AN EMPIRICAL RELATION BETWEEN DENSITY, FLOW VELOCITY AND HELIOCENTRIC DISTANCE IN THE SOLAR WIND

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1. INTRODUCTION

Solar wind flow quantities such as matter flux, momentum flux and energy flux, may be closely related to the mechanism responsible for the evolution of the solar wind. In the highly supersonic flow regime their study is facilitated by the fact that the contribution of thermal motions to the momentum and energy fluxes is negligibly small, and thus all three quantities are expressible in terms of proton density n and flow velocity u. If a relation between n, u and heliocentric distance r can be established, the study of these quantities is further simplified. In the following we point out that such a relation does in fact exist, and comment on its implications.

2. THE (n,u,r) RELATION

In looking for a relation between n, u and r we have the suspicion that such a relation may be lost with heliocentric distance due to stream-stream interactions. For our analysis we therefore used data from Helios 1 (Rosenbauer et al., 1977) which is the most recent data available to us, and includes data measured as close as 0.3 AU to the sun. The published data were averaged over time intervals ranging typically over half a day to five days, restricting the variance in velocity in any given interval to less than about 100 km/s. The details will appear elsewhere.

We fitted by least squares the data from Helios 1 to the relation

$$\log n = a \log u + b \log r + C \quad (1)$$

Here n is in protons/cm^3, u is in km/s and r is in AU. From the fit we obtain $a = -2.0$; $b = -2.0$ and $C = 6.1$, yielding the result

$$n = 1.3 \times 10^6 \, r^{-2.0} \, u^{-2.0} \quad (2)$$

Relation (2) gives the sought after dependence of n on u.

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The average flow velocity u measured by Helios closer to the sun was smaller than at larger distances and correspondingly n attained higher values closer to the sun. This velocity bias simulates a stronger decrease of n with r than the correct one, giving $n \sim r^{-2.35}$ instead of $n \sim r^{-2}$. However, we can see from relation (2) that nu^2 does not depend on velocity and thus we obtain $nu^2 \sim r^{-2.0}$. In figure 1 we plot $\log(nu^2)$ against log r. The slope of the fitted line is exactly -2.0. The figure also shows that the spread in the distribution of $\log(nu^2)$ increases with heliocentric distance.

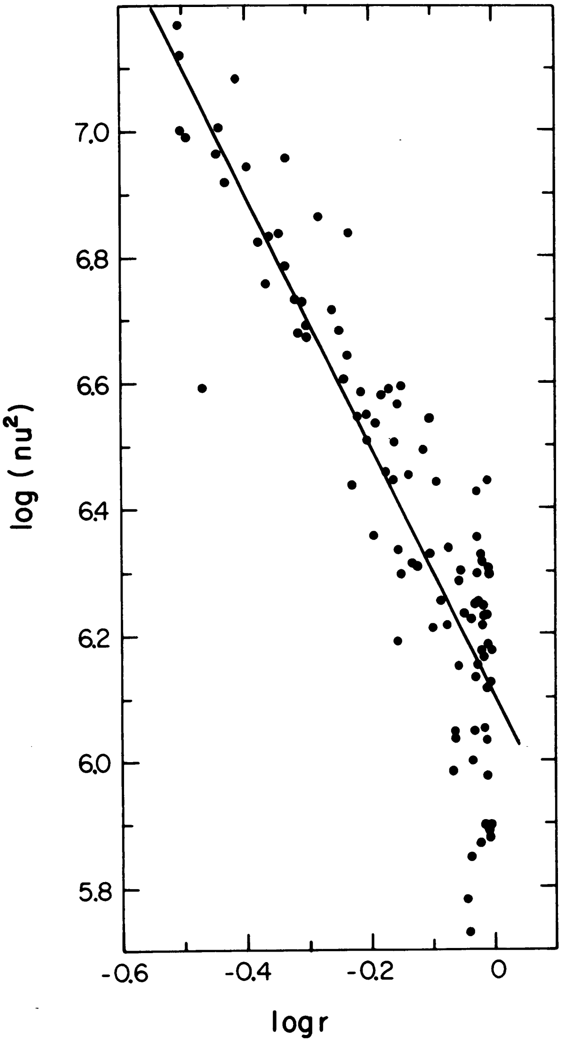

Figure 1. $\log(nu^2)$ vs. log r from Helios 1 data.

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3. DISCUSSION

The relation given by equation 2 can be interpreted as an invariance of the momentum flux density $F_\mu = mnu^2$, relative to stream structure at a given heliocentric distance. The relation also implies that the matter flux density $F_m = mnu$ decreases with increasing flow velocity.

Coronal holes are characterized by the smaller radiative losses in the U.V. compared to other parts of the corona. Thus our finding that the kinetic energy flux density ($\frac{1}{2}$ mnu^3) increases with flow velocity, supports the notion that fast streams originate in coronal holes.

From the increase of the dispersion of $\log(nu^2)$ with r, we conclude that our initial suspicion is correct, and that the relation between n and u may indeed be lost due to stream-stream interaction. In passing we note that also the dispersion of the logarithm of proton temperature T increases with r.

The dispersion in $\log(nu^2)$ or log T may be smaller for streams originating in higher solar latitudes, presumably because the stream-stream interaction due to solar rotation becomes less effective with higher solar latitude of the wind origin. This idea can be verified in the future, when measurements out of the ecliptic will become available.

REFERENCE

Rosenbauer, H., Schwenn, R., Marsch, E., Meyer, B., Miggenrieder, H., Montgomery, M.D., Mühlhäuser, K.H., Pilipp, W., Voges, W., and Zink, S.M.: 1977, *J. Geophys.*, 42, pp. 561-580.

DISCUSSION

LaBonte: (1) Is the increasing fluctuation of the quantity nu^2 with radial distance real or instrumental? (2) What is its cause? (3) Do data from spacecraft at radial distances >1 AU show a continuation of this effect?

Eyni: (1) The increasing fluctuations of the quantity $\underline{\log nu^2}$ with radial distance is real. The proton temperature shows a similar behavior.

(2) The cause could be stream-stream interaction.

(3) We did not make a similar analysis for radial distances >1 AU. The effect has to diminish at large heliocentric distances, because the interaction between streams makes the stream pattern disappear at large distances from the Sun. Indeed, Intriligator has shown that the variance of velocity decreases with the distance.

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Ahluwalia: What is the range of velocities (u) used by you in your correlation analysis? I ask this question because if u varies over a very narrow range then the way you have set-up your equations, the correlation analysis becomes independent of u. We must then end up with the relation: $n \propto \frac{1}{r^2}$, which is not a very surprising result!

Eyni: The velocity range of the present Helios 1 analysis is 300-720 km/s. This range (see, also, the accompanying paper by *Steinitz and Eyni*) cannot be considered to be a narrow range for u.

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