Interplanetary Discontinuities in Corotating Streams and Their interaction Regions

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ABSTRACT

in this study, we investigate the discontinuity properties in the low latitude corotating stream regions which are encountered during, Ulysses traveling from the south to north heliographic poles in 1995, Through the occurrence rates of directional discontinuities and tangential discontinuities, we find that there are three different regions around a high speed stream. The leading edge regions of the stream have the occurrence rate about 50 DDs/day and 10 TDs/day. These TDs are mostly associated with HCS crossings. Plasma β and anisotropy R are relatively low. In the stream velocity peak region, the magnetic field magnitude is low and stable. The occurrence rate of DDs is twice as high as in other two regions, but there are very few or no TDs. The stream trailing regions have similar occurrence rates of DDs and TDs to the leading edge regions. However, the structures of the TDs are significantly different. These TDs are mostly found at the edges of mirror-mode structures and with large β and anisotropy ratios R.

INTRODUCTION

A previous study has examined the frequency of occurrence of rotational discontinuities (RDs) and tangential discontinuities (TDs) during a solar maximum period dominated by coronal mass eject ions (Neugebauer and Alexander, 1991) using ISEE-3 magnetic field and plasma data, The present study examines the frequency of occurrence of directional discontinuities (DDs) and TDs during the declining phase of the solar cycle when corotating streams dominate interplanetary structure (1995). We usc the Ulysses field and plasma data to examine discontinuities within stream structures as the spacecraft traverses the ecliptic plane at 1.3 AU in its transversal from the south pole towards the north pole.

Method of Analyses

We use one minute average magnetic field data and apply the Tsurutani and Smith (1 979) selection criteria to identify the occurrence of directional discontinuities. We refer the reader to this article for details. Next, we perform minimum variance analyses (Sonnerup and Cahill, 1967) on high temporal resolution 1 -s field data. From these analyses, normals to the discontinuities (B_N) arc obtained for each discontinuity. By hand analyses, the larger magnetic field magnitude on either side of the discontinuity (B_L) and the magnetic field jump across the discontinuity ($\Delta|B|$) arc obtained, All discontinuities arc plotted in $\Delta|B|/B_L$, B_N/B_L phase space and TDs are selected by the Smith (1973) criteria where $B_N/B_L < 0.2$ and $\Delta|B|/B_L > 0.2$. The plasma velocity, density and temperature are used to identify the leading edges, peaks and trailing edges of the streams. Temporal resolution of the instrument is not high enough to analyze the discontinuities themselves.

For this paper, we have identified all discontinuities within a 17 day period, days 46-62 (Feb. 15- March 3), 1995. This interval incorporates three corotating streams out of the ten streams discussed recently by Smith et al. (1 995) and Gosling et al. (1995). The total number of discontinuities (DDs) in this study is 1085.

The coordinate system used in this study is the Solar-Heliosphere RTN system where $\hat{R}$ points radially away from the sun, $\hat{T}$ is $\hat{\Omega} \times \hat{R}/|\hat{\Omega} \times \hat{R}|$ where $\hat{\Omega}$ is the solar rotation (north) axis, and $\hat{N}$ completes the right hand system.

Results

Figure 1 shows the three corotating streams and their interaction regions. Ulysses encountered these streams at -14° to 0° heliographic latitude and at a radial distance of 1,37 to 1.34 AU, respectively. From the top of the Figure, we have the proton density (N_p), temperature. (T_p), solar wind speed (V_{sw}), plasma ion beta $\beta = 8\pi k(N_pT_p+N_{HE}T_{He})/B^2$, the mirror mode an isotropy rati o $R = (\beta_\perp / \beta_{//}) / (1+1$ /Pd.), three axes of the magnetic field, and field magnitude. At the very bottom of the figure are the number of directional discontinuities per day and the number of tangential discontinuities per day.

The different shadings in the top of the 1 'igure are used to identify three parts of the corotating streams. The diagonally striped regions from days 46 to the beginning of day 49, from the end of day 51 to the end of day 53, and from the middle of day 56 to the beginning of day 59 are the leading portions of the three streams. They are denoted by positive velocity gradients and higher magnetic field magnitudes. These high field regions have been called corotating interaction regions (CIRs) which are created by the interactions of high-speed streams with the upstream slow speed streams (Smith and Wolfe, 1976). Ulysses has shown that these high-speed streams emanate from coronal holes, which during this phase of the solar cycle, extend to low latitudes.

The unshaded regions contain the peaks of the streams (after the reverse shocks, RS in the figure) and their immediate decline, The magnetic field magnitudes typically decrease gradually and in a relatively smooth fashion.

The third region of the streams is the far trailing portion of the streams indicated by a dot-pattern. The boundaries between the peak regions and trailing portions are not obvious and are chosen somewhat arbitrarily. We have mainly used solar wind velocity and magnetic field strength to separate these two. The peak regions contain the highest solar wind speeds and low, stable fields (rarefaction regions after reversal shocks), while the trailing portions have low solar wind speed and lowest field fluctuations (rarefaction region before the next stream).

Two clear features can be noted in the peak of the stream regions. These occur on days: 48, 54 and 59-60. The first and last intervals arc characterized by high occurrence rates in DDs. This is consistent with the dominance of RDs associated with large amplitude Alfvén waves present in high-speed coronal hole streams noted by Ulysses in the polar regions

(Tsurutani et al. 1994; 1996). The very low occurrence rate of TDs at the peaks of the streams is somewhat different than at polar latitudes (Ho et al., 1995; Tsurutani et al, this issue). The reason for this difference is unclear, but we note that the peak velocities in the three streams range from 500 to 700 kms-^{1} whereas the center of coronal hole streams has a speed of 750 to 800 kms-^{1}. Clearly, these high speed streams detected near the ecliptic plane were not at central portion of the coronal hole.

The middle stream peak velocity was onl y 500 km s^{-1}. We note that the DD occurrence rate did not change significantly and we again ascribe that to not being in the main portion of the coronal hole stream which should be dominated by large amplitude Alfvén waves. We also find that while the middle stream is from the north polar hole, the other streams are from the south polar hole.

The leading edges of the stream and the corresponding CIRs are characterized by about -55 DDs/day and about 5-10 TDs/day. The DD rate is half of that for the peak of the streams.

The trailing portions, days 49-51, 55, and 61-62, are characterized by a similar rate (-SO/day) of occurrence of DDs (to that of the CIR regions) and a slightly higher rate of '1'1.1s (1 O-15 TDs/day). We will later show that the characteristics of the TDs in the two regions arc significantly different. In the following, wc will use three typical days of data to ident ify their characteristics in detail.

Figure 2 gives the field and plasma data for day 48 in the same format as Figure 1. This interval contains the peak speed of the first stream just after the reverse shock (around 01 UT). The field is characterized by large angular fluctuations with little or no magnitude variations. The plasma beta is between 1 to 2.5 and R is slightly less than or equal to 1. The tot al magnetic field is stable and no large depression regions are seen. However, high resolution data shows a few mirror-mode like field dips. Because these dips are so narrow (less than 1 minute), they cannot be identified as discontinuities by our selection criteria applied to one minute average data.

We next show a CIR (day 47, leading portions of the stream) in Figure 3. The TDs present are identified by vertical lines across the panels. The B_x and B_y components reverse sign for the events at 0910,0932, 1202, and 1305 UT. Such field reversals arc characteristic of heliospheric current sheet crossings (HCSs). Clearly, Ulysses has multiple encounters with this structure during this day (Smith et al.,1995) or the HCS is fragmentary (Crooker ct al. 1993). Beta is typically less 1.0 and R is 0.2 to 0.7. So the plasma is more isotropic except around 0200 UT.

Figure 4 gives the data for one of the trailing edges of the stream on day 49. Again, vertical lines denote TD events. The magnetic field is very weak (~ 2 nT) but with many large relative changes. The TDs in this case are located at the edges of broader field decreases. This is a rarefaction region found after a high-speed stream prior to the next stream. In this region, there arc more turbulent, bubble or mirror-mode like field depression structures. We sec that most TDs appear at the boundaries of the mirror-mode structures. There usually are large ion temperature anisotropies and therefore we expect mirror mode instability inside these regions ($R > 1.0$) as shown between 1000- 1500 UT. However, wc also sec a TD associated with current sheet around 1715 UT.

High resolution data (1 s) show that there are many more small dips in the total magnetic field. We have identified those dips which have a decrease > 0.5 nT and a duration < 60s. They are mostly mirror-mode-like structures. In this day (day 49) we find there are 207 such structures. As a comparison, in day 048, 157 small dips arc found. Thus in the trailing portion there are more dips than in the peak region. The trailing portions have much larger β (2-1 O) and higher R (near or greater than 1), suggesting that the dips may result from the mirror mode instability.

To examine the instability in the leading regions (CIR), we have plotted both parameters of β and R as a function of directional changes across discontinuities in Figure 5, Usually, across a 'I'D which bounds a mirror-mode. structure, there is only a small direction change, while there is large directional change across a current sheet-associated TD. We find that in the leading edge region, the TDs have large directional changes > 30°. Most TDs have a distribution of $\beta < 3.0$ and $R < 0.8$. In the trailing edge regions, there are small direction changes. Most TDs have angles < 70°. R (0.5 ~ 1.S) and β values are higher than those in the leading edge regions. These results indicate that in the leading edges most TDs consist of current sheet structures, while in the trailing edges of streams TDs are associated with mirror-mode-like structures.

Summary

We have used occurrence rates of discontinuities (1)Ds and TDs) to identify three different regions around a high speed stream near ccl iptic plane: the leading edge of stream where CIRs arc present, peak region of' streams and the trailing portion of streams.

In the leading edge regions, because the downstream high speed flow compresses the upstream slow flow, the magnetic field is high and the velocity gradient is positive (see Pizzo, 1985). The occurrence rate is about 50 DDs/day and 10 TDs/day. These TDs are mostly associated with HCS crossings. The magnetic field has larger angular changes across the TDs. Plasma β and ani sotropy R arc relative] y low in these regions.

In the velocity peak region, the stream speed starts at the highest value and extends into the immediate region of velocity decrease. The magnetic field magnitude is low and stable. The field components are highly variable due to the presence, of nonlinear Alfven waves. The occurrence rate of DDs is twice as high as in the other two regions. There are very few or no TDs. This region is clearly dominated by the high speed stream and large amplitude rotational discontinuities.

In the trailing edge regions, the region with negative velocity gradients, the field strengths are lowest. The TD rate is almost same as in the leading edge regions. This region is also characterized by small (<1 min.) and medium (<1 O min.) scale field depression regions. Because these depressions arc usually associated with high β values and large anisotropy ratios R, they are mostly identified as mirror-mode structure. The TD are often found at the edges of the mirror-mode structures. I'bus, they have a different generation mechanism from those TDs in the leading edge regions.

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Figure Captions

Figure 1. Three solar wind high speed streams and their interacting regions seen by Ulysses near ecliptic plane. We have identified three different regions in each stream region by the discontinuity (DD and TD) properties: leading edge (L), peak region (P) and trailing portion (P).

Figure 2, A typical stream peak region on Day 48, 1995. Because the field magnitude is very stable, no TD is seen. However, The occurrence rate of DDs is very high due to large Alfvenic fluctuations in three field components.

Figure 3. A stream leading edge region on day 47. Vertical lines donate TDs. These TDs arc mainly associated with HCS crossings. This region has strong magnetic field, positive velocity gradient, and low β and R.

Figure *4.* A trailing portion of stream on day 49. This region is characterized by very low field strength, low solar wind speed, but high β and R. There are many field depression regions which are bounded by TDs.

Figure 5. Plasma β and anisotropy ratio R as a function of the field angular changes across TDs for two different stream regions. in the leading edge region TDs have large angular changes, low β and R. in the trailing edge regions, TDs have small angular changes, relatively high β and R.

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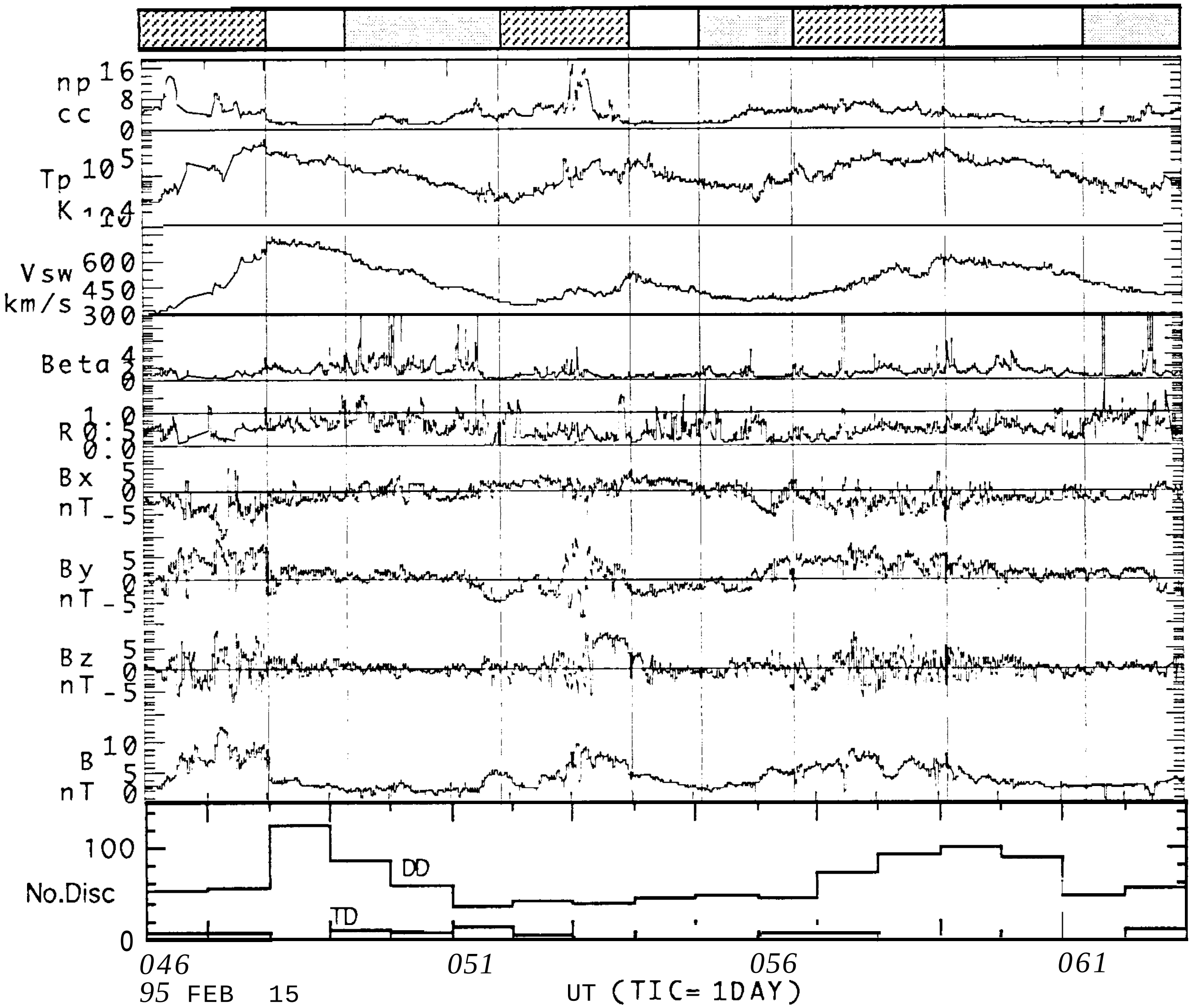
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Fig. 1

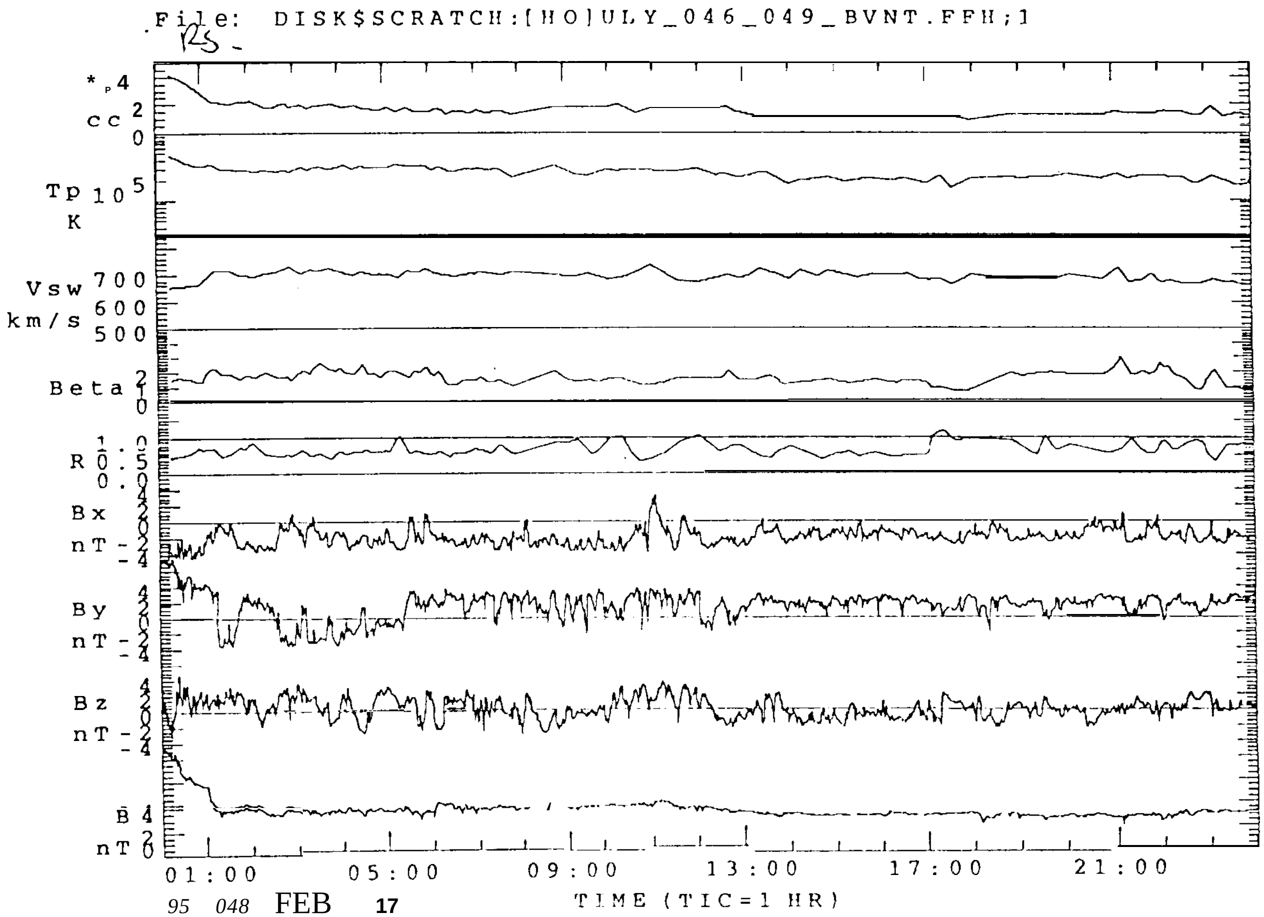
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Figure 2

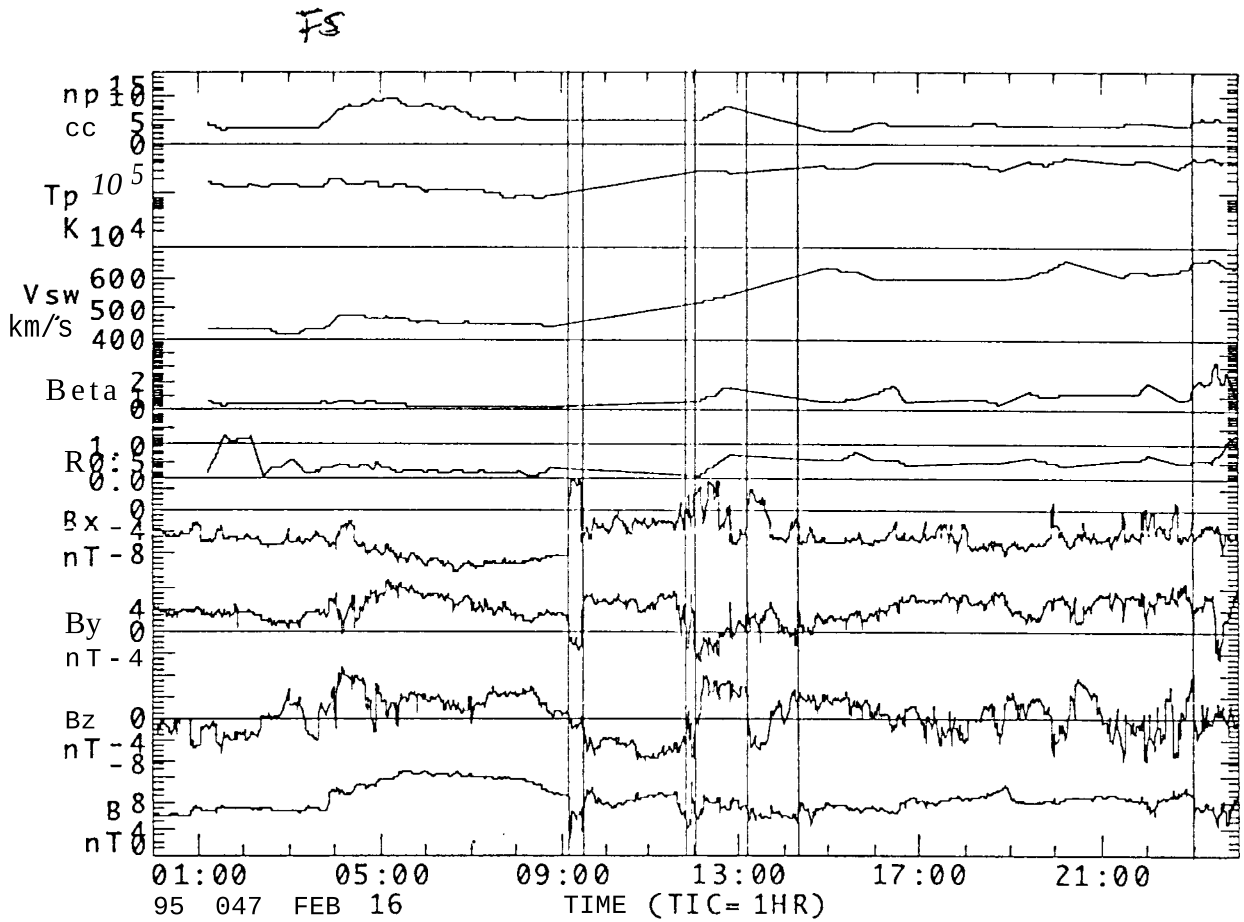
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Figure 3

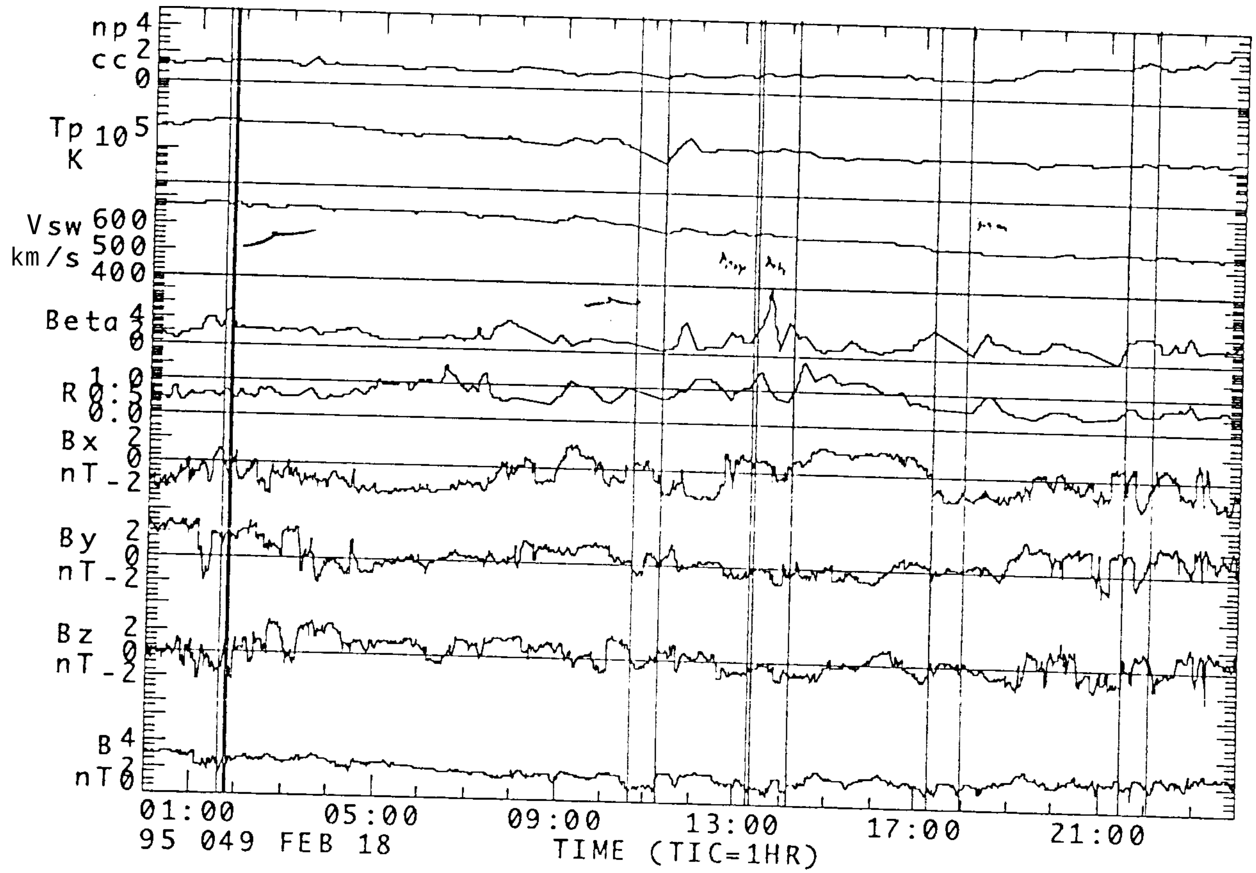

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Fig. 4

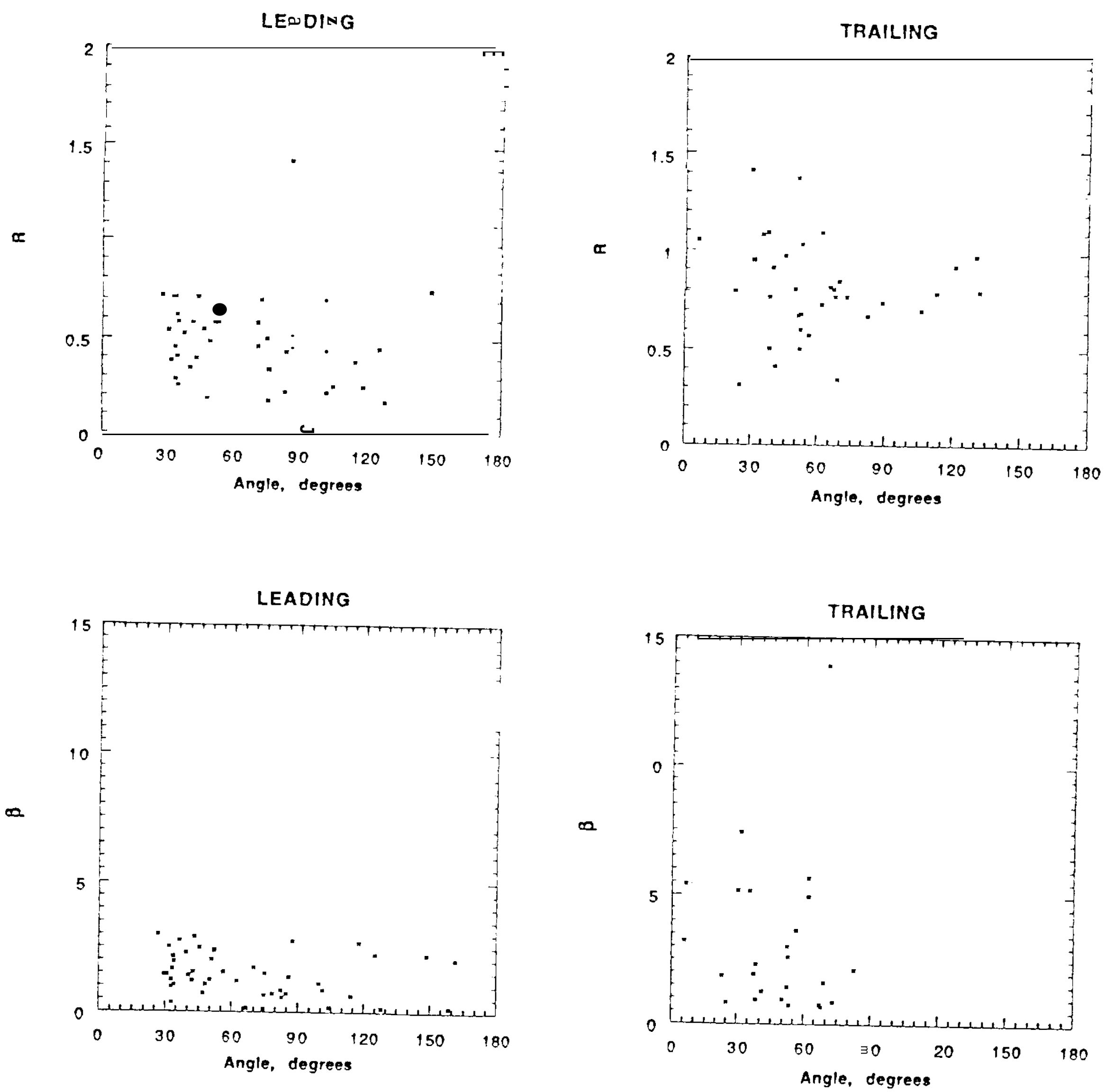
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Figure 5