§14. Energetic Solar Wind Acceleration by Means of the Viscous Force

Hirano, K., Mimura, M. (Osaka City Univ.)

The electromagnetic (EM) accelerator of the plasma can be quite a high power beam source. The power density of the ideal EM beam system can be as high as ~10^4 times to that of the usual NBI source. The key item for the success has shown to be in the super thermal plasma injection into the accelerator[1,2], since the EM force works to decelerate the subthermal flow. Therefore, the development of the heat engine becomes important that boosts the injected cold gas up to the plasma flow of a super thermal state.

The theoretical study[3] of the heat engine tells that the viscous force has a potential effect in accelerating the plasma to a very high energy. The Navier-Stokes (NS) predicts that if the flow velocity as normalized by the thermal velocity of the plasma were larger than $\sqrt{2}$, then the viscous force plays the most important role in driving the flow.

The present report confirms the theoretical prediction on the importance of the viscous force using the solar wind, every data of which are observed to be quite energetic. The mass flux conservation through the cone with the apex on the center of the sun makes it possible to rewrite the NS equation for the solar wind motion in the normalized form:

$$(u^2-1)\frac{u'}{u}=\frac{2}{\varsigma}\left(1-\frac{T_g}{T}\frac{1}{\varsigma}\right)+C_{vis}\varsigma^2 uu'', \qquad (1)$$

where u and ς are the flow velocity and radial position, respectively, each of which is normalized by the thermal speed of the plasma and the radius of the sun; the temperature equivalent $T_g(=GM_{\Theta}m/4kR_{\Theta})$ of the gravitational potential and the coefficient of the viscous effect $C_{vis}(=c_{\eta}T^{5/2}/i_{*}R_{\Theta})$ are also defined using the plasma temperature T, the gravitational constant G, the mass of the sun M_{Θ}, proton mass m, the sun radius R_{Θ} and the plasma flux density i_{*} through the cone with the unit area on the surface of the sun.

Observations show that the solar wind is ejecting out from the isothermal coronal layer on the surface of the sun. Here, if C_{vis} is taken to be zero, then Eq. (1) simply turns into the classical Parker[4] form. Using data given in ref. 5, Fig.1 is depicted. The parameter V_{Parker} in the figure gives the upper limit of the initial velocity V_0 on the surface of the sun under the Parker physics. It is noted that no solution exists if V_0 is greater than V_{Parker}.

Viscosity is retained and Fig. 2 is drawn up. As is seen the difference between the two is evident; the solution exists even if the value V_0 is greater than that of V_{Parker}. It may be said, therefore, that Fig. 2 gives an answer to the mystery why the solar wind is more energetic[6] than the value as estimated by the Parker model.

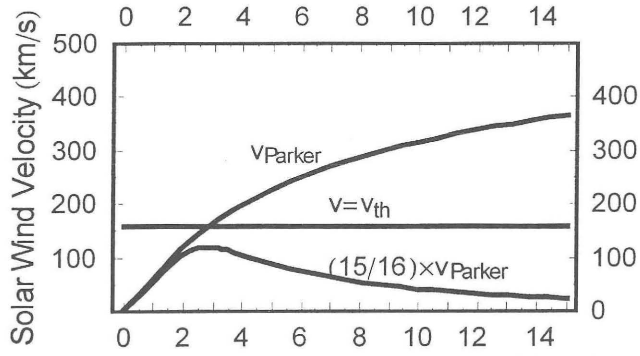

Fig. 1: The solar wind velocity after the classical Parker model.

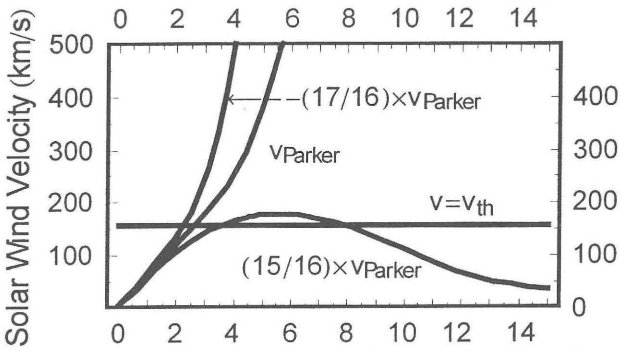

Fig. 2: The solar wind velocity taking including viscosity into account.

References:
1. Hirano, K., Journal of Plasma and Fusion Research 69 (1993) 684
2. Hirano, K., Journal of Plasma and Fusion Research 69 (1993) 806
3. Hirano, K., Phys. Plasmas 8 1734 (2001)
4. E. N. Parker, *in Interplanetary dynamic processes* (Interscience, New York,1963) p. 51
5. M. Stix, in *The Sun: An Introduction* (Springer-Verlag, Berlin 1989)
6. K. R. Lang, in *Sun, Earth and Sky* (Springer-Verlag, Berlin 1995)