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# COSMIC RAYS AND DYNAMICS OF THE SOLAR WIND

II

by

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# COSMIC RAYS AND DYNAMICS OF THE SOLAR WIND

## II

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by I. V. Dorman
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SUMMARY

It is shown that the region of the solution of the nonlinear differential equation of 2nd order, describing the interaction of galactic cosmic rays with the solar wind is broken down into four regions. In the first two regions (nearest to the Sun), just as also in the latter (closest to the turbulent layer) an approximate analytical solution is obtained. A numerical solution is found for the third region. The wind velocity variation with recession from the Sun is determined, just as is the distance to the turlent layer in solar activity maximum and minimum.

*
* *

We obtained in [1] an integro-differential equation describing the interaction of galactic cosmic rays with the solar wind; it was shown that for reasonable values of solar wind and cosmic ray parameters, this equation is sufficiently precisely reduced to the differential equation of 2nd order

$$\psi'' = \psi'(5\cdot 10^{-12} u_\delta^2 N_\delta \rho^{-2}\psi'\psi^{-2} + 2\rho^{-1} + \psi'\psi^{-1} - \lambda_0'\lambda_0^{-1}) \qquad (1)$$

(the denotations here being the same as in [1]; in particular $\rho \equiv r/r_\delta$, and $\psi \equiv u(r)/u_\delta$).

In the present work we shall find an approximate solution of this equation for the wind velocity u(r) in periods of solar activity maximum and minimum.

Approximate Solution for Wind Velocity. About the Quantity $\psi'(1)$

From a series of considerations, one should anticipate that $\psi'(1) \ll 1$. This stems from the fact that the density of solar wind and its velocity near Earth's orbit

is so high that the pressure of the wind exceeds by many factors the pressure of cosmic rays, so that the solar wind deceleration in this region may practically be neglected. Only with increase of distance from the Sun and wind density decrease (just about as $\rho^{-2}$), will the solar wind deceleration by cosmic rays be gradually increasing. This is why one may anticipate that for small values of $\rho$, so will be $\psi'(\rho)$, while $\psi(\rho) \approx 1$. This allows us to substantially simplify Eq.(1) and find its approximate solution.

Estimate of the Right-Hand Part of (1) and Finding the First Approximation. Let us consider at the outset the case $\lambda_0$ = const (the fact that such a case is much rather realized is seen from works [2, 3]). Then the first term fo the right-hand part of (1) vanishes, while the ratios of the third and first terms to the second will be

$$\frac{(1)}{(2)} = \frac{2{,}5 \cdot 10^{-12} u_\odot^2 N_\odot \psi'}{\rho \psi^2}, \quad \frac{(3)}{(2)} = \frac{\psi' \rho}{2\psi}, \tag{2}$$

Inasmuch as $\psi'(1) \ll 1$, one may expect in a certain region of $\rho$ variation that these ratios will also be $\ll 1$, and then in this region Eq.(1) will be substantially simplified

$$\psi'' = 2\rho^{-1}\psi', \tag{3}$$

and its solution is

$$\psi = 1 - \frac{q}{3}(\rho^3 - 1). \tag{4}$$

where account has been taken that $\psi(1) = 1$ and $\psi'(1) = -q$. With an error not exceeding five percent (5%), expression (4) will represent the real solution provided it is required that ratios (1)/(2) and (3)/(2) be smaller than 0.05. Postulating (3)/(2) = 0.05, we find with the help of (4) the corresponding equation for the determination of the critical value of $\rho$ (which we shall denote $\rho_{32}$)

$$q^2 \rho_{32}^6 + 3q\rho_{32}^3 - 0{,}30 = 0, \tag{5}$$

from which follows

$$\rho_{32} = 0{,}108\, q^{-1/3}. \tag{6}$$

Analogously, for the determination of $\rho_{12}$ from the ratio (1)/(2) = 0.05, we obtain

$$2{,}78 \cdot 10^5 \alpha_1^2 \alpha_2 q \rho = 1 - \frac{2q}{3}\rho^3, \tag{7}$$

where was introduced the denotation

$$\alpha_1 \equiv u_\delta / 3\cdot 10^7 \text{ см/sec}, \quad \alpha_2 \equiv N_\delta / 5 \text{ см}^{-3} \tag{8}$$

(i.e. the values $\alpha_1$ and $\alpha_2 \sim 1$ correspond to conditions near epoch of solar activity minimum). Inasmuch as $\rho \leqslant \rho_{32}$, determinable by (6), the second term of the right-hand part of (7) will knowingly be $\leqslant 0.072$, so that by comparison with the unity, it may be neglected. Therefore,

$$\rho_{12} = \frac{3{,}6\cdot 10^{-6}}{\alpha_1^2 \alpha_2 q}. \tag{9}$$

Then the condition of applicability of the approximation (4) is

$$\rho \leqslant \min(\rho_{32}, \rho_{12}). \tag{10}$$

Determination of q. In (4), $q = -\psi'(1)$ is still not determined. In order to find it we shall proceed as follows, utilizing the relations equivalent to Eq.(7) of [1]. Having assumed that (10) is fulfilled, we shall find $\beta(r_c^+, u)$ with the aid of (15) of the work [1], and then $Y(\beta, R_{min})$. On the other hand, Y can be found with the aid of (24) of work [1] at $\rho = 1$ on the basis of (4). Equating both relations, we shall obtain the equation for the determination of q. Thus, substituting (4) into (15) from [1], we shall find

$$\beta(r_\delta, u) = \frac{5{,}2 u_\delta q^{-1/3}}{c\lambda_0} = 5{,}2\cdot 10^{-2}\alpha_1\alpha_3^{-1}q^{-1/3}, \tag{11}$$

where **by analogy** with (8) we introduced the denotation

$$\lambda_0 = 0{,}1\,\alpha_3 \tag{12}$$

(that is, $\alpha_3 = 1$ corresponds to $\Lambda_\rho = 1.5\ 10^{12}$ cm). Substituting (4) into (24) of work [1], we obtain

$$Y = 3{,}75\cdot 10^5\,\alpha_1\alpha_2\alpha_3 q. \tag{13}$$

Below it will be shown that $\beta$, determined by relation (11), is found to be sufficiently great, so that we may use the asymptotic representation (18) of [1] for the determination of Y. Substituting (11) into (18) of [1], and taking into account (13), we shall obtain

$$3{,}75\cdot 10^5\,\alpha_1\alpha_2\alpha_3 q = 1{,}5(5{,}2\cdot 10^{-2}\alpha_1\alpha_3^{-1})^{-1/2} q^{1/2}, \tag{14}$$

and hence

$$q = 1{,}13\cdot 10^{-7}\,\alpha_1^{-5}\alpha_2^{-2}\alpha_3, \tag{15}$$

i. e., q, as was to be expected, is indeed a very small quantity.

Substituting (15) into (11), we shall find

$$\beta(r_\delta, u) = 10{,}7\alpha_1'^{1/3}\alpha_2'^{1/3}\alpha_3^{-1/3}. \qquad (16)$$

Thus, $\beta(r_\delta, u) \gg 1$, which justifies the application of the asymptotic representation (18) of [1].

Estimate of the Region of Applicability of the First Approximation.

Substituting (15) into (6) and (9), we find

$$\rho_{32} = 23{,}5\alpha_1'^{1/3}\alpha_2'^{1/3}\alpha_3^{-1/3}, \quad \rho_{12} = 31{,}9\alpha_1^3\alpha_2\alpha_3^{-1}. \qquad (17)$$

Inasmuch as $\alpha_1$ and $\alpha_2$ rise with the increase of solar activity, while $\alpha_3$ decreases, the values (17) at $\alpha_1 = \alpha_2 = \alpha_3 = 1$ are minimum, whereupon, according to (10), the region of applicability of the approximation (4) will be determined by the value of $\rho_{32}$. Substituting (17) and (15) into (4), we find

$$\psi_0(\rho_{32}) = 1 - 4{,}9\cdot10^{-4}, \quad \psi_0'(\rho_{32}) = -6{,}23\cdot10^{-5}\alpha_1^{-5/3}\alpha_2^{-2/3}\alpha_3^{1/3}. \qquad (18)$$

Solution of (1) in the Region $\rho \geqslant \rho_{32}$. Let us pass to the new variables

$$\rho = \varepsilon\rho_{32}(\varepsilon \geqslant 1), \quad \chi = \psi / \psi(\rho_{32}), \qquad (19)$$

in which Eq.(1) is rewritten in the form

$$\chi'' = \chi'(0{,}817\alpha_1^{-4/3}\alpha_2^{-4/3}\alpha_3^{5/3}\varepsilon^{-2}\chi'\chi^{-2} + 2\varepsilon^{-1} + \chi'\chi^{-1}) \qquad (20)$$

with initial conditions

$$\chi(1) = 1, \quad \chi'(1) = -1{,}46\cdot10^{-3}. \qquad (21)$$

The character of $\chi$ dependence on $\varepsilon$ is determined in such a fashion, but only by the value of the parameter

$$\alpha_0 = \alpha_1^{-4/3}\alpha_2^{-4/3}\alpha_3^{5/3}.$$

For the solution of (20), we shall take advantage of the case, that the first and the third terms remain smaller than the second. This is why, having chosen for the first approximation for $\chi$ an expression analogous to (4), we shall find for the second approximation of the equation

$$\frac{\chi''}{\chi'} = 2\varepsilon^{-1} - 1{,}19\cdot10^{-3}\alpha_0 - 1{,}46\cdot10^{-3}\varepsilon^2 - 1{,}16\cdot10^{-6}\varepsilon^3 - 0{,}714\cdot10^{-6}\varepsilon^5, \qquad (22)$$

valid with a precision to 5% through $\varepsilon \leqslant 7.5$. At initial conditions (21) solution of (22) will be

$$\chi'(\varepsilon) = -1{,}46\cdot10^{-3}(1 + 0{,}49\cdot10^{-3} + 1{,}19\cdot10^{-3}\alpha_0)\varepsilon^2[1 - 10^{-3}(1{,}19\alpha_0\varepsilon + 0{,}49\varepsilon^3 + 2{,}9\cdot10^{-4}\varepsilon^4 + 1{,}19\cdot10^{-4}\varepsilon^6)], \qquad (23)$$

.../..

$$\chi(\varepsilon) = 1 - 1{,}13\cdot10^{-3}\left[ (1 + 0{,}49\cdot10^{-3} + 1{,}19\cdot10^{-3}\alpha_0)\frac{\varepsilon^3 - 1}{3} - \right.$$

$$\left. - 2{,}98\cdot10^{-4}\alpha_0(\varepsilon^4 - 1) - 8{,}1\cdot10^{-5}(\varepsilon^6 - 1) - 4{,}15\cdot10^{-5}(\varepsilon^7 - 1) - 1{,}32\cdot10^{-5}(\varepsilon^9 - 1) \right];$$

For $\varepsilon \geq 7.5$, Eq.(20) is resolved by the trapezoid method with initial conditions at $\varepsilon = 7.5$ compiled in Table 1. The initial conditions are found in accord with (23) and (24) for the values $\alpha_0 = 3.1$, 0.3 and 0.1.

TABLE 1

| $\alpha_0$ | 3 | 1 | 0,3 | 0,1 |
|---|---|---|---|---|
| $\chi(7,5)$ | 0,821 | 0,819 | 0,818 | 0,818 |
| $-\chi'(7,5)$ | 0,0612 | 0,0626 | 0,0630 | 0,0631 |

Therefore, the initial conditions at $\varepsilon = 7.5$ for the four indicated values of $\alpha_0$ are found to be rather close (this is due to the fact that in the interval $1 \leq \varepsilon \leq 7.5$, the influence of the first term in the right-hand part of (20) is still weaker). The results of the numerical solution of (20) by the trapezoid method in the region $\varepsilon > 7.5$ are compiled in Table 2, where given also are the values of $\chi'$ and $\chi''$, showing the character of solar wind velocity variation.

TABLE 2

| $\alpha$ | Funct. | $\varepsilon$ 7,5 | 8,5 | 10 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|---|
| 3 | $\chi$ | 0,821 | 0,754 | 0,638 | 0,469 | 0,307 | 0,176 | 0,0868 |
| | $\chi'$ | −0,0612 | −0,0719 | −0,0839 | −0,0863 | −0,0753 | −0,0554 | −0,0337 |
| | $\chi''$ | −0,00116 | −0,0097 | −0,0054 | 0,0020 | 0,0087 | 0,0112 | 0,0104 |
| 1 | $\chi$ | 0,819 | 0,751 | 0,632 | 0,459 | 0,295 | 0,164 | 0,0764 |
| | $\chi'$ | −0,0626 | −0,0734 | −0,0849 | −0,0879 | −0,0763 | −0,0551 | −0,0325 |
| | $\chi''$ | −0,0118 | −0,0100 | −0,0054 | 0,0024 | 0,0092 | 0,0120 | 0,0106 |
| 0,3 | $\chi$ | 0,818 | 0,750 | 0,630 | 0,455 | 0,290 | 0,158 | 0,0715 |
| | $\chi'$ | −0,0630 | −0,0739 | −0,0854 | −0,0834 | −0,0766 | −0,0550 | −0,0318 |
| | $\chi''$ | −0,0118 | −0,0100 | −0,0055 | 0,0025 | 0,0093 | 0,0123 | 0,0109 |
| 0,1 | $\chi$ | 0,818 | 0,749 | 0,629 | 0,455 | 0,290 | 0,158 | 0,0707 |
| | $\chi'$ | −0,0631 | −0,0741 | −0,0856 | −0,0885 | −0,0768 | −0,0552 | −0,0320 |
| | $\chi''$ | −0,0120 | −0,0100 | −0,0053 | 0,0024 | 0,0093 | 0,0123 | 0,0109 |

It may be seen from Table 2 that $\chi$ is rather feebly dependent on $\alpha_0$, whereupon the solar wind decreases by 18% in all through $\varepsilon \approx 7.5$ (that is, to distances $r \gtrsim 170$ a.u.), while for $\varepsilon \approx 11$ the wind velocity alr ady decreases by a factor of 2. Accretion of $\chi'$ takes place through $\varepsilon \approx 11$, i. e. the rate of velocity decrease $\chi'' < 0$). However, for $\varepsilon \gtrsim 11$, we have $\chi'' > 0$, and $\chi'$ decreases.

For $\varepsilon \approx 18$ (that is, $r \gtrsim 400$ a.u.), the wind velocity decreases relative to the initial by 11 - 14 times (respectively as a function of the values of $\alpha_0$ from 3 to 0.1). As $\varepsilon$ increases, the relative contribution of the first and third terms of the right-hand part of (20) drops, so that for $\varepsilon \geqslant 18$, one may with sufficient accuracy take into account only the third term. Then, Eq.(20) will be simplified

$$\chi''\chi = (\chi')^2 \tag{25}$$

and its solution in the region $\varepsilon \geqslant 18$, taking into account the initial consitions at $\varepsilon = 18$, (see Table 2) will be

$$\chi(\varepsilon) = \begin{cases} 0{,}0608 \exp[-0{,}388(\varepsilon - 18)] & \text{for } \alpha_0 = 3, \\ 0{,}0764 \exp[-0{,}426(\varepsilon - 18)] & \text{for } \alpha_0 = 1, \\ 0{,}0715 \exp.[-0{,}445(\varepsilon - 18)] & \text{for } \alpha_0 = 0{,}3, \\ 0{,}0707 \exp[-0{,}452(\varepsilon - 18)] & \text{for } \alpha_0 = 0{,}1. \end{cases}$$

Estimate of the Solution for the Case $\lambda_0 \neq$ const. It is assumed in a series of works that $\lambda_0 \sim \rho$ or even $\lambda_0 \sim \rho^2$. Although it was shown in [2, 3] that $\lambda_0$ = const would, as an average, be the most realistic assumption for the whole modulation region, it makes sense to attempt to estimate the solution for the indicated cases. If $\lambda_0 \sim \rho$, we have $\lambda_0'\chi_0^{-1} = \rho^{-1}$. Neglecting the first and the third terms in the right-hand part of (1) by c-mparison with the term $\rho^{-1}$, we shall obtain instead of (3)

$$\psi'' = \rho^{-1}\psi', \tag{27}$$

whose solution is

$$\psi = 1 - \frac{q}{2}(\rho^2 - 1), \tag{28}$$

where, as previosuly, it has been taken into account that $\psi(1) = 1$ and it was denoted $\psi'(1) = -q$. The dimension of the region $\rho_{32}$, in which (28) is valid, will be determined by the equation

$$\rho_{32}^4 q^2 + 2q\rho_{32}^2 - 0{,}1 = 0, \tag{29}$$

whose solution is

$$\rho_{32} = 0{,}322 q^{-1/4}. \tag{30}$$

Substituting (28) into (15) of [1], we shall find by analogy with (11)

../..

$$\beta(r_\odot, u) = \frac{2{,}4\, n_\odot}{c\lambda_0} \ln(2q^{-1}) \cdot 2{,}4\cdot 10^{-2}\alpha_1\alpha^{-1}\ln(2q^{-1}), \qquad (31)$$

where, by analogy with (12) $\alpha_3 = 10\lambda_0(1)$ and $\lambda_0(1)\lambda_0/\rho$. Substituting (28) into (24) from [1], we shall find the expression for Y, coinciding with (13). Inasmuch as at assumed values of $R_{min}$ the quantity $Y \leqslant 7.15$, and the parameter $\alpha_1\alpha_2\alpha_3 \geqslant 1$, it follows at once from (13) that in any case $q < 2\cdot 10^{-5}$. For these values of q the value of $\beta(r_\odot, u)$, according to (31), is found to be comparable with the unity, and none of the asymptotic representations (17) and (18) of [1] are valid. The graphical method of solution of equation

$$3{,}75\cdot 10^5\alpha_1\alpha_2\alpha_3 q = Y[2{,}4\cdot 10^{-2}\alpha_1\alpha_3^{-1}\ln(2q^{-1}), R_{min}], \qquad (32)$$

with the aid of data compiled in Table 5 of [1] yields for the solar activity minimum ($\alpha_1 = \alpha_2 = \alpha_3 = 1$) $q = 2.83\cdot 10^{-6}$ and $4.55\cdot 10^{-6}$ at $\varepsilon_{min} = 0.5$ and 0.05 Bv. As the solar activity increases, q decreases. For example, at $\alpha_1\alpha_2\alpha_3 = 3$ and $\alpha_1\alpha_3^{-1} = 3$, we find $q = 5.0\cdot 10^{-7}$ and $5.6\cdot 10^{-7}$ respectively for $\varepsilon_{min} = 0.5$ and 0,05 Bv. In this way, the dimension of the region $\rho_{32}$, in which the solution (28) is valid, will be $1.32\cdot 10^2$ and $1.6\cdot 10^2$ at solar activity minimum and $R_{min} = 0.5$ and 0.05 Bv. In solar activity maximum these values will be $3.14\cdot 10^2$ and $2.97\cdot 10^2$ respectively for $R_{min} = 0.5$ and 0.05 Bv. The substitution of (28) into (30) shows that, because of cosmic rays, the solar wind velocity attenuates only by 2.5% at such great distances from the Sun. Estimates, analogous to those that were carried out for the case $\lambda_0 = const$, show that in the assumption that pressure of cosmic rays acts only, a substantial attenuation (by more than a factor of 10) of solar wind velocity can be expected only at distances from the Sun notably exceeding $10^3$ a.u. But if $\lambda_0$ rises with distance faster than $\sim \rho$, the role of cosmic rays in the attenuation of solar wind velocity will be still less.

Dimensions of the Solar Wind Region and Requirement of Accounting for Other Factors. It follows from the above considerations that for an admitted spectrum of primary cosmic rays beyond the limits of the solar system and at $\lambda_0 = const$, the velocity of solar wind decreases in the solar activity minimum by 10% at a distance of ~ 100 a.u., by 50% in the region 230 - 250 a.u. and by more than 90% at a distance $\gtrsim$ 400 a.u. from the Sun. In solar activity maximum these distances increases by about a factor of 2 (for example, if we assign an increase of $u_\odot$ from $3\cdot 10^7$ to $4.5\cdot 10^7$ cm/sec, of $N_\odot$ from 5 to 10 $cm^{-3}$ and $\lambda_0$

from 0.1 to 0.3 a.u., we shall find that, according to (17), the above distances will increase by a factor of 2.2). What then should we consider as the dimensions of the solar wind region ?

It was shown in [3] that the regular motion of the solar wind must pass into a turbulent motion at a certain distance $r_0$. At that distance the energy densities of both the turbulent and directed motions, just as the energy density of magnetic fields of solar wind in interstellar space must be of same order. If near the Earth's orbit the root-mean-square scattering of solar wind velocity constitutes $\langle \Delta u_\delta^2 \rangle$, the variation of energy density of turbulent motion will be determined by the relation $\rho \langle \Delta u \rangle r^2 = \text{const}$ (in reality this quantity will increase somewhat with the increase of $r$ on account of possible pump-over of part of directed motion's kinetic energy into turbulent motion energy because of possible instability development). Since

$$\langle \Delta u^2 \rangle = \langle \Delta u_\delta \rangle^2 r_\delta r^{-1}, \tag{33}$$

whence it follows that the energy densities of turbulent and directed motions of solar plasma will be comparable at a distance

$$r_0 \approx r_\delta \frac{\langle \Delta u_\delta \rangle^2}{u^2(r)}, \tag{34}$$

where u(r) is determined by the solution of Eq.(7) of [1]. Inasmuch as, according to direct measurements near the Earth s orbit $\langle \Delta u_\delta \rangle^2 \sim 10^{14}$ cm$^2$/sec$^2$, we shall find, by taking into account the results of the preceding section, two cases of $\lambda_0 = \text{const}$.

$$\varepsilon_0 = \frac{\langle \Delta u_\delta \rangle^2}{u_\delta^2 \chi(\varepsilon_0)}, \tag{35}$$

where $\varepsilon_0 = r_0/r_+\rho_{32}$, and $\chi(\varepsilon)$ is determined by expression (26). The solutions of (35) at $\alpha_1^{-2} = \alpha_0 = 3.1$, 0.3, 0.1 yield respectively $\varepsilon_0 = 22.9$, 24.9, 27.4 and 28.2. In solar activity maximum $\alpha_1 = 1.5$ (i. e. $u_{+\delta} \approx 4.5 \cdot 10^7$ cm/sec). $\alpha_2 \approx 2$ (i. e. $N_{+\delta} \approx 10^{-3}$ cm) and $\alpha_3 \approx 1$ (i.e. $\lambda_0 \approx 0.1$ a.e.) so that $\alpha_0 \approx 0.232$, and, consequently, $\varepsilon_0 = 27.6$. With the assumed values $\alpha_1, \alpha_2$ and $\alpha_3$ we obtaim, according to (17), that $\rho_{32} = 73$, and consequently $r_0 \approx$ 2000 a.u. (at that distance the velocity of turbulent motions $u_{turb} \approx u \approx 0.001\, u_{+\delta}$). In solar activity minimum $\alpha_1 \approx \alpha$ (i.e. $u_{+\delta} = 3\ 10^7$ cm/sec), $\alpha_2 \approx 1$ (i.e. $N_{+\delta} \approx 5$ cm$^{-3}$) and $\alpha_3 \approx 3$ (i.e. $\lambda_0 \approx 0.3$ a.u.), so that $\alpha_0 \approx 6.2$ and $\varepsilon_0 \approx 20 - 21$. Inasmuch as for the assumed values of $\alpha_1, \alpha_2$ and $\alpha_3$ the quantity $\rho_{32} = 16{,}3$,

$r_T \approx 330$ a.u. (at such a distance $u_{turb} \approx u \approx 0.034\ u_\odot$). These results show the solar wind as having dimensions substantially greater than those following from data on cosmic rays [3]. However, it is necessary to take into account the following. The fact is that the velocity of turbulent motions in solar wind will in reality be higher than what follows from (33), and this on account of development of plasma instability as the distance from the Sun increases. At the same time, part of the kinetic energy of the directed motion must transfer into energy of turbulent pulsations. This will result to a certain decrease of $\varepsilon_0$ (and consequently, of $r_0$), as follows from (35). Further, the transition boundary of solar wind into the turbulent layer will be determined in the presence of turbulent motions in the interstellar plasma with frozen-in magnetic field mainly by the equality of kinetic energy densities of the directed motions of the wind and turbulent motions of interstellar gas. According to [4], the latter's density is apparently of same order as the energy density of the galactic magnetic field $H_g$. If in the vicinity of the solar system $H_g \approx 3\ 10^{-6}$ gauss (i. e. the energy density of the magnetic field $W_H \approx 3.6\ 10^{-13}$ erg/cm$^3$), for $n_g \sim 1$ cm$^{-3}$ we shall obtain $u_{g\ turb} \approx 7$ km/sec. If we consider that near $r_g$, that is, the interface between the solar wind and the turbulent layer, the energy density of the directed motion of solar wind

$$W = \frac{N_\odot M u_\odot r_\odot^2 u}{2 r_T^2} \tag{36}$$

is of the same order as the indicated density of the indicated turbulent motions of interstellar gas, we shall obtain for $r_T$ the equation

$$\frac{\psi(\rho_T)}{\rho_T^2} = 9{,}6 \cdot 10^{-5} \alpha_1^{-2} \alpha_3^{-1}, \tag{37}$$

if $\rho_T \lesssim \rho_{32}$, or

$$\frac{\chi(\varepsilon_T)}{\varepsilon_T^2} = 2{,}25 \cdot 10^{-3} (\alpha_1 \alpha_2 \alpha_3)^{-1/3}, \tag{38}$$

if $\rho_T \gtrsim \rho_{32}$ (here $\rho_T = r_T / r_\odot$ and $\varepsilon_T = \rho_T / \rho_{32}$). Analysis shows that for real variations of $\alpha_1$, $\alpha_2$ and $\alpha_3$ the quantity $\rho_T > \rho_{32}$, so that for the determination of $\rho_T$ one should make use of Eq.(38). Its solution with the aid of Table 2 for the solar activity maximum will yield $\varepsilon_T = 14.3$, i. e. $r_T = 1040$ a.u. At the same time $u(r_T) = 0.27\ u_\odot = 120$ km/sec . For the solar activity minimum $\varepsilon_T = 14.7$, which corresponds to $r_T = 240$ a.u. and $u(r_T) = 0.277\ u_\odot \approx 81$ km/s.

The results obtained here are dependent on the form of the spectrum of the density of cosmic rays beyond the limits of the solar system. According to (8) from [1], we have chosen it in the form ~ $R^{-2.5}$. At the same time, the total density of cosmic rays in interstellar space is found to be only 1.32 ev/cm$^3$ even when integrating from R = 0. This is why the abobe results should be considered as the illustration of the solution of the equation determining the interaction of cosmic rays with solar wind. In essence, they give us the upper estimate of solar wind dimensions.

**** T H E  E N D ****

I Z M I R A N

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