OBSERVATIONS OF INTERPLANETARY SCINTILLATION AND A THEORY OF HIGH-SPEED SOLAR WIND

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1. IPS OBSERVATIONS OF HIGH-SPEED SOLAR WIND

It has been confirmed that the high-speed solar wind flows out of the coronal holes at low latitudes, where the magnetic fields open and the temperature is low (e.g., Krieger et al. 1973). But there has not been direct observation of the solar wind out of the polar regions of corona. We report here that the observations of interplanetary scintillation (IPS) show the existence of the high-speed flow of 800 km/s out of the polar coronal regions and the well-coincidence to the model of the coronal holes extending from the polar regions.

The observations of IPS of radio sources at 69 MHz have been made at three stations, Toyokawa, Fuji and Sugadaira. The velocity of the diffraction pattern moving across the earth can be derived by a cross-correlation analysis. The pattern speed, in most cases, is interpreted to be the solar wind speed at the point of closest approach of the line of sight to the sun, but we have to take into account the integration effect along the line of sight when there is latitude dependence of the solar wind velocity.

We have found that daily variations of pattern speed consist of two parts during the minimum phases of solar activity: the variation due to the latitude dependence of the velocity of the quiet solar wind which is represented by the lower envelope of the observations, and the variation due to a coronal high-speed stream.

We derived latitudinal velocity distribution of the quiet solar wind, which shows the wind velocity increases rapidly with latitude and is 800 km/s for latitudes higher than 45° (Kakinuma, 1977), that is, shows the existence of the polar high-speed region.

As seen in the observations of 3C48 in 1974, the amplitude of the speed enhancement due to a recurrent stream apparently decreases with increasing latitude, and the maximum speed remains about 700 km/s for several rotations. This stream can be interpreted to be by the equatorward extension of the above high-speed region at high latitudes. We have assumed two corotating streams in 1974, the extension from the north centered on 250° Carrington longitude and the extension from the south centered on 90° longitude. This model is consistent with the observations of K-corona

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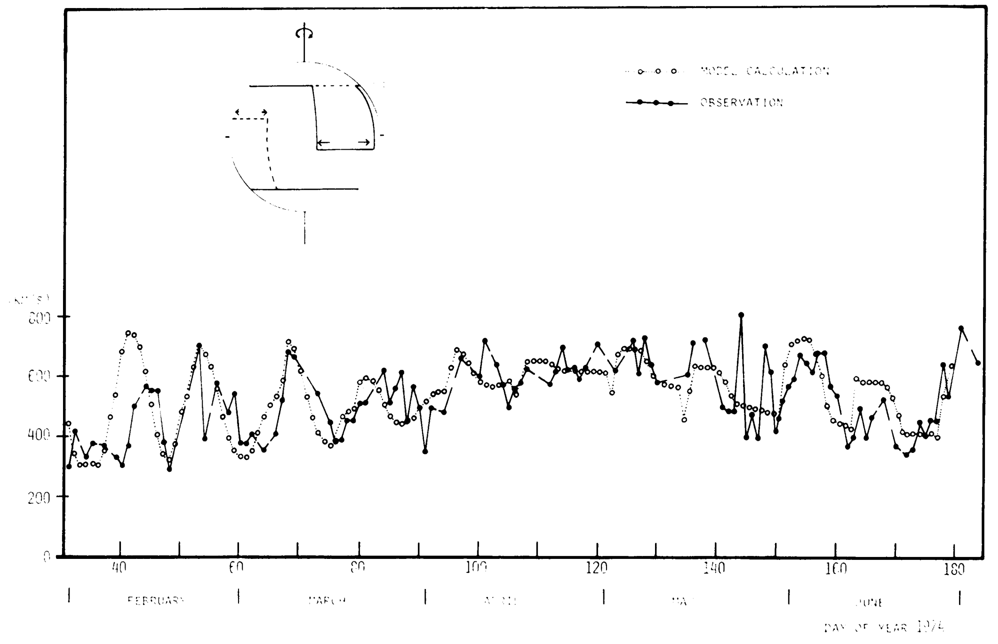

Figure 1. IPS velocity observations for 3C48 in 1974 and a model calculation.

(Hansen et. al., 1976). We have found that the observations in 1974 can be accounted for by this velocity distribution, as shown in Figure 1. IPS observations give evidence for the existence of high-speed streams of 800 km/s extending from the polar regions.

2. A THEORY OF HIGH-SPEED SOLAR WIND

The super-sonic flow of the solar wind was first explained by Parker's model in which the plasma kinetic pressure and the solar gravity are considered to be basic forces which act on the solar wind near the sun. But the high-speed solar wind from the open field regions where the coronal temperature is low can not be explained by only two kinds of forces.

We consider, as the third force, the ponderomotive force due to Alfvén waves which propagate from the sun to the interplanetary space along the magnetic fields. Theories of the ponderomotive force in magnetized plasma (fluid model) have been given by one of the authors (Washimi, 1973) and by Washimi and Karpman (1976). The expression of the force is reduced to

$$F = \frac{1}{8\pi}\left(\nabla_{\parallel} + \frac{2}{V_g}\frac{\partial}{\partial t} + 2\kappa \right) |\mathbb{B}|^2 , \qquad (1)$$

where $\mathbb{B}$ is the magnetic field of Alfvén wave, V_g the group velocity and κ the absorption coefficient of the wave. Recently Hatori and

Washimi (1979) have derived the ponderomotive potentials by using Lie-operator approach for a single particle, in the oscillation-center coordinate,

$$\phi = -\frac{1}{2}\,(\,\boldsymbol{\xi}\cdot\mathbb{E}\,) \quad \text{and} \quad \mathbb{A} = -\frac{1}{2}\,[\,\boldsymbol{\xi}\times\mathbb{B}\,]\,. \tag{2}$$

Here $\boldsymbol{\xi}$ means a excursion due to the electric and magnetic fields. They have found that the set of expressions in (2) can be rewritten to a covariant form and are consistent with (1).

It may be worth to note that the first term of the r.h.s. of (1) is not a repulsive force (solar wind acceleration) but an attractive force(deceleration), while the second and the third terms are for the acceleration. We consider the nonstationary Alfvén waves by which the effect due to the two terms overcome the one due to the first term.

We can see, in eq. (1), that the ponderomotive force due to nonstationary Alfvén waves shakes the element of the solar wind back and forth whenever wave-packets get ahead of the element, and on the average accelerates the element. In the course of the passage of wave-packets through the element, the heating mechanism which is a kind of stochastic process may also work. The heating rate is proportional to ion mass. This heating effect is expected to be so strong that the heating of the solar corona may be due to the mechanism (Washimi, 1979).

Our simple computational example shows that Alfvén waves of moderate intensity in the open fields first heat the low temperature plasma up to 10^6 K in the coronal regions and accelerate the solar corona. Subsequently they heat and accelerate the solar wind. Though the cooling effect due to the plasma expansion is dominant in the outer region of corona, the temperature of several times of 10^4 K can be still preserved near 1 AU while the velocity reaches to about 800 km/s.

Finally we suggest that the above acceleration and heating mechanisms may be expected in stellar atmospheres.

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References

Hansen, R. T., Hansen, S. F. and Sawyer, C.: 1976, Planet. Space Sci. 24, 381.

Hatori, T. and Washimi, H.: 1979, in submission.

Krieger, A. S., Timothy, A. F. and Roelof, E. C.: 1973, Solar Phys. 29, 505.

Kakinuma, T.: 1976 'Proceedings of the L. D. de Feiter Memorial Symposium' (M. A. Shea, D. F. Smart and S. T. Wu, Eds.), D. Reidel, Dordrecht, p. 101

Washimi, H.: 1973, J. Phys. Soc. Japan 34, 1373.

Washimi, H.: 1979, in Proceedings of the Fourth Solar Wind Conference (H. Rosenbauer, Ed.), Springer-Verlag, Heidelburg, in press.

Washimi, H. and Karpman, V. I.: 1976 Soviet Phys. JETP 44, 528.

DISCUSSION

Couturier: I don't agree with the momentum equation you are using, particularly for the gradient of Alfven wave pressure. There is a lot of published papers which have treated that term (Belcher and Davis, Alazsaki and Couturier, Hollweg, Jacques..). As we have said to you last year in Solar Wind Conference 4, I suppose you miss the fact that Alfven waves are propagating radially outward from the sun and the gradient of Alfven wave pressure comes from the spherical geometry. The equations you are using are perhaps for plane geometry.

Washimi: Our expression includes the term due to the 'centrifugal wave effect' which you mentioned. In a weakly inhomogeneous plasma, such as in the interplanetary plasma, the Alfven wave is not purely a transverse one but is coupled weakly with longitudinal modes. In this case the parallel component of the Alfven wave, which I suppose you missed, can not be neglected. I am afraid all the papers which you referred to are incorrect.

Newkirk: You present velocity and temperature from a specific application of your model. What values of Alfven wave flux and absorption coefficient were used in that example?

Washimi: Alfven wave flux is given by $V_g \cdot \frac{|B|^2}{8\pi}$ which is about $3 \cdot 10^{-4}$ erg/cm^2 sec at 1 AU. The absorption of $|B|^2$ is assumed to be proportional to R^{-2} (R is the radius from the sun), so that $|B|^2/|B_o|^2$ is a constant (= 0.04) for all regions.