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Differential flow between protons and alphas in the solar wind: Prognoz 7 observations

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Abstract. Solar wind data obtained with plasma experiment on the Prognoz 7 satellite have been reanalyzed to study the dependence of α particle and proton differential flow on both proton velocity V_p and the type of solar wind stream. It is found that velocity difference, $\Delta V = |V_\alpha| - |V_p|$, increases with increasing V_p in streams from coronal holes and decreases in high-velocity streams behind interplanetary shocks and in coronal mass ejections. Thus the Prognoz 7 data do not contradict the results of earlier papers and confirm the conclusion that at 1 AU there is strong differential streaming in fast streams from coronal holes but not in fast streams from coronal mass ejections.

Introduction

In a recent paper, *Neugebauer et al.* [1994] studied the differential flow between solar wind α particles and protons observed by the plasma experiment on the Ulysses spacecraft. In particular, the dependences of alpha proton velocity difference, $\Delta V = |V_\alpha| - |V_p|$, on the solar wind velocity, V_p, in streams from coronal holes (CH) and coronal mass ejections (CME) were analyzed and compared with data from other spacecraft. In this comparison, they used Prognoz 7 data from a paper by *Yermolaev et al.* [1989] and noted that the Prognoz 7 data did not agree with the other results.

We believe that a cause of this conclusion is the form of the Prognoz 7 data presentation by *Yermolaev et al.* [1989]: the Prognoz 7 data had not been sorted on the basis of the different types of solar wind streams. In more recent papers [*Yermolaev*, 1991; *Yermolaev et al.*, 1991] the Prognoz 7 data were studied separately for several stream types and the results were mainly similar to the previous results, but a detailed analysis of the velocity difference was beyond the scope of those publications.

Motivated by the paper by *Neugebauer et al.* [1994] we have continued this study and in this paper we provide additional information on the α particle and proton differential flow in different types of solar wind streams as observed by the Prognoz 7 satellite.

Methods of Measurement and Data Selection

The Prognoz 7 solar wind experiment is described in detail by *Vaisberg et al.* [1979] and *Yermolaev et al.* [1989]. An important advantage of these measurements was that the energy distributions of α particles and protons along the Earth–Sun line were selectively measured with an electrostatic analyzer with a Wien filter. More than 11,000 energy spectra for each ion component were obtained over the period November 1978 to June 1979.

Hydrodynamic parameters of the protons and α particles, that is, the velocities, V_α and V_p, the temperatures, T_α and T_p, and the density ratio n_α/n_p were derived from the measured spectra based on an assumption of convected, isotropic Maxwellian velocity distributions. Because of restrictions on the velocity ranges (230-900 km/s for protons and 170-620 km/s for α particles), ΔV vs V_p dependences were limited to $V_p \leq 550$ km/s. The accuracy of the velocity determination is about 2-3%. The time resolution of the measurements is 8 min, but to increase reliability of results, we used hour-averaged data for the analysis in this paper.

On the basis of solar wind parameter distributions on the "density - velocity plane" we selected five different types of the solar wind streams which may be related to the well known solar coronal structures and phenomena: (1) the heliospheric current sheet, (2) streams from coronal streamers, (3) streams from coronal holes, (4) solar wind streams observed after passage of interplanetary shocks, and (5) plasma of coronal mass ejections [*Yermolaev*, 1991]. This selection allows us to study the dynamics of α particles and protons in the different types of solar wind streams.

Results and Discussion

The dependences of the alpha proton velocity difference ΔV on the solar wind velocity V_p are presented in Figure 1 separately for high-velocity ($\geq$400 km/s) streams from coronal holes (circles) and streams of shocked plasma and plasma of coronal mass ejections (crosses). To increase statistics in these velocity intervals, the data have been averaged over a V_p range of 50 km/s.

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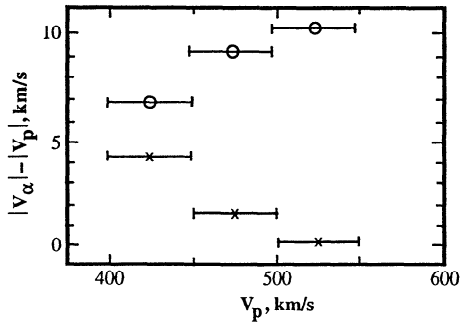

Figure 1. Dependences of α particle and proton velocity difference, $\Delta V = |V_\alpha| - |V_p|$, on the solar wind (proton) velocity V_p derived separately for different types of fast solar wind streams: streams from CHs (circles) and shocked and CME plasmas (crosses).

As can be seen in the figure the velocity difference increases from 7 to 10 km/s with increasing proton velocity from 400 to 550 km/s in streams from CHs and decreases from 4 km/s to 0 in shocked streams and CMEs. Velocity differences averaged over the total velocity range differ for the different types of solar wind streams: 8.2±7.5 km/s for streams from CHs, 2.7±5.3 km/s for CME plasma, and −0.9±5.7 km/s for shocked plasma.

The results obtained for streams from CHs are in a good agreement with other observations of fast solar wind streams on Vela 3 [*Hirshberg et al.*, 1974], IMP 6-8 [*Asbridge et al.*, 1976; *Feldman et al.*, 1978], Heos 2 [*Grunwaldt and Rosenbauer*, 1978], OGO 5 and Explorer 43 [*Neugebauer*, 1981] and ISEE 3 [*Ogilvie et al.*, 1982].

On the basis of Prognoz 7 measurements, *Yermolaev* [1991] and *Yermolaev et al.*, [1991] noted that the maximum velocity difference is observed in streams from CHs. On the other hand, based on the results of recent papers and especially on the data shown in Figure 1, it is evident that ΔV is small or negative in shocked solar wind streams and CMEs. It should be noted that the most negative value of velocity difference is observed during first 10–30 min downstream of shock front. The fact that negative velocity differences were observed downstream of interplanetary shocks has been previously reported on the basis of the first alpha proton selective measurements on the Prognoz 1 [*Zertsalov et al.*, 1976] and more recent selective experiments on the Prognoz 7 and 8 satellites [*Zastenker and Borodkova*, 1984a, b; *Avanov et al.*, 1987; *Yermolaev et al.*, 1988].

Thus our analysis shows that the Prognoz 7 data do not contradict the results of earlier papers or the paper by *Neugebauer et al.* [1994] and confirm the conclusion that at 1 AU there is strong differential streaming in fast streams from CHs but not in fast streams from CMEs.

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