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Symmetry in discontinuity properties at the north and south heliographic poles: Ulysses

Bruce T. Tsurutani[1], **Christian M. Ho**[1], **Regina Sakurai**[1], **Bruce E. Goldstein**[1], **Andre Balogh**[2], **and John L. Phillips**[2]

[1] Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 169-506, Pasadena, CA 91109- 8099, USA
[2] Imperial College of Science and Technology, The Blackett Laboratory, Prince Consort Road, London, SW7 2BZ, England
[3] Los Alamos National Laboratory, Los Alamos, New Mexico, USA

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Abstract. A study of directional discontinuities (DDs) that occurred during 4 days of the Ulysses north polar pass was conducted (461 directional discontinuities total) using magnetic field and plasma data. We find that the total number of directional discontinuities selected by the Tsurutani and Smith (1979) method are the same in the north and south polar regions (within statistical errors) if the radial gradient is taken into account. We also find that tangential discontinuities (TDs) occur at edges of mirror mode structures. Approximately half of these structures are locally unstable. TDs are also associated with interplanetary current sheets, some of which are in regions of positive solar wind velocity gradients. To first order, we find no difference in the number of directional discontinuities, number of TDs, or the types of TDs in the north polar region from the south polar region.

Key words: interplanetary medium – plasmas

1. Introduction

The NASA/ESA Ulysses mission is the first to explore our heliosphere at both the south and north polar regions. Ulysses reached -80.2° latitude on September 13, 1994 ($r = 2.3$ AU from the Sun) and $+80.2^\circ$ latitude on July 31, 1995 ($r = 2.0$ AU). A survey of directional discontinuities over the south polar region has been discussed in Tsurutani et al. (1996). The properties of tangential discontinuities (TDs) at the south pole was recently discussed in Ho et al. (1995). The purpose of this present paper is for the first time to discuss the properties of DDs and TDs that are present in the solar wind at the north pole and to intercompare these results with those at the south pole.

Send offprint requests to: B.T. Tsurutani

2. Method of analysis

We first select directional discontinuities (DDs) by computer analyses of one-minute average field vectors using the Tsurutani-Smith (1979) criteria. For brevity, we will not repeat the criteria here. Then with each DD identified, we use high time resolution, 1-s magnetic field vectors and apply minimum variance analyses to these data. We use the notation B_1, B_2 and B_3 correspond to the field in the maximum, intermediate and minimum variance directions. By hand analyses of the discontinuity data plots, the field magnitude and field magnitude jump ($\Delta|B|$) across each discontinuity are measured.

Following the Smith (1973) method of identifying TDs, values B_3/B_L and $\Delta|B|/B_L$ are calculated and each discontinuity plotted as a point on a scatter diagram. For the above, B_L is the larger field magnitude on either side of the discontinuity, and B_3 is the field in the minimum variance direction.

The plasma data temporal resolution is too low to use to help determine the discontinuity type. However, parameters such as the solar wind velocity, density, and temperature are very useful to identify the discontinuity dependence on stream/microstream structures and are used in this manner in this paper. The magnetometer is described in Balogh et al. (1992) and the plasma instrument in Bame et al. (1992).

3. Results

Figure 1 from top to bottom are the solar wind density, temperature, velocity, magnetic field magnitude, daily rate of occurrence of interplanetary discontinuities (ROIDs), and satellite location in distance from the sun and heliographic latitude. We note that the five plasma and field parameters are nearly constant throughout the two intervals shown. The density, temperature, magnetic field magnitude $|B|$, and ROID value are all slightly higher at the north polar pass than at the south pole, however.

At the North pole at 2.0 AU, the (ROID) value is 115 DD/day. The rate of discontinuities/day at the south pole was 105 DD/day. The Ulysses south polar encounter occurred at 2.3 AU from the

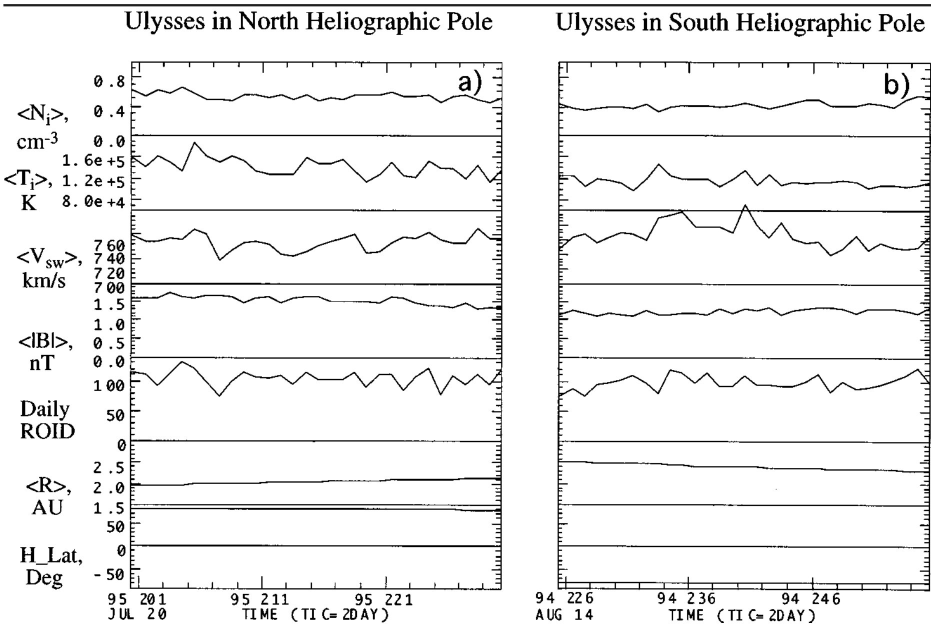

Fig. 1a and b. From top to bottom are the average solar wind density, temperature and velocity, field magnitude, discontinuity daily occurrence rate, Ulysses heliocentric radial distance and latitude. **a** is the data from the north polar pass and **b** is from the south polar pass. The ROID values are relatively constant for both polar passes

sun. If we normalize this value by the experimentally determined radial gradient of $e^{-(r-1)/5\mathrm{AU}}$ (Tsurutani et al., 1996), we get a value of 113 discs/day at 2.0 AU. Besides a slight difference in value, the ROID value is approximately the same over the two poles.

Figure 2 is a scatter plot of the 461 discontinuities that occurred on days 218–221, 1995 which were identified by the TS criteria. Each point represents one discontinuity. The discontinuities with large B_3/B_L and small $\Delta|B|/B_L$ are believed to be rotational discontinuities (RDs) and the events with large $\Delta|B|/B_L$ and small B_3/B_L are identified as TDs. The cutoffs for these different types are arbitrary, but here we use the values of Smith (1973): $B_3/B_L > 0.4$ and $\Delta|B|/B_L < 0.2$ for RDs, and $\Delta|B|/B_L > 0.2$ and $B_3/B_L < 0.2$ for TDs. The discontinuities with $B_3/B_L < 0.4$ and $\Delta|B|/B_L < 0.2$ are indeterminate and will be discussed in a future paper.

It is noted from the figure that there is still a considerable percentage (6.1%) of TDs at these high latitudes. This value is quite close to the value determined for the south polar region (6.3%) based on 1486 discontinuities and discussed in Ho et al. (1995).

An example of a TD using both field and plasma data is shown in Figure 3. In this example, B_3/B_L is equal to 0.03. From top to bottom are: the three components of the field in minimum variance coordinates, the field polar angle (δ) measured from the $\hat{R} - \hat{T}$ plane, the azimuthal angle (ϕ) increasing anti-clockwise from the $\hat{R}$ direction in the $\hat{R} - \hat{T}$ plane, B-magnitude, solar wind density, temperature and velocity. In this SH coordinate system, $\hat{R}$ the radial direction from the sun, $\hat{T} = \hat{\Omega} \times \hat{R}/|\hat{\Omega} \times \hat{R}|$ and $\hat{N}$ completes the right-hand system. $\hat{\Omega}$ is the solar rotational axis. The bottom two plots are plasma beta, $8\pi[Nk(T_i + T_e) + N_{\mathrm{He}}kT_{\mathrm{He}}]/B^2$, and R equal to $(\beta_\perp/\beta_\parallel)(1 + 1/\beta_\perp)$. The latter expression indicates mirror-mode instability for $R > 1$ and stability for $R < 1$. We note a kinetic expression for instability is given in Barnes (1966).

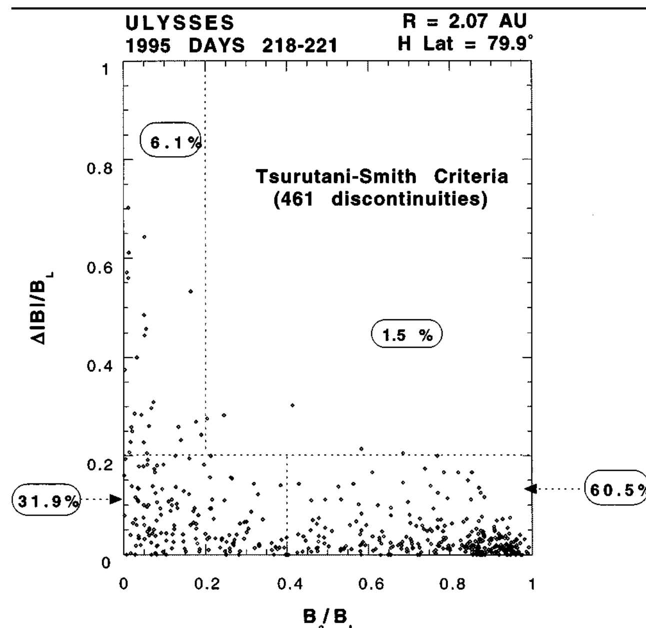

Fig. 2. Discontinuity phase space (B_3/B_L, $\Delta|B|/B_L$) distributions for days 218–221, 1993 at the north heliographic pole

The TD occurs at the edge of a large decrease in $|B|$ at $\sim$ 2057 UT day 218, 1995. The field magnitude recovers to its pre-TD value by 2102 UT. The minimum variance analysis was applied to the interval between the vertical dashed lines. It is noted that the TD occurs at small gradients in T_p and in V_{SW}. The value of R is ~ 1.2 in the vicinity of the magnetic dip, indicating that local mirror mode growth should be occurring.

The magnetic dip leads to the field decrease from 1.6 nT to 0.2 nT, and to a very large increase in β to ~ 70 (off the scale). The field angles δ and ϕ have minimal changes across both the

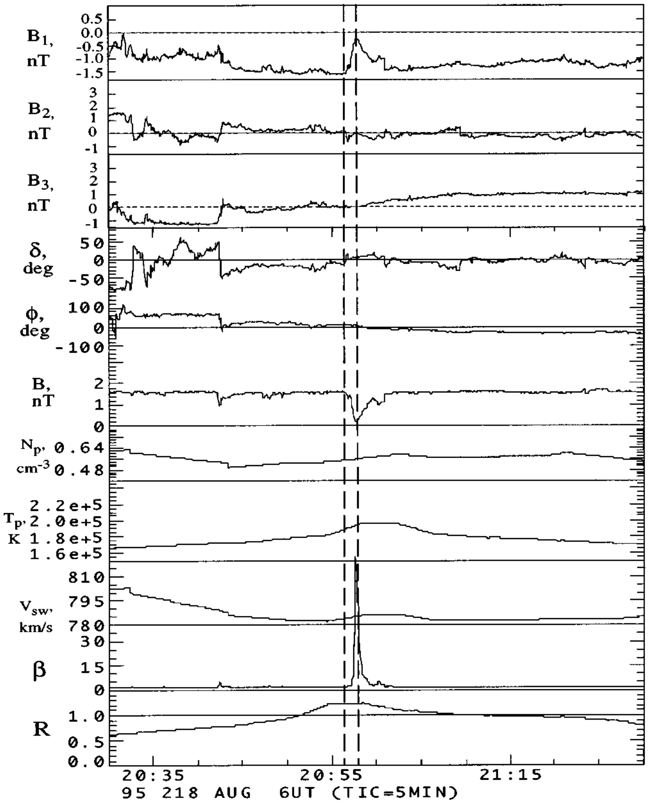

Fig. 3. An example of a mirror mode-related TD. The TD is found at an edge of a mirror mode structure

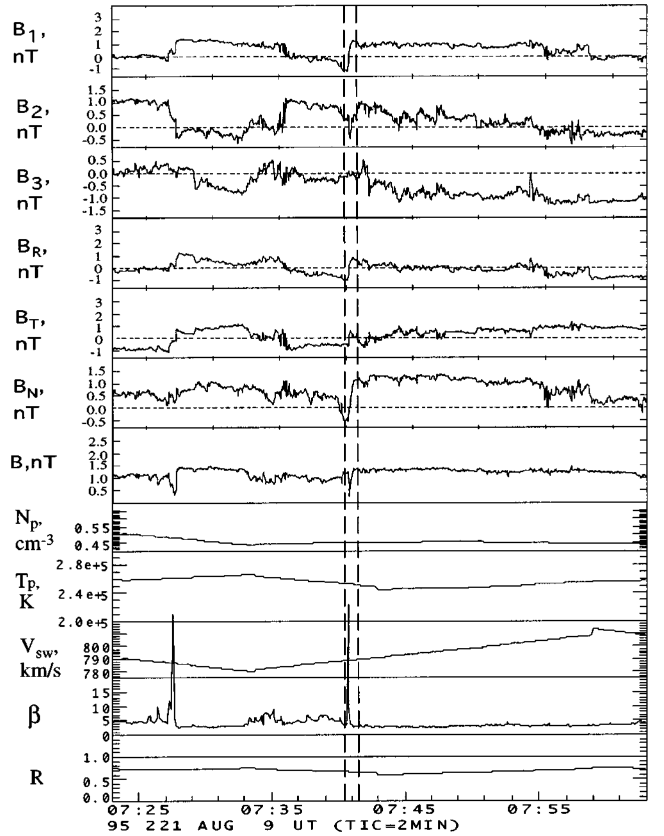

Fig. 4. A current sheet-associated TD. The TD occurs in a region of positive solar wind velocity gradient

TD and the whole mirror mode structure (as is expected for mirror mode structures).

Figure 4 is a second example of a TD occurring over the northern polar region. For this example B_3/B_L is 0.04. The format of this figure is the same as in Fig. 3 except we have added the field components in SH Cartesian coordinates. From the three field components, it can be noted that the gross structure of the magnetic field changes across the TD. B_R changes from -1.0 to 0.9 nT, B_T changes from -0.8 to $+0.7$ nT and B_N changes from -0.6 to $+1.2$ nT.

The TD occurs in a region of positive velocity (V_{SW}) gradient, but because of the paucity of plasma data points, one cannot say how great the gradient is in the immediate region of the discontinuity. There is also a small temperature decrease in the region of the TD. The beta value increases dramatically to a value ~ 65 within the current layer. R is ~ 0.6 near the discontinuity, indicating that the plasma is stable to mirror mode growth.

The above characteristics of the TDs are similar to those of TDs detected at current sheet crossings at the south pole, reported by Ho et al. (1995). However, because of the low time-resolution of the plasma data, it is not possible to determine if the same plasma criteria hold or not.

All of the TDs in Fig. 2 have been studied in detail. Minimum variance analyses were performed on each event and the directional changes in the magnetic field across the TDs were measured. The results are shown in Fig. 5. As in Ho et al. [1995], we separate the TDs into two prominent groups, those that occur at the boundaries of mirror mode structures (D-sheets, Burlaga 1977) and those associated with current sheets. TDs associated with mirror mode structures are shown in the top panel as cross-hatched events, and current sheet associated events as open bars. The remaining discontinuities are indicated by dark bars.

It is interesting to note that the "remaining" discontinuities have field directional charges that are quite similar to mirror mode associated events ($\theta < 75°$). A somewhat similar result was obtained for south polar TDs (Ho et al. 1995).

Of 4 events where R is clearly greater than 1.0, three of these are associated with mirror mode-related TDs.

4. Summary and conclusions

From a study of 461 discontinuities at the northern most extent of the Ulysses trajectory, we find that:

1) The percentage of clear TDs at the north pole (6.1%) is essentially the same as the south pole (6.3%).

2) TDs detected at the boundaries of mirror mode structures and those associated with current sheets have the following percentages: 26% mirror mode related, 44% current sheet- related, and 30% unknown. From the Ho et al. study at the south pole

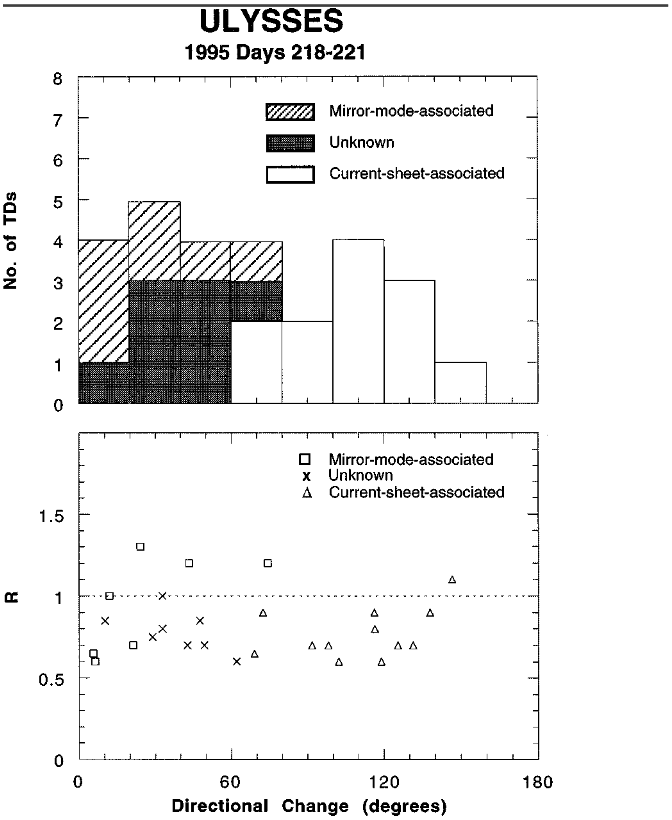

Fig. 5. The field angular change for TDs, and the instability criteria, *R*, for mirror mode growth. The mirror mode related TDs and current sheet related TDs have quite separate angular change distributions

pass, the percentages are quite similar: 19% mirror mode related, 50% current sheet related, and 31% unknown.

3) The mirror mode structures are locally unstable about half of the time (3 out of 6 cases). At the south pole the ratio is 7 out of 14 cases, or again half the time.

4) The rate of interplanetary discontinuities (ROID) is 115 DD/day at the north pole at 2.0 AU. At the south pole the ROID value was 105 DD/day. If we use the radial gradient value of $e^{-(r-1)/5\mathrm{AU}}$, the ROID value at the south pole would be normalized to 113 DD/day at 2.0 AU.

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