THE TRANSITION BETWEEN FAST AND SLOW SOLAR WIND FROM COMPOSITION DATA

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Abstract. The transition between coronal hole associated fast solar wind and slow solar wind is studied using data from the high resolution mass spectrometer SWICS on ACE. We discuss the data in the framework of a recent theory about the global heliospheric magnetic field and conclude that the data are consistent with magnetic connections between field-lines in the fast and in the slow wind.

Key words: coronal holes, solar wind, ion composition, elemental fractionation, Ulysses, ACE

1. Introduction

The transition between fast and slow solar wind is determined close to the Sun, at the boundaries of coronal holes. Even though the kinetic properties of the streams may be changed due to the dynamic interaction between fast and slow wind, the elemental and charge composition remains unchanged in the heliosphere. It therefore carries valuable information about the small-scale properties of coronal hole boundaries close to the Sun.

It has been pointed out by Geiss *et al.* (1996) that during the mid-latitude phase of Ulysses from 1992 to mid-1993, the average compositional patterns clearly indicated the qualitative difference between fast and slow wind. Figure 1 has been reproduced from Geiss *et al.* (1994). It shows a superposed-epoch analysis of SWICS-Ulysses data. Slow solar wind is observed to have a higher oxygen freeze-in temperature than fast, coronal hole associated wind. Additionally, slow wind shows an enrichment of Mg/O, with Mg enhanced due to its low first ionization potential (FIP). Possible reasons for this difference in composition have recently been discussed by Schwadron *et al.* (1998). For a short summary, see also Zurbuchen *et al.* (1998). Other differences in the two types of flow, such as a greater variability in the composition, were previously suggested by Axford (1977) based on the magnetic field configuration in the low corona. In the superposed epoch analysis of Ulysses data, the average transition time from one solar wind type to the other (τ_{s-f} from slow to fast, τ_{f-s} from fast to slow wind) is an upper limit to the actual transition time in any one case. Figure 1 shows that $\tau_{f-s} < 1$ day and $\tau_{s-f} < 4$ days for this data-set.

Traditionally, compositional studies have concentrated on the leading edge of the high speed streams (see, e.g., Wimmer-Schweingruber *et al.* 1997). There, the

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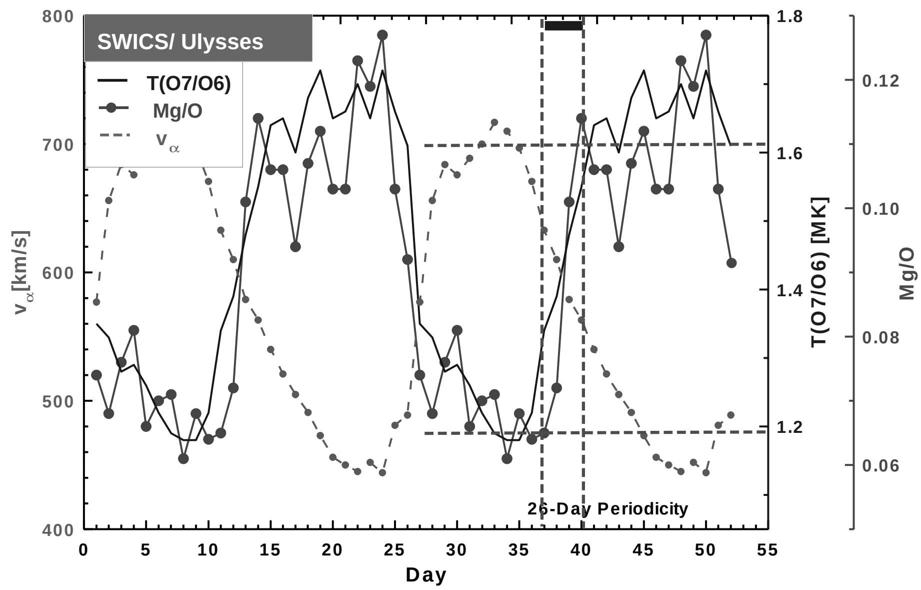

Figure 1. Superposed epoch analysis showing compositional variations derived from 1992 day 191 to 1993 day 98. The solar wind composition reflects a qualitative difference between slow and fast wind. The transition times in this analysis are upper limits to the transition time in any particular event (Figure adapted from Geiss *et al.* 1994).

density is large and therefore statistically accurate results are more easily obtained. Data from the trailing edge, however, provide a much more sensitive measure for the actual small-scale processes relevant for the transition between solar wind streams because all the geometrical quantities are literally *stretched out*.

In this paper we use high-resolution composition data from SWICS-ACE (for instrumental details, see Gloeckler *et al.* 1998) to further explore the transition times between different solar wind streams, in particular between fast and following slow solar wind. We then discuss the result in the framework of the Fisk *et al.* theory described in this volume.

2. Fast-Slow Transitions from SWICS-ACE

We use SWICS-ACE data during the period from day 203 to 210 in 1998. In Figure 2 we show V_α, Fe/O and T_{O} in the same format as presented in Figure 1. The time-resolution for V_α and T_{O} is 13 minutes, for Fe/O $\sim$ 1 hour. First, ACE was immersed in low speed solar wind with high variability in the freeze-in temperature and elemental composition. During day 203 a transition occurs into fast solar wind originating from a low-latitude coronal hole. After a period of steady coronal hole

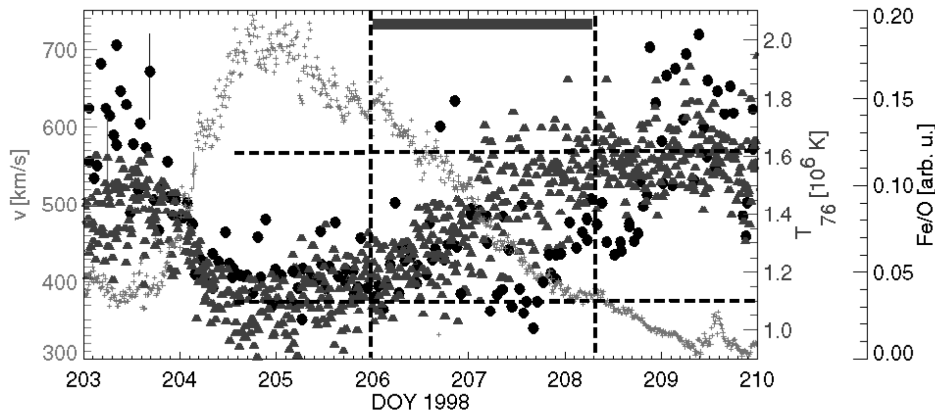

Figure 2. SWICS-ACE data during a fast solar wind stream in 1998. The format is adapted to Figure 1. The triangles denote the freeze-in temperature of O, the solid circles denote Fe/O, and crosses the solar wind speed. The typical uncertainties are mostly given by the counting statistics.

associated wind, the compositional signatures gradually turn back to a slow solar wind composition. Notice that even though there is a great deal of structure in both Fe/O and $T_{\rm O}$, there is nowhere a clear step between *fast* and *slow* compositions. The transition time from fast to slow solar wind occurs on a scale of $\tau_{f-s} \sim 50$ hrs. consistent with the upper limits of Geiss *et al.* (1994) in case of the polar coronal hole.

Generally, for a total number of eight fast-slow transitions measured by SWICS-ACE we found no example of a clear step transition between *fast* and *slow* compositions in the trailing edge of fast streams. Interestingly, the transitions in elemental and charge state compositions sometimes do not occur at exactly the same time or have even more structure than shown in Figure 2.

3. Discussion and Conclusions

During the first months of the SWICS-ACE measurements, transitions between fast and slow solar wind have been observed. Generally, they are associated with solar wind emanating from low-latitude coronal holes as described by Burlaga *et al.*, in this volume. The compositional patterns of those holes seem to be very much comparable with the observations of high-latitude, polar coronal holes as shown in Figure 1. The transitions between the two states do not necessarily appear to occur on the shortest time-scale. We find fast transitions from fast to slow wind on the time-scale of $\tau_{s-f} \sim$ hours or sometimes from one measurement time to the next. In the trailing edge of the fast stream, where no dynamic steepening can take place, we find a rather steady transition on a time-scale of $\tau_{f-s} \sim 40$ hrs or more. These transition times are consistent with the previous analysis by Geiss *et al.* (1994) shown in Figure 1.

In a paper by Fisk *et al.* in this volume, a theory of the magnetic nature of fast and slow solar wind has been presented. It is pointed out that the expansion of magnetic field-lines from the differentially rotating photosphere into a pressure-equilibrated corona puts constraints on the solar magnetic field. In particular, it leads to a transport of open field from coronal holes into a region with predominantly closed magnetic field, thereby causing reconnection between field-lines carrying *fast* and *slow* solar wind. If this reconnection process occurs, *slow* and *fast* solar wind composition can be found in one and the same field-line. Very likely, this reconnection also occurs within the sonic point, where the thermal speed is larger than the bulk speed of the plasma, allowing for mixing of the plasma along magnetic field-lines. This would lead to a steady transition as shown in Figure 2.

Notice that the solar wind plasma can only be efficiently mixed along the magnetic field and not perpendicular to it. If fast and slow solar wind streams flow in magnetically disconnected flux-tubes, the transition is expected to have a more step-like character which is clearly not observed in Figure 2.

This steady transition has been observed in all unperturbed fast-slow transitions observed by ACE-SWICS during a 200 day period. However, it is important to keep in mind that transitions between fast and slow solar wind are not always identical and also, effects dependent on the solar cycle may be important (see, e.g., Schwenn 1990). Only a study based on the combined analysis of solar, compositional, and plasma data is expected to provide a conclusive picture.

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