Differential velocity between solar wind protons and alpha particles in pressure balance structures

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[1] Pressure balance structures (PBSs) are a common high-plasma beta feature in high-latitude, high-speed solar wind. They have been proposed as remnants of coronal plumes. If true, they should reflect the observation that plumes are rooted in unipolar magnetic flux concentrations in the photosphere and are heated as oppositely directed flux is advected into and reconnects with the flux concentration. A minimum variance analysis (MVA) of magnetic discontinuities in PBSs showed there is a larger proportion of tangential discontinuities than in the surrounding high-speed wind, supporting the hypothesis that plasmoids or extended current sheets are formed during reconnection at the base of plumes. To further evaluate the character of magnetic field discontinuities in PBSs, differential streaming between alpha particles and protons is analyzed here for the same sample of PBSs used in the MVA. Alpha particles in high-speed wind generally have a higher radial flow speed than protons. However, if the magnetic field is folded back on itself, as in a large-amplitude Alfvén wave, alpha particles will locally have a radial flow speed less than protons. This characteristic is used here to distinguish between folded back magnetic fields (which would contain rotational discontinuities) and tangential discontinuities using Ulysses high-latitude, high-speed solar wind data. The analysis indicates that almost all reversals in the radial magnetic field in PBSs are folded back field lines. This is found to also be true outside PBSs, supporting existing results for typical high-speed, high-latitude wind. There remains a small number of cases that appear not to be folds in the magnetic field and which may be flux tubes with both ends rooted in the Sun. The distinct difference in MVA results inside and outside PBSs remains unexplained. INDEX TERMS: 2169 Interplanetary Physics: Sources of the solar wind; 2134 Interplanetary Physics: Interplanetary magnetic fields; 2109 Interplanetary Physics: Discontinuities; 7507 Solar Physics, Astrophysics, and Astronomy: Chromosphere; KEYWORDS: solar wind, Ulysses, plumes, pressure balance structures, Alfvén waves

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1. Introduction

[2] Pressure balance structures (PBSs) are intervals in the solar wind in which changes in the plasma and magnetic pressures balance one another while total pressure remains approximately constant. In fact, the solar wind is generally in near pressure balance everywhere except where dynamic interactions dominate, as, for example, at the fronts of corotating interaction regions (CIRs). However, PBSs have been identified as a well-defined class of features in high-speed, high-latitude wind that is associated with high-plasma beta (β) intervals lasting several hours. These intervals permeate the high-speed wind and are suggested to be the interplanetary remnants of coronal plumes [McComas et al., 1996]. This is because they have compatible geometric and statistical properties and plumes are a common feature in coronal holes, in particular at solar activity minimum [Thieme et al., 1988, 1990; Velli et al., 1994; Casalbuoni et al., 1999]. Support for the plume-PBS relationship comes from a correlation between fluctuations in β and in helium abundance across PBSs [Reisenfeld et al., 1999]. Since solar wind abundances are fixed in the chromosphere and transition region and since polar coronal holes are source regions of high-speed solar wind, Reisenfeld et al. [1999] concluded that the solar origin for PBSs may be plumes.

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potentially contain plasmoids, loops which close back to the Sun, and/or true TDs.

[13] For comparison with the PBS in Figure 3, a non-PBS interval observed at 0327-0950 UT on 6 December 1994 is shown in Figure 5. A discontinuity at ∼0525 UT was identified as an RD in the MVA. The correlation is again almost −1 in the entire interval so the MVA result is in agreement with the differential streaming result for this case, in contrast to the example in Figure 3 where the MVA failed. Overall, the correlation here is similar to that shown in Figure 3 in a PBS and there is no reason to suggest a significant difference between PBSs and non-PBSs based on these results.

3. Results

[14] To evaluate, first, the overall relationship between the radial magnetic field and radial differential streaming in all the identified PBSs, the average correlation, $\langle C_{VB} \rangle$, was computed for intervals in the 53 PBSs lying between 1 hour before and 1 hour after the time at which the MVA was applied. The result is that $\langle C_{VB} \rangle = -0.84 \pm 0.17$. This is the average of values in the 1-hour window which, at most, was computed with 15 data points or 13 degrees of freedom. For a sample of this size, any correlation above ∼0.5 is statistically significant at the 99% level. The rms deviation (±0.17) was computed from the variations within the set of correlation coefficients and does not depend on the number of degrees of freedom for each individual coefficient. The conclusion that can be derived from this is that local reversals in B_r in PBSs are commonly due to kinks in the magnetic field, magnetic switchbacks or large amplitude Alfvénic fluctuations containing RDs and not plasmoids or current sheets. This is a statistical statement about the most common result and does not say anything about specific individual cases which might deviate from the norm.

[15] In the comparison sample outside PBSs, the average correlation in the vicinity of radial magnetic field reversals where an MVA was carried out in 70 non-PBSs, derived in the same manner as for PBSs, is $\langle C_{VB} \rangle = -0.86 \pm 0.13$. This leads to the same conclusion as above, that reversals in B_r in non-PBSs where the MVA was applied are also commonly caused by magnetic switchbacks. It is entirely consistent with the earlier conclusions of Balogh et al. [1999], based on the propagation direction of waves during magnetic polarity inversions (reversals in $\boldsymbol{B}$). The number of degrees of freedom is the same as for PBSs, and again this is a statistical statement about the most common case and does not say anything about specific individual cases which might deviate from the norm.

[16] These overall statistical results confirm that the typical situation in high-latitude, high-speed solar wind when there is a reversal in the radial component of the magnetic field is a magnetic switchback. The magnetic field is locally folded back on itself but the overall field is continuous. In typical high-speed wind these are Alfvénic fluctuations [e.g., Balogh et al., 1999; Belcher and Davis, 1971], but we retain the switchback nomenclature since differential streaming is independent of Alfvénicity. This provides the basis to search for times which differ from this typical case. To do this, the entire set of PBSs and non-PBSs was scanned for times when the correlation was distinctly positive, opposite to what is expected for the southern polar coronal hole at this time in the Hale magnetic cycle. The result of this search is that only at one time was there a significant local reversal in the sign of the correlation at the time of a reversal in B_r

tangential discontinuities, while they are preferentially rotational discontinuities in non-PBSs [Yamauchi et al., 2002]. The difference from the present results remains unexplained. However, in view of the present results, the MVA result cannot be used to conclude that there are plasmoids or expanding loops in PBSs.

[24] In addition to computing the correlation between B_r and $V_{\alpha p}$