial plane, $\lambda_s \approx 1$ AU for typical solar wind speeds. Thus with the exceptions noted above, $\lambda \gg \lambda_s$, and at distances where the interstellar particle density is nonnegligible the magnetic field lines are approximately circular. Accordingly, in the following we assume that the new ions move radially outward at the solar wind speed. We do not treat the case of He, which has been considered separately by *Holzer and Axford* [1971] and *Feldman et al.* [1972*a*, *b*].

In a steady state the outward flux density of interstellar ions at a distance r is found by integrating the ionization rate inside an infinitesimal solid angle segment of a sphere of radius r and dividing by its surface area. If n_i is the number density of ions of a given species, the outward flux density F_i (r, θ) is

$$F_i = n_i V_{sw} = \frac{a^2}{r^2 \tau_a} \int_0^r dr' \; N(r', \theta) \tag{5}$$

which, with the neutral density N given by (1), can be integrated to yield

$$F_i = N_0 V_0 \frac{\lambda^2}{r^2 \sin \theta} \left[\theta \psi\left(\frac{b_1}{\lambda \theta}\right) + (2\pi - \theta) \psi\left(\frac{b_2}{\lambda(2\pi - \theta)}\right) \right] \tag{6}$$

where the function $\psi(x)$ is given by

$$\psi(x) = xe^{-1/x} - \mathrm{Ei}\,(1/x) \tag{7}$$

and Ei is the exponential integral $\mathrm{Ei}(z) = \int_z^\infty dt/t \; e^{-t}$.

Equation (6) gives the net outward flux density of interstellar ions. The integrated omnidirectional intensity always lies between F_i and $2F_i$, as can be easily shown from the fact, to be discussed later, that the maximum speed of the interstellar ions is equal to $2V_{sw}$. The normalized flux density F_i/N_0V_0 is a function of the normalized distance r/λ, position angle relative to the sun's motion θ, and the dimensionless parameter $(1 - \mu)GM\tau_a/V_0a^2$. To illustrate the behavior of the solution, we show F_i/N_0V_0 in Figure 1 as a function of r/λ at $\theta = 0$ and in Figure 2 as a function of θ at $r/\lambda = 1$. Four cases are plotted: V_0 = 5, 10, and 20 km s^{-1} (which covers the range usually encountered in the literature), with $\mu = 0$ (i.e., radiation pressure ignored) and a^2/τ_a appropriate to hydrogen, and the case $\mu = 1$ in which the radiation pressure exactly balances the solar gravity (formally, this corresponds also to $V_0 \to \infty$). This last case is mathematically convenient and allows a number of properties to be derived analytically. (The distribution of neutral hydrogen in this case has been calculated by *Thomas* [1972], who also discusses the applicability of the assumption $\mu = 1$.)

TABLE 1. Characteristic Distance λ for Various Species

Species	$1/\tau_a'$,* 10^{-7} s^{-1}	λ, AU
H	10.0	15
H_2	6.3	9.5
He	0.47	0.7
Ne	1.1	1.7
A	5.7	8.6
O	5.3	8.0
N	3.5	5.3
H_2O	12.0	18
OH	7.7	12
NO	15.3	23
CO	9.6	14
CH_4	10.7	16

* From *Siscoe and Mukherjee* [1972]; a = 1 AU.

The curves exhibit a rather similar behavior for all four cases. At $\theta = 0$, F_i reaches its maximum value, of the order of 10–30% of the ambient neutral particle flux density N_0V_0, at a value of r close to λ. For $r \ll \lambda$ the neutral particle density is low, and few ions are produced. For $r \gg \lambda$ the ionization rate is low, and most of the ions have been produced at smaller r and convected outward; hence F_i varies as $1/r^2$. The remarkable feature is the very slow variation of F_i with r in the vicinity of the maximum. In the case V_0 = 10 km s^{-1}, for example, F_i is within a factor of 2 of its maximum value over the distance range $0.2\lambda < r < 5\lambda$; over the same range the solar wind ion flux density decreases by a factor of 625. The variation of F_i with angle is similarly slow. Over the hemisphere $0° < \theta < 90°$, F_i decreases from its maximum at $\theta = 0$ by less than a factor of 3 for the case $\mu = 1$ and by less than a factor of 2 for the others. For $\theta > 90°$, F_i decreases significantly if V_0 is large (or μ is close to 1) and then increases sharply near $\theta = 180°$ as a result of gravitational focusing.

In a review of all the data bearing on the local interstellar neutral hydrogen density, *Axford* [1972] gives a range 0.03 cm$^{-3} \lesssim N_0 \lesssim 0.3$ cm^{-3} as the most likely. With $N_0 = 0.1$ cm^{-3} as the nominal value and with the ionization time τ_a given in Table 1, we obtain the results for the predicted flux density F_H of interstellar hydrogen ions given in Table 2, which lists, for $\theta = 0$ and various values of V_0 and μ, the maximum value of F_H and the range of distances over which F_H exceeds 10^4 cm^{-2} s^{-1}. Since our calculation has neglected the thermal spread in velocities of the neutral particles, the results are strictly applicable to the case of a cold interstellar medium, such as an HI region discussed theoretically by *Spitzer* [1968] in which the temperature of the neutral hydrogen at a density of 0.1 cm^{-3} would range between 24°K and 120°K. The interstellar medium in the vicinity of the sun, however, appears to be relatively hot, with a temperature of 5×10^3 to 10^4 K (corresponding to a most probable thermal speed of some 10–14 km s^{-1}) [*Bertaux and Blamont*, 1972; *Thomas*, 1972].

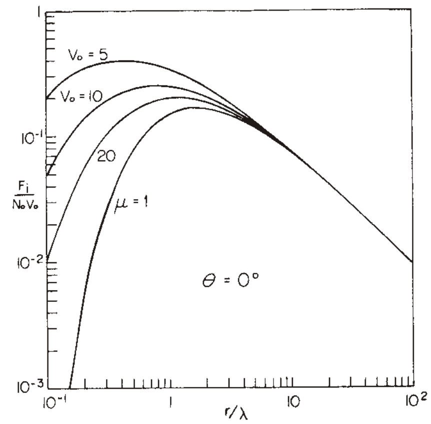

Fig. 1. The flux density of interstellar ions as a function of distance from the sun at $\theta = 0°$, for three values of V_0 with $\mu = 0$ and for $\mu = 1$.

Our results for fixed V_0 and θ then need to be averaged over a distribution of V_0 and θ specified by the velocity distribution function of the neutral hydrogen; since the results are already relatively insensitive to changes of V_0 and θ, they will not be greatly changed by the averaging (except in the vicinity of $\theta = 180°$). We conclude that the flux density of hydrogen ions of interstellar origin should be of the order of 10^4 cm^{-2} s^{-1} over a distance range between a few and about 100 AU.

ENERGY SPECTRUM OF INTERSTELLAR IONS

The kinetic energy of an interstellar neutral atom and the energy imparted to it by the ionization process are both very small in comparison with the kinetic energy of an ion moving at the solar wind speed. With respect to a frame of reference moving with the local solar wind speed V_{sw}, then, a newly created interstellar ion initially moves toward the sun with the speed $v = V_{sw}$; the Lorentz force changes this motion into a gyration about the interplanetary magnetic field **B**. The thermal velocity distribution (i.e., the distribution with respect to the frame of reference of the solar wind) of locally created interstellar ions thus contains very nearly the single speed V_{sw} and the single pitch angle α equal to the angle between **B** and the solar wind velocity (at the large distances we are considering, $\alpha \approx \pi/2$); in a sun-fixed inertial frame the speed ranges between 0 and $2V_{sw}$. As the ions are convected outward by the solar wind, their thermal speed is decreased by adiabatic deceleration.

TABLE 2. Predicted Flux Densities of Interstellar Hydrogen Ions

V_0, km s^{-1}	μ	λ, AU	Maximum F_H, 10^4 cm^{-2} s^{-1}	Range of r,* AU
20	0	7.5	4	1.5–120
20	1	7.5	3	3–120
10	0	15	2.5	2.4–105
10	1	15	2	9–105
5	0	30	2	3–80
5	1	30	0.9	···

$N_0 = 0.1$ cm^{-3} and $\theta = 0$.
* $F_H > 10^4$ cm^{-2} s^{-1}.

Such a velocity distribution has been shown to be unstable to the generation of several types of plasma waves [*Davidson et al.*, 1972; *Wu and Davidson*, 1972; *Hartle and Wu*, 1973]. The linear growth times of these instabilities are generally short in comparison with the characteristic flow time $\tau_f = r/V_{sw}$ of the solar wind. However, to our knowledge, neither the nonlinear saturation level of the plasma waves nor the resulting energy diffusion and pitch angle diffusion times τ_K and τ_α have yet been calculated. The usual assumption has been that τ_K and τ_θ are both much shorter than τ_f; the interstellar hydrogen ions then rapidly become thermalized and indistinguishable from the solar wind ions, the net result being merely the local heating of the solar wind [*Semar*, 1970; *Wallis*, 1971, 1972; *Fahr*, 1972; *Holzer*, 1972; *Holzer and Leer*, 1973]. Here we explore the consequences of two opposite assumptions: (case 1) τ_K and τ_α are both much longer than τ_f, so that randomization by plasma waves can be neglected entirely and the ion velocity distribution is changed only by adiabatic effects, and (case 2) $\tau_\alpha \ll \tau_f \ll \tau_K$, so that the effect of the plasma waves is to produce rapid pitch angle scattering (to the point of near isotropy) but negligible change in energy. (The counterpart of case 1 for He^+ ions has been previously treated by *Feldman et al.* [1972*a*, *b*]. A search of Vela data failed to reveal the presence of thermalized He^+ interstellar ions in the solar wind at 1 AU [*Feldman et al.*, 1974]. Such fluxes should have been detected if the ions are indeed thermalized, and the result suggests that rapid thermalization of the new ions is not occurring.)

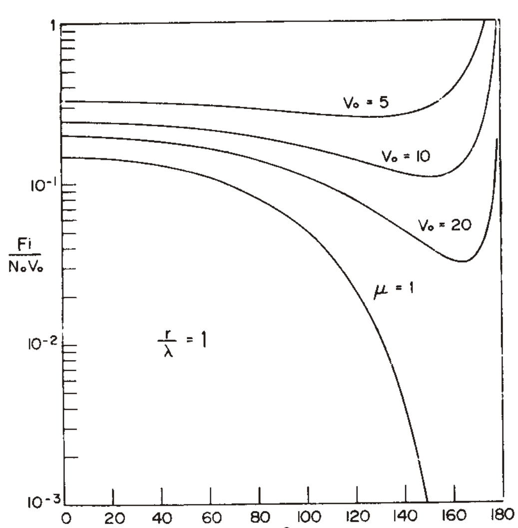

Fig. 2. The flux density of interstellar ions as a function of angle θ from the apex direction at a fixed distance $r = \lambda$.

We take the solar wind speed V_{sw} as constant (even when heating by complete thermalization of interstellar ions is assumed, this is a good approximation at least out to 15 AU) and the magnetic field as azimuthal and therefore varying as r^{-1} (this is appropriate, as noted before, at all distances where significant interstellar ion intensities can be expected). A newly created ion then initially has pitch angle $\alpha = \pi/2$ and thermal energy $K_0 \equiv (1/2)mV_{sw}^2$. For case 1, α remains equal to $\pi/2$, while for case 2 it quickly assumes a random value with $\cos\alpha$ uniformly distributed between +1 and −1. The thermal energy K decreases from the maximum value K_0 as a result of adiabatic deceleration. The variation of K with distance can be computed from the constancy of the first adiabatic invariant (case 1) or from the adiabatic law for an isotropic gas (case 2), the result being that $K^\nu r$ = const, where $\nu = 1$ for case 1 and $\nu = \frac{3}{2}$ for case 2. An interstellar ion with thermal energy $K \leq K_{sw}$ at a distance r must therefore have been created at the distance $(K/K_{sw})^\nu r$. Equating the net outward flux of ions with thermal energies between K and K_{sw} through the surface of a sphere of radius r to the ionization rate in the spherical shell between r and $(K/K_{sw})^\nu r$, we obtain

$$V_{sw}\int_{K}^{K_{sw}} n(K')\,dK' = \frac{a^2}{r^2\tau_a}\int_{(K/K_{sw})^{\nu}r}^{r} N(r')\,dr' \qquad (8)$$

where $n(K)\,dK$ is the number density of ions in the thermal energy range K to $K + dK$ and $N(r)$ is the neutral particle density given by (1); differentiating with respect to K then gives

$$V_{sw}n(K) = \frac{a^2}{r^2\tau_a}\frac{r}{K_{sw}}\,N\left(\frac{K}{K_0}\right)^{\nu} r\nu\left(\frac{K}{K_{sw}}\right)^{\nu-1} \qquad (9)$$

Instead of $n(K)$ it is convenient to consider the velocity distribution function $f(\mathbf{v})$; it can be readily shown that, for the flat pitch angle distribution ($\alpha = \pi/2$) of case 1,

$$f(v_\perp, v_\parallel) = \frac{m}{2\pi}\,n\left(\frac{1}{2}\,mv_\perp^2\right)\delta(v_\parallel) \qquad (10a)$$

and for the isotropic distribution of case 2,

$$f(v) = \frac{m}{4\pi v}\,n\left(\frac{1}{2}\,mv^2\right) \qquad (10b)$$

For illustrative purposes we take $\mu = 1$ (gravity balanced by radiation pressure), which is mathematically simple and, as noted earlier, is not altogether unrealistic for the important case of hydrogen; in any case, as is evident from Figures 1 and 2, the assumption $\mu = 1$ provides a lower bound to the interstellar ion flux at any given distance. Combining (1), (9), and (10), we obtain, for case 1,

$$\begin{aligned} f(v_\perp, v_\parallel) &= \frac{N_0 V_0}{\pi V_{sw}^3}\frac{\lambda}{r} \\ &\cdot \exp -\left\{\frac{\lambda}{r}\frac{\theta}{\sin\theta}\left(\frac{V_{sw}}{v_\perp}\right)^2\right\}\delta(v_\parallel) \qquad v_\perp < V_{sw} \\ f(v_\perp, v_\parallel) &= 0 \qquad v_\perp > V_{sw} \end{aligned} \qquad (11a)$$

and for case 2,

$$\begin{aligned} f(v) &= \frac{3}{8\pi}\frac{N_0 V_0}{V_{sw}^4}\left(\frac{V_{sw}}{v}\right)^{3/4}\frac{\lambda}{r} \\ &\cdot \exp -\left\{\frac{\lambda}{r}\frac{\theta}{\sin\theta}\left(\frac{V_{sw}}{v}\right)^{3/2}\right\} \qquad v < V_{sw} \\ f(v) &= 0 \qquad v > V_{sw} \end{aligned} \qquad (11b)$$

The distribution functions for the two cases are shown in Figures 3 and 4, respectively. Also shown, for comparison, is the distribution function of the solar wind protons, modeled as an isotropic Maxwellian with velocity and temperature having the average values measured at 1 AU. It is apparent that the interstellar ion distribution functions are highly nonthermal and occupy a large volume in velocity space, in contrast to the solar wind proton distribution which forms a narrow beam already at 1 AU (and even more so at larger distances, where the proton temperature is expected to be smaller). The velocity space volume over which the total number of interstellar ions is spread can be described as a circular loop (case 1) or a spherical shell (case 2) centered around the solar wind beam, with outer radius V_{sw} and a thickness that is an appreciable fraction of V_{sw}. This also points up a practical aspect to the detection of interstellar ions. A detector with a narrow resolution in velocity space will receive only a small fraction of the total ion intensity. A detector with large velocity space acceptance windows that avoid the solar wind beam would seem to be more advantageous for the observation of the relatively weak interstellar ion intensity; such a detector, with a minimum detectable intensity level somewhat below 10^4 cm^{-2} s^{-1} (see previous section), should be capable of observing the interstellar hydrogen ions, in the presence of the enormously larger total flux density of solar wind protons, at distances well inside 10 AU.

VARIATIONS IN IONIZATION TIME

So far we have treated the ionization rate at a given distance as constant. This rate, however, depends on the intensities of solar wind protons and energetic solar photons, which are variable. At one extreme are variations on a solar cycle time scale, which are long in comparison with the time required for the solar wind to flow through the region of interest; then the ionization time can be assumed to have a constant value appropriate to the current phase of the solar cycle. At the other extreme a sudden increase in the intensity of ionizing photons at the time of a major solar flare produces a sudden increase in the total number of ions in a radial column; however, this increase is small in comparison with the number already present because the duration of the ionizing event is short (typically 10 min or less).

A more interesting effect occurs at an intermediate time scale. At 1 AU the type of solar wind variation characterized by alternating fast and slow streams has a typical time scale of 1–5 days; the associated compressions and rarefactions produce large variations in density and flux with the same time scale (see, e.g., reviews by *Davis* [1972] and *Wolfe* [1972]). Inhomogeneities of this type are associated with long-lived fixed sources on the sun. As a result of the radial motion of the wind combined with the rotation of the source, the inhomogeneous features acquire a spiral configuration in

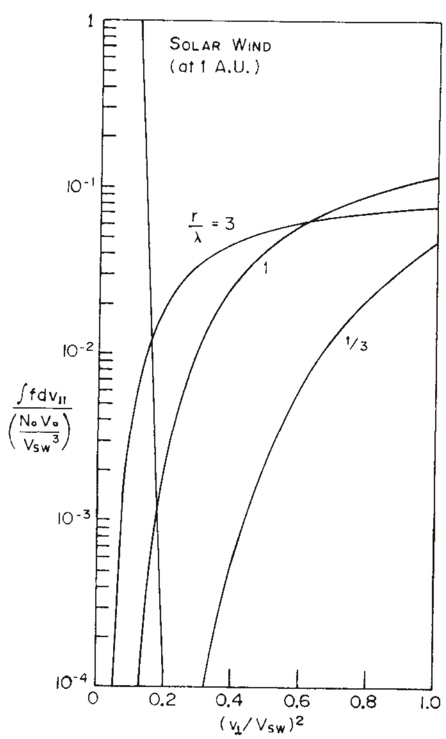

Fig. 3. The velocity distribution function of interstellar ions for case 1 (flat pitch angle distribution). For $v_\perp^2 > V_{sw}^2$, $f = 0$. The curves are drawn for $\theta = 0°$; for other angles, r/λ is replaced by $r \sin\theta/\lambda\theta$, and the absolute values are changed. For comparison with the solar wind the interstellar ions have been assumed to be protons, $N_{sw}V_{sw} = 3 \times 10^3 N_0 V_0$ (corresponding, for example, to $N_0 = 0.1$ cm^{-3}, $V_0 = 10$ km s^{-1}, and at 1 AU, $N_{sw} = 10$ cm^{-3}, $V_{sw} = 300$ km s^{-1}), and the ratio of V_{sw} to solar wind proton thermal speed is equal to 10 at 1 AU.

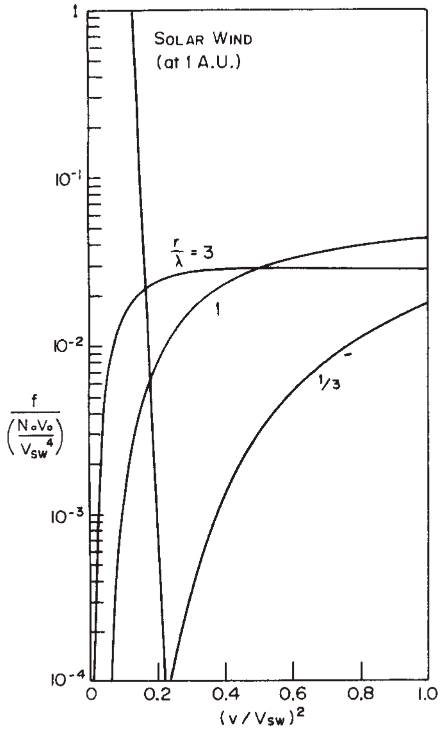

Fig. 4. The velocity distribution function of interstellar ions for case 2 (isotropic pitch angle distribution). For $v^2 > V_{sw}^2$, $f = 0$. Same remarks as for Figure 3.

space in the same way as the magnetic field; at the large distances concerning us the spirals are wound into approximate circular bands (or segments of circular bands if the source lifetime is less than the rotation period of the sun). The circular bands of enhanced or reduced density then move radially outward at the local solar wind speed. The interstellar ions created within a given density band thus will travel along with it, to a good approximation.

These large solar wind density variations will result in correspondingly large variations in the number of interstellar hydrogen ions produced by charge exchange and hence (since the ionization of the interstellar hydrogen by charge exchange is comparable to or greater than photoionization [*Axford*, 1972; *Siscoe and Mukherjee*, 1972]) large variations in the total number of ions. Evidently, the effect can be calculated by simply setting the ionization time, where it appears explicitly in (5), (8), or (9), to the value appropriate for a given density band. (The ionization time also appears implicitly in the parameter λ, but this relates to the neutral hydrogen density. Since a neutral hydrogen atom moves much less than 1 AU in the 1-5 days between density bands, the neutral hydrogen profile should be computed using a constant ionization time averaged over many density bands.)

If the flux densities of interstellar hydrogen atoms and of solar wind protons can be separately measured as functions of time at a fixed heliocentric distance, a plot of the first versus the second should yield a straight line whose slope is proportional to the rate of ionization by charge exchange and whose intercept is proportional to the rate of photoionization. This would provide a direct determination of the relative efficiencies of photoionization and charge exchange as well as a check on the identification of the interstellar hydrogen ions. (The requirement of measurements of a fixed distance imposes no practical difficulty since many density bands will pass over a spacecraft before it moves an appreciable distance.)

CONCLUSION

The analysis we have presented provides a simple model for the spatial distribution and the energy spectrum of ions resulting from ionization of the local interstellar neutral particles and subsequent acceleration by the solar wind electric and magnetic fields. The flux density of these ions exhibits a maximum in the neighborhood of 10 AU and in the direction of the sun's motion relative to the neutral medium (the apex direction), but the maximum is so broad that the flux density is nearly constant over several tens of astronomical units and over more than a hemisphere from the apex. For interstellar protons the maximum flux density estimated from presently believed parameters is in excess of 10^4 cm^{-2} s^{-1}. The velocity distribution of the ions, assuming no energy diffusion (thermalization) but including the effects of adiabatic deceleration and a possible isotropic pitch angle distribution maintained by plasma wave turbulence, extends over a large volume in velocity space (a thick circular loop or spherical shell of radius equal to the solar wind speed) centered around and well separated from the solar wind ion beam; with suitable detectors it is thus possible to distinguish the interstellar and the solar wind components in the general flux of charged particles moving away from the sun. Since, at large distances from the sun, both the interstellar ions and the density variations associated with the solar wind stream structure move together, a linear relation between simultaneously measured values of the interstellar ion intensity and the solar wind density is expected; the parameters in the relation depend on the relative contributions of charge exchange and photoionization to the ionization rate of interstellar neutral particles.

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