Alfvén Waves, Alpha Particles, and Pickup Ions in the Solar Wind

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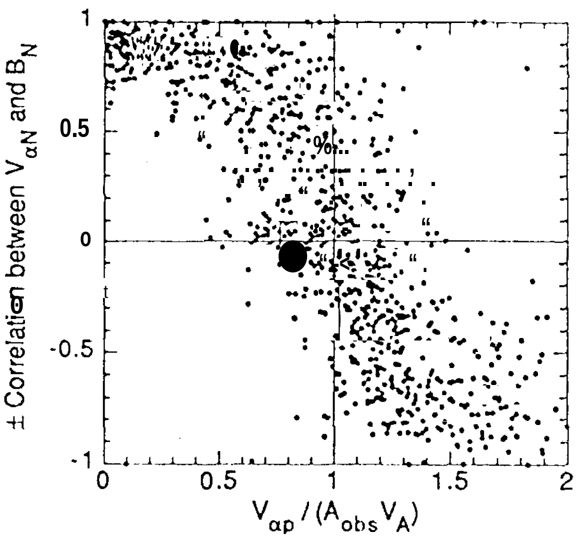
Past studies of the properties of Alfvén waves in the solar wind have indicated that: the amplitude of the velocity fluctuations is almost always smaller than expected on the basis of the amplitude of the field fluctuations, even when the anisotropy of the plasma is taken into account, and the alpha particle transverse velocities are less (often close to zero) than proton velocities because the alpha particles in the high speed solar wind are traveling faster than the protons (by roughly the Alfvén speed, *Marsch et al.*, 1982). Ulysses data are used to show [hat: (1) [he velocity/field amplitude discrepancy is greater at high heliographic latitudes than in the ecliptic, and (2) the transverse velocity of the alpha particles is either in phase or out of phase with that of protons depending on whether the differential flow speed between the alphas and protons is greater than or less than the "observed" wave speed, $V_{wave} = \delta V B_0/\delta B$, as determined from the ratio of amplitudes of velocity, δV, and magnetic fluctuations, δB.

Data for this study were obtained from the Ulysses plasma and magnetic field experiments. Analysis periods were chosen to exclude CMEs and interaction regions, and have small fluctuations in field magnitude ($\delta B/B<0.1$) and good (>0.8) velocity/magnetic field correlations. The proton velocity components had the expected correlation for outgoing Alfvén waves, whereas alpha particles at high latitudes typically had a correlation opposite to that expected. This can be explained if the alpha particles are traveling along the magnetic field faster than the wave speed such that in the. wave frame the alpha particles move along the field in the direction opposite to protons. Investigation showed that even at high latitudes the alpha particles were not traveling faster than the Alfvén speed as calculated including corrections for ion and electron pressure anisotropies and proton-alpha particle streaming, However, the effective wave speed estimated from the relative amplitudes of the transverse components of fluid velocity and magnetic field was considerably less than the calculated Alfvén speed, and the alpha particles were traveling faster than the effective wave speed, When calculating the effective wave speed, it was assumed that all fluctuations were due to either inward or outward going Alfvén waves;. the corrections for "inward going Alfvén waves" were only a few percent,

The figure below shows, for the combined in-ecliptic and high latitude data set, the correlation between the North-South (N) components V_N and B_N for alpha particles as a function of [be difference between the field-aligned alpha particle and proton velocity components normalized to the "observed" wave speed, V_{wave}. The sign of the ordinate is + (-) if the alphas are in phase (out of phase) with the protons.

Inhere arc two new and striking results: 1) the alpha particles at high latitudes are traveling significantly faster than the effective wave speed, unlike the in-ecliptic situation, and 2) the discrepancy between effective wave speed and the Alfvén speed calculated with all known corrections is also larger than in the ecliptic. The discrepancy in effective wave speed might be attributed to the effects of MHD turbulence in which magnetic fluctuations are energetically larger than velocity fluctuations (*Roberts et al.*, 1992). However, previous in-ecliptic studies of rotational discontinuities (*Neugebauer et* al., 1984) also find the wave propagation speed discrepancy. We suggest instead that the discrepancy might be due to highly anisotropic pickup ions that are not scattered and contribute significantly to the parallel pressure of the solar wind, Athough there is evidence for such anisotropies (*Gloeckler et al.*, 1994), the observed anisotropies may not be large enough to support this explanation. A more detailed version of this work is in press in Geophysical Research Letters.



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