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ABSTRACT

During the outbound leg of its passage through the Jovian magnetosphere in July 1979, the Voyager 2 spacecraft observed > 50 traversals of the magnetotail current sheet during a 10-day period at distances between 30 and 130 R_J. Analysis of these observations has shown that the Jovian tail sheet tends to lie approximately parallel to the ecliptic plane and to oscillate about the tail axis with the 10-hour planetary rotation period. This more detailed study of these data show that the magnetic structure near and within the current sheet was variable with time and distance from Jupiter, but generally corresponded to one of the following four types: 1. Simple rotation of field across the sheet, with an approximately southward direction in the sheet (generally northward beyond a distance from Jupiter of $\sim$ 84 R_J); 2. Field having a southward component in a broad region near the sheet, but northward in a restricted region at the sheet itself; 3. A clear bipolar variation of the sheet-normal field component as the sheet was crossed (i.e., the field became northward and then southward, or vice versa, in crossing the sheet); 4. Large amplitude fluctuations in all field components near and in the sheet, with alternating northward and southward polarities. Considering Voyager 1 and 2 observations together, twice as many of type 1 signatures were seen as types 2 and 4, which occurred approximately in equal numbers, whereas type 3's were only half as frequent as the latter types. These magnetic structures are all morphologically similar to those observed at the current sheet in the earth's magnetotail at different times. While type 1 and 2 structures are indicative of a simple, static current sheet geometry, types 3 and 4 provide evidence for a more complex and dynamic internal sheet structure at the times of those traversals, suggesting a loop geometry and fine structure consistent with occurrence of the tearing mode instability.

INTRODUCTION

There have been numerous experimental investigations of the current sheet in Earth's magnetotail. Those carried out during the past decade have included Schindler and Ness (1972, 1974), Speiser (1973), Bowling (1975), Bowling and Russell (1976), Lui et al. (1978), Akasofu et al. (1978), Caan et al. (1979), Fairfield (1980), Fairfield et al. (1981), Nishida et al. (1981), Speiser and Forbes (1981), Speiser and Schindler (1981), and Frank et al. (1982). These studies have addressed questions concerning the position, shape and detailed structure of the so-called 'neutral sheet', both from the standpoint of a steady-state, omnipresent entity and with regard to transient behavior.

A similarly vigorous amount of effort during the same period of time has gone into attempts to develop a theoretical understanding of the existence and characteristics of such sheets. These studies include the work of Cowley (1973, 1978), Kan (1973), Speiser (1973), Eastwood (1972, 1974, 1975), Galeev et al. (1978), Birn (1980), Birn and Hones (1981), Hamilton and Eastwood (1982) and Matthaeus (1982). There also have been laboratory plasma experiments which have demonstrated the formation of magnetically neutral sheets, tearing and island formation and have contributed to a greater understanding of the detailed physics of reconnection processes (Stenzel et al., 1981; Stenzel and Gekelman, 1981; Gekelman and Stenzel, 1981; Gekelman et al., 1982; Stenzel et al., 1982).

The interest in magnetotail current sheets is not limited to studies of the magnetic tail of Earth. They appear to be common features of planetary magnetospheres in general. Their characteristics are important for a complete understanding of the physical processes occurring in magnetotails and the contribution of such processes to total magnetospheric energetics. Whether or not reconnection is taking place at the sheet is important for investigations of phenomena such as particle acceleration and substorm occurrence. If there is no large-scale reconnection, but rather only a highly distended but still closing magnetic field across the sheet, then we must consider localized, "small scale" reconnection events or perhaps different processes altogether as for the source of such observed phenomena.

There are indications from near-Earth tail studies that reconnection occurs, but as a spatially localized and/or time-dependent process (e.g., Galeev et al., 1978; Speiser and Schindler, 1981; Speiser and Forbes, 1981). A detailed analysis of sheet structure can lead to a clearer understanding as to which of the reconnection alternatives is correct. The results presented here lend support to the view that at Jupiter, as also probably at Earth, there is time-dependent, and possibly also spatially-localized, reconnection taking place.

A previous study addressed the large-scale shape, orientation and thickness of the Jovian tail current sheet (Behannon et al., 1981). The present work presents new evidence concerning the detailed structure of the magnetic field in and near the Jovian tail sheet and attempts to deduce, as far as this can be done with single spacecraft observations, temporal variations in sheet structure. It will be demonstrated using data from Voyagers 1 and 2 that although the local sheet structure tended to vary with time and distance from Jupiter, it generally corresponded to one of four general types. The signatures of each of these types also have been seen at various times at the current sheet in the geomagnetic tail. The observations and their interpretation will be presented in the next section according to the following plan:

a. Classification of the four types of structure, including examples, and possible geometries associated with each type;
b. Locations of each sheet crossing studied, identified by type, within the tail (along the respective spacecraft trajectories);

The final section summarizes the results briefly and states the conclusions drawn from them.

OBSERVATIONS AND INTERPRETATION

Classification of Current Sheet Types Observed

The Voyager magnetometer instrumentation has been described in detail by Behannon (1977). Both 1.92 and 9.6s average vector magnetic field data were used in this study. Which of the two was used in a given case was determined by the apparent relative speed between the current sheet and the spacecraft. Distances are given in units of Jovian radii ($R_J \approx 71{,}372$ km), and the basic data analyzed are in spacecraft-centered heliographic (HG) coordinates, a spherical system with azimuth $\lambda = \tan^{-1} (B_T/B_R)$ and latitude $\delta = \sin^{-1} (B_N/B)$, where $\hat{R}$ is radially away from the sun, $\hat{T}$ is perpendicular to $\hat{R}$ and parallel to the solar equatorial plane, positive in the direction of Jupiter's motion, and $\hat{N} = \hat{R} \times \hat{T}$. The data will be presented in terms of coordinates X, Y, Z, where $\hat{Z} = \hat{N}$, $\hat{X} = -\hat{R}$, and $\hat{Y} = -\hat{T}$.

The Voyagers observed generally four different types of magnetic signatures in traversing the magnetotail current sheet of Jupiter. These are most easily illustrated in terms of the observed variations in the Z component of the field, B_z, for the special subset of the sheet crossings in which the sheet tended to lie, at least locally, in the equatorial (B_x-B_y) plane. Figure 1 shows the different signature types schematically. The investigation of each type of sheet field geometry included application of the minimum variance analysis (MVA) of Sonnerup and Cahill (1967) to estimate the direction in which the variation of $\Delta \underset{\sim}{B}$ is minimal, normal to the plane which best fits the maximum variation of the difference vectors ($\underset{\sim}{B}_i - \langle \underset{\sim}{B} \rangle$). For type 1a structures, the direction $\hat{Z}$ is assumed to be normal to the current sheet surface; for type 1b it lies in the sheet. In the latter cases the magnetic field rotates smoothly in a plane perpendicular to the sheet in closing across it and reversing direction from one side of the sheet to the other. The MVA of type 2 structures gives results similar to those of type 1a structures. We shall now describe and illustrate each of the types in turn.

The type 1 signature illustrated (top row in Figure 1) is that of simple rotation of the magnetic field vector approximately parallel to a plane. This plane was found to have various orientations relative to the HG equatorial plane as a result of both large scale and local motions of the current sheet. Only the subsets in which the rotation was (a) nearly parallel (left-hand sketch) or (b) nearly perpendicular to the equatorial plane (right-hand sketch) were used in this study because only those cases could be unambiguously differentiated as to subtype. The criterion used required the orientation to be within 20° of parallel or perpendicular, respectively, for subtypes (a) and (b). Ideally, in type 1a the rotation of $\mathbf{B}$ is parallel to the XY-plane but with a component along the Z axis also present within the sheet; in type 1b the rotation is parallel to the XZ-plane. In the latter case, the B_z component at the center of the sheet is the total field at that point. In both cases the magnitude of the field is reduced to a minimum within the sheet (near the sheet center).

An example of a type 1a simple rotation of the field, with a southward B_z component within and near the current sheet, is shown in Figure 2. A southward field is consistent with the direction of Jupiter's dipole field at the equator. The data are 9.6s average magnetic field vectors projected onto XZ- (above) and XY-planes (below) which again are parallel to the HG RN- and RT-planes, respectively, with positive X pointing toward the sun (and Jupiter) and Z positive northward. It has been assumed here that to a good approximation the relative motion between the spacecraft and the sheet is entirely in the $\hat{Z}$ (sheet normal) direction. The distance scale is arbitrary since the relative speeds are not known but can only be modeled in each case. In these examples the tick marks can, for example, represent 5000 km for a relative speed along $\hat{Z}$ of 150 km/s. With the nonzero B_z component, this type of sheet structure resembles a rotational discontinuity (RD) in its magnetic characteristics, although strictly speaking an RD is a propagating "limited-wave" mode. Of course, there is the possibility of slow propagation in this case if plasma is moving in the Z direction also.

The type 1b structure is illustrated by the two cases shown in Figure 3. The format is similar to that of Figure 2. On the left are XZ-plane projections; the other views, on the right, are in this case the YZ projections, i.e., the view toward Jupiter and the sun from down the tail. The latter illustrate how well the magnetic field vectors remained parallel to the XZ-plane throughout the rotation of the field across the sheet. The data plotted in 3a are 9.6s averages and in 3b 1.92s averages; in the latter case either the sheet was thinner than in the case shown in Figures 2 and 3a, the relative speed was greater, or both effects combined were present. Here the tick marks would represent 2500 km for a speed of 150 km/sec, for example.

Out of 20 cases observed jointly by Voyagers 1 and 2 with MVA normals either perpendicular (1a only) or parallel (1b) to the X-Y ($\hat{R}$ - $\hat{T}$) plane, 14 were of type 1a, with all but one observed at radial distances less than 80 R_J from Jupiter. Of the 6 cases of type 1b, all but one were observed at distances from Jupiter > 80 R_J. Although all of the 1a cases studied had southward-directed B_z components, only half of the 1b cases had southward components. An example is shown in Figure 3b. Those with northward components were observed only by Voyager 2 and only at distances r > 80 R_J; an example is included in Figure 3a. There were additional sheet traversals during which "apparent" northward components were seen, but they were cases in which the field rotated in planes of intermediate orientation ($20° < \theta_N < 45°$). The location in the tail of the various types of structure observed will be summarized and discussed in more detail in the next section.

The type 2 signature is identical to that of type 1a except that within the current sheet the B_z component changes sign relative to its polarity in the surrounding plasma sheet. The question mark in Figure 1 next to the sketch of this type (middle left) indicates that the interpretation of this type of field geometry is not completely understood. 9.6s vector measurements throughout a traversal of a typical type 2 structure are given in Figure 4. These data demonstrate that the normal B_z component of the field at the current sheet is oppositely directed to that just outside the sheet on each side. To further illustrate this type of magnetic field geometry and its frequency of occurrence, Figure 5 shows a series of normal or B_z field components observed by Voyager 2 at increasing distances from Jupiter. In each case, 16 minutes of data are shown centered on the estimated sheet crossing time, which is denoted by the vertical dashed line. Note the tendency in each case for the B_z component of the field to be southward away from the sheet but northward in the sheet.

A type 2 signature was seen on 9 crossings of the current sheet by Voyager 2 and on 3 crossings by Voyager 1. It has been observed in the earth's magnetotail also (Speiser and Forbes, 1981), where of course the magnetic field directions are opposite to those in the Jovian tail. The only explanation that has been advanced to account for this type of field geometry is that suggested by Dessler and Hill (1970) and sketched in Figure 6, with field directions appropriate for Jupiter. In this view it is attributed to two processes: a thinning of the plasma sheet in the antisolar direction (to the right), with a corresponding gradient in the diamagnetic effect, and a field component in the current sheet directed oppositely to the southward component in the plasma sheet because of the existence of a cross-tail neutral line nearer the planet than the point of observation.

The problem with this explanation for the case of the Jovian tail is that the clean and unambiguous examples of this type of structure were all observed in the near planet region of the tail ($r < 80\ R_J$), and thus would argue that a neutral line was frequently as near the planet as $X = -20\ R_J$. It has been shown that there are northward sheet fields in type 1b geometries at greater distances ($-X > 70\ R_J$). If there is a neutral line in the near tail, it is possible that the plasma sheet thins with increasing distance down the tail only to a distance of $\sim 70\ R_J$ and then has a more nearly constant thickness beyond that distance, at which point the B_z component of the field in the surrounding plasma sheet changes sign to become the same as that within the embedded current sheet.

An alternative interpretation to a single, large-scale neutral line near the planet would be that there are multiple neutral points within the current sheet as first suggested for the earth's tail sheet by Schindler and Ness (1974), and thus either a northward or a southward directed B_z component could be observed in the current sheet at any distance down the tail. In the case of type 1 and type 2 geometries, the crossings of the sheet were rapid enough relative to longitudinal motions of the fine structure within the sheet that only a unidirected B_z component was seen. It could have been either northward or southward, depending on whether the spacecraft crossed to the inside or outside of the nearest "local" neutral line (or if near a neutral point in a two-dimensional array of cells, the sign of B_z could also depend on whether the path passed to the east or the west of the point).

If the current sheet itself undergoes spatial and/or temporal changes on time scales comparable to or shorter than the sheet traversal time, then a more complex signature is to be expected in the magnetic field observations. The type 3 and 4 signatures provide evidence for this more complex structure and time variability. The majority of sheet crossings beyond 80 R_J yielded signatures of this type. They support the concept of an internal magnetic loop or bubble structure to the sheet as deduced by Schindler and Ness (1974) for Earth's magnetotail. In type 3 signatures, a single bipolar B_z variation (either +/- or -/+) is observed (Figure 1 middle right). As shown in the sketch, one possible interpretation is in terms of a loop structure moving past the spacecraft as it crosses the sheet.

Figure 7 provides an example of the vector data (9.6s averages) for the single loop type of variation. At the top are the XZ-plane projections for the three successive time intervals indicated. Below these are the corresponding views toward the sun from down the tail. The motion of the Voyager 2 spacecraft relative to the current sheet is indicated by the vertical arrows, where an oscillatory motion of the sheet has been inferred. During the first interval, the relative motion was northward, in the second southward, and then in the third northward again to complete the full traversal. During the first two intervals, the magnetic field component normal to the sheet is seen to have been northward, but had veered southward by the final interval. The projections in the lower part of the figure show that the field tended to remain in or near the XZ-plane throughout the multiple traversal.

An explanation in terms of the unsteady crossing of a magnetic loop or bubble is illustrated by the sketches in Figure 8. The loop is taken to be similar to the tearing mode magnetic island structure considered by Galeev et al. (1978). It is suggested that the structure drifts across the path of the spacecraft while the current sheet is either flapping rigidly or undergoes wavelike oscillations, as depicted in Figure 8b. This would produce the unsteady crossing indicated in 8a, and a change in the direction of the field component normal to the sheet would be observed. Such a signature was seen as a single, isolated variation of the magnetic field on four Voyager 2 crossings, all at distances > 80 R_J from Jupiter, and once by Voyager 1 at ~ 65 R_J.

Type 4 variations (Figure 1, bottom) are related to the previous type in that they are the signatures of complex sheet traversals and generally include repeated occurrences of type 3 signatures, as well as those of simpler structures, during multiple sheet crossings were seen over an extended time period and range of distance in the Z direction, indicating considerable sheet motion. Similar alternations of B_z or successive sheet crossings have been analyzed in the case of the earth's magnetotail by Speiser (1973), Lui et al. (1978), Fairfield et al. (1981), Speiser and Forbes (1981), Nishida and Hones (1982 and others. The observations were interpreted by Nishida and Hones (1982) as undulations of a current sheet containing field line loops. Fairfield et al. (1981) found a similarity between the occurrence of negative-positive oscillations in B_z at several crossings of the terrestrial sheet and the signature of dayside magnetopause 'flux transfer events'.

A typical Jovian type 4 case is illustrated using 9.6s average data in Figure 9. In addition to field magnitude, B, and the direction of the magnetic field in HG coordinate angles, λ, δ, the spacecraft-sun line component of the field, B_x, is included also. This demonstrates how the spacecraft penetrated to a greater distance across the sheet on each successive oscillation (+, - polarity change of B_x) during a one-hour period until the traversal was complete. In addition to the sheet motion implied by these data, individual crossings in the sequence indicate a complex, structured sheet with the type 3 signature seen in some cases. There were 9 occurrences of such multiple crossing sets in the Voyager 2 tail observations and 4 in the Voyager 1 data. They were seen most frequently beyond $X = -60\ R_J$ by Voyager 2.

During these multiple sheet crossings, oscillations are sometimes seen in B_y as well as B_z. This has been observed also in the earth's tail, and the possibility of wave motion in the dawn-dusk direction has been discussed by Lui et al. (1978). They concluded that the geotail current sheet often shows local departure from a plane surface. Because of the similarity of the Jovian tail sheet data to those recorded in the earth's tail, it is likely that the magnetic field variations are produced by similar oscillations in the two cases.

Speiser and Forbes (1981) consider an alternating sign of B_z at successive sheet crossings as evidence for the occurrence of the tearing mode instability. This interpretation in connection with signature types 3 and 4 will be discussed at greater length in the following section.

Location in the Tail

In Figure 10 are summarized the occurrence locations in the Jovian magnetotail of the different types of current sheet crossing signatures. The data are given along the Voyager 1 and Voyager 2 trajectory projections in the plane of Jupiter's orbit about the sun. Signature types are identified by the type numbers introduced and defined in the preceding sections, except for type 1. Instead, as indicated in the legend, those are identified by either S for southward field in the sheet or N for northward. As discussed earlier, the Voyager 2 crossings of type 1 at greater distances from Jupiter than $r = 80\ R_J$ in the tail were all type 1b. All but one of those inside that distance were type 1a. All of the Voyager 1 crossings labeled S were 1a.

There are clear differences in type occurrence between the near and far regions of the magnetotail. Because of the limited quantity of data, it is not clear whether the change is a function of radial distance or of distance down the tail (along -X). This is emphasized by the two dashed reference lines, one at a constant radius of $80\ R_J$ and the other across the tail at $X = -70\ R_J$. Another dashed curve at the constant radius of $30\ R_J$ delineates the inner boundary of the tail sheet observations.

It is obvious from Figure 9 that in the near-planet region of the tail the southward-directed type 1a signatures and the similar type 2 signatures dominated the observations. A few occurrences of multiple traversals (type 4) were found as well, and on Voyager 1 one case of type 3. In the more distant tail, on the other hand, at least along the outbound path of Voyager 2, the more complex type 3 and 4 signatures dominated, with a lesser number of mostly northward-directed type 1b's seen. Thus the types of structures which may signify occurrence of the tearing mode instability and possibly merging were preferentially observed at the greater distances, though not on every crossing of the sheet. They also show that the current sheet was subject to greater fluctuation in position at larger distances.

The merging of magnetic fields at a current sheet can be associated either with the spontaneously-excited resistive tearing mode instability or with the

Petschek-type externally driven reconnection (Sato and Hasegawa, 1982; Sato and Walker, 1982). The latter process is associated with the strong jetting of plasma and probably plays a role in explosive phenomena such as substorms. Galeev et al. (1978) have suggested that explosive tearing mode reconnection can be involved in such phenomena, also. Signatures of both types of processes have been found in the geomagnetic tail (Nishida et al., 1981; Nishida and Hones, 1982). The similarity of those signatures to the type 3 and 4 Jovian tail sheet signatures strongly suggests that these processes also occur at least sporadically in Jupiter's magnetotail. The observation of field-aligned energetic proton streaming events (Schardt et al., 1981) gives additional support to the possibility of reconnection in the Jovian tail.

For the case of the terrestrial magnetotail, calculations using typical plasma sheet parameters have shown that the ion tearing mode instability can grow to saturation there on a reasonable time scale. In an investigation of linear growth, Schindler (1974) found a characteristic time of $\sim$ 5 min. for the tearing dynamics to develop. Galeev et al. (1978), who have studied nonlinear explosive growth, have concluded that the linear mode would require at least three exponentiations to reach a high saturation amplitude, whereas in the nonlinear case, saturation can be reached in a time that is less than the characteristic time for linear growth. They thus suggest that the tearing mode could exhibit two different time scales in the geomagnetotail; tens of minutes to reach the nonlinear threshold, and also a much shorter explosive growth phase to saturation. Speiser and Schindler (1981) have found further that the characteristic time for plasmoid (loop, bubble, magnetic island) motion along the sheet lies in the approximate range of one to ten minutes, where the time is estimated using $\tau = L/V$ with L the scale size of the plasmoid ($\sim$ 10 R_E) and V a typical substorm-associated flow velocity (100-1000 km/s). This is of the same order as the estimated growth time for tearing, and thus shows consistency of the loop formation time with loop drift speeds.

Similar considerations can be applied to Jupiter's tail current sheet. There have been no definitive measurements yet of "substorm-associated" flow speeds in the Jovian magnetotail. However, there have been several estimates of flow speeds for $\gtrsim$ 30 keV ions in the nightside plasma sheet at distances of

$\sim$ 80 R_J to $\sim$ 120 R_J (Lanzarotti et al., 1980). These give averages of $\sim$ 800 km/s for the assumption of an all-proton flow and 250-300 km/s for oxygen. This speed would lie between the two extremes for a mixture of the two ion species. Using then the same flow speed range applied in the case of Earth (100-1000 km/s) and the average Jovian tail sheet thickness of 4.7 R_J (Behannon et al., 1981), a characteristic time for plasmoid motion ranging from 12 min to $\sim$ 6 hrs is obtained. For the much thinner "field reversal" or neutral sheet layer (0.3 R_J, thick on average), the times range from 2.3 to 23 min. These times range from being of the order of those found for the earth's tail (Speiser and Schindler, 1981) to being somewhat longer, with the longest times associated with the lowest speeds. From the formulation of Galeev et al. (1978) for nonlinear tearing mode growth, a time scale ranging from minutes to several hours can be estimated from the limited data available for Jupiter's tail sheet. This is consistent with the range estimated for plasmoid motion times, as was also found at Earth.

SUMMARY AND CONCLUSIONS

The magnetotail current sheets of both Earth and Jupiter have been found by spacecraft magnetometer measurements to exhibit considerable time variability in both internal magnetic structure and position. For Earth this variability and the variability of other characteristics such as sheet thickness have been shown to be manifestations of dynamic processes occurring in the magnetotail during times of geomagnetic activity.

Voyager observations in the Jovian tail show that the magnetic structure in the night-side current sheet is variable both with time and distance from Jupiter, with the signature of sheet traversals generally one of four types. These range from the simple, static geometry of continuous closure of tail lobe fields across the sheet to forms consistent with magnetic loops or bubbles associated with "plasmoids" and/or X-type neutral line (or point) geometry. A series of the latter configurations were seen at times by the Voyagers when fluctuations of sheet position produced multiple crossings of the sheet.

The different types of signatures observed in the Jovian tail have been seen also in the terrestrial magnetotail at various times. In the case of

Earth, there is considerable evidence for the occurrence of the tearing mode instability, probably in association with magnetic reconnection that is possibly driven, at least in some cases, by substorm processes. The observation of the same types of magnetic structures and temporal behavior in Jupiter's tail current sheet suggests that similar phenomena may be taking place there. Using the limited data available from the Voyager encounters, it is found to be plausible for the tearing mode to occur in the Jovian magnetotail environment; additional data are needed to establish this conclusively, as well as to demonstrate that such behavior is related to the occurrence of substorms at Jupiter.

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Stenzel, R. L., W. Gekelman, and N. Wild, Magnetic field line reconnection experiments 4. Resistivity, heating, and energy flow, J. Geophys. Res., 87, 111, 1982.

Figure Captions

Figure 1 Sketches of types of variations seen in the component of $\vec{B}$ in the direction estimated to be normal to the plane of the Jovian tail current sheet during traversals of that sheet. Observed variation generally has one of the four signatures illustrated: (1) simple rotation of field across sheet, either parallel to plane of sheet (left) or perpendicular to it (right); (2) simple rotation but with sign of B_Z at sheet center opposite to that at edges of sheet; (3) B_Z reverses sign on crossing center of sheet, suggesting magnetic loop structure; and (4) considerable variability seen in B_Z, over an extended interval of time, suggesting both complex internal structure and sheet motion (see text).

Figure 2 Vector magnetic field projections onto planes perpendicular (above) and parallel (below) to the heliographic equatorial plane, with X positive sunward and Z positive northward. These data illustrate a simple rotation of the field parallel to the plane of the current sheet (type 1a) with a southward-directed component in the sheet-normal direction. Relative spacecraft motion in the Z direction only is assumed. Distance scale is arbitrary because of dependence on relative speed. Radial distance from Saturn is given.

Figure 3 Examples of type 1b geometries with both northward (above) and southward (below) field components at center of sheet. Format is similar to that of Figure 2 except that projections shown at right are for YZ plane. These cases clearly demonstrate that rotation of the field was confined to the plane perpendicular to the HG equatorial plane (approximately the plane of the sheet).

Figure 4 Vector projections illustrating type 2 magnetic field structure, with same format as in Figure 2. As in Figure 2, rotation is parallel to XY plane except Z-component of field at center of sheet was directed opposite to that above and below it.

Figure 5 — B_Z component magnitudes as functions of time and distance from Jupiter for 6 cases of type 2 geometry, including that shown in Figure 4. Although temporal fluctuations were almost always present, brief reversal of B_Z to positive values at center of sheet clearly are identifiable in each case.

Figure 6 — Schematic representation of magnetic field geometry in plane perpendicular to that of current sheet as proposed by Dessler and Hill (1970) to explain type 2 signatures observed in Earth's tail (see text).

Figure 7 — Magnetic field vector projections onto XZ (above) and YZ (below) planes for 3 successive time intervals during Jovian current sheet crossing. Interpretation is that Voyager 2 crossed the sheet from below to above during the first interval, returned to below the sheet during the second, and finally crossed again from below to above in the third, where it remained. Note tendency of field rotations to occur parallel to XZ plane as in type 1b.

Figure 8 — (a) Schematic illustration of possible loop structure during current sheet traversal of Figure 7. (b) Relative motion between spacecraft and sheet during crossing could have resulted from rigid flapping of sheet or wave-like undulations of sheet.

Figure 9 — Magnetic field magnitude B (top), direction in terms of HG longitude (λ) and latitude (δ) angles (center panels) and field component parallel to spacecraft-sun line B_X (bottom) showing case of sustained oscillatory sheet motion during a period of approximately one hour. Complex B_Z variations (essentially identical to those for δ) are representative of type 4 signature. Some of the individual traversals in the series had type 3 signatures.

Figure 10 Voyager 1 (V1) and 2 (V2) trajectories projected on plane of Jupiter's orbit about sun. Model dawnside magntopause (MP) boundary locations are also shown. Locations of sheet crossings are identified by type (see legend and discussion in text). Note tendency of structure type to be different for more distant V2 crossings from that seen nearer Jupiter, i.e., for $X > -70\ R_J$ (or $r < 80\ R_J$).

B_Z SIGNATURES IN JOVIAN CURRENT SHEET

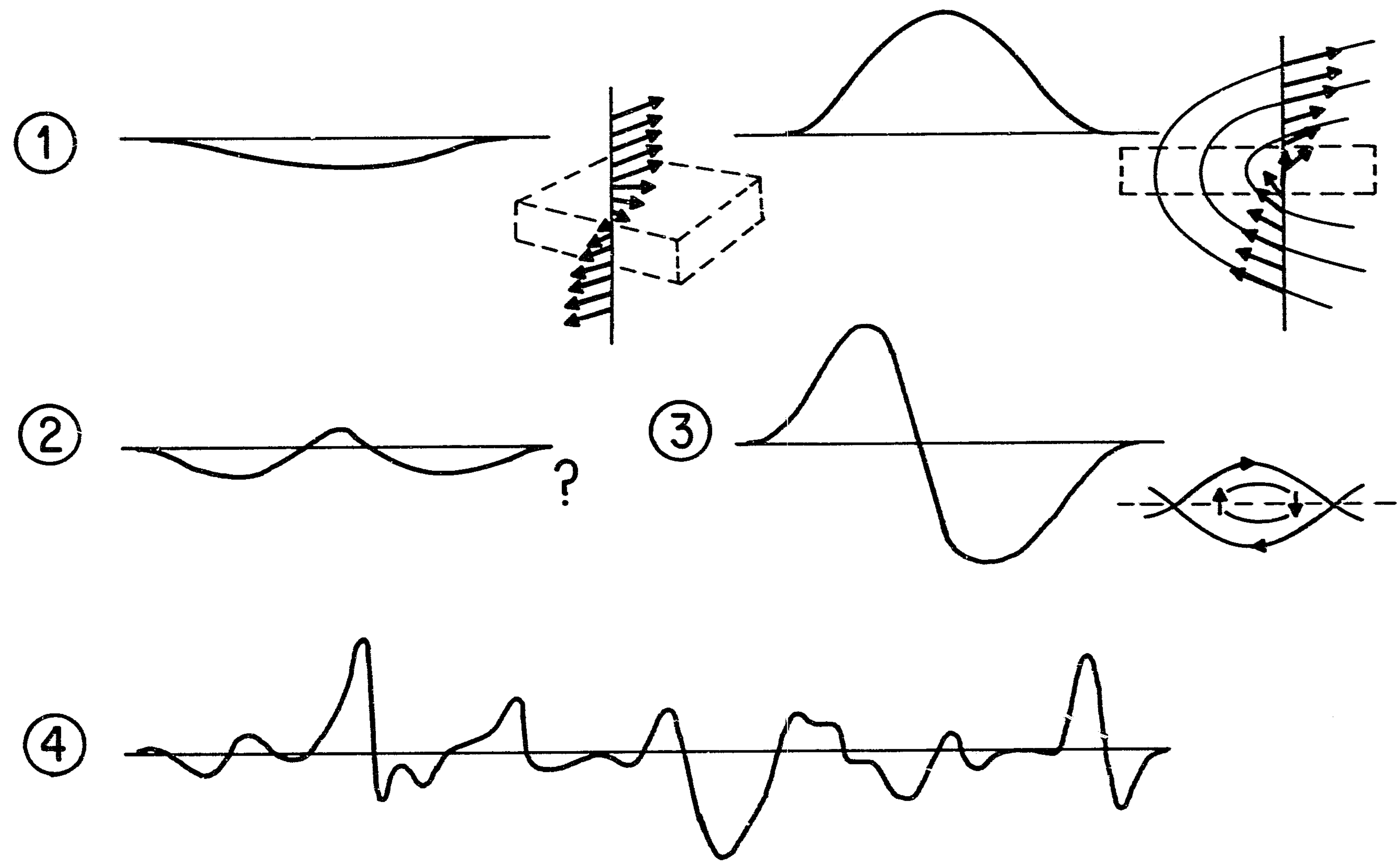


Figure 1

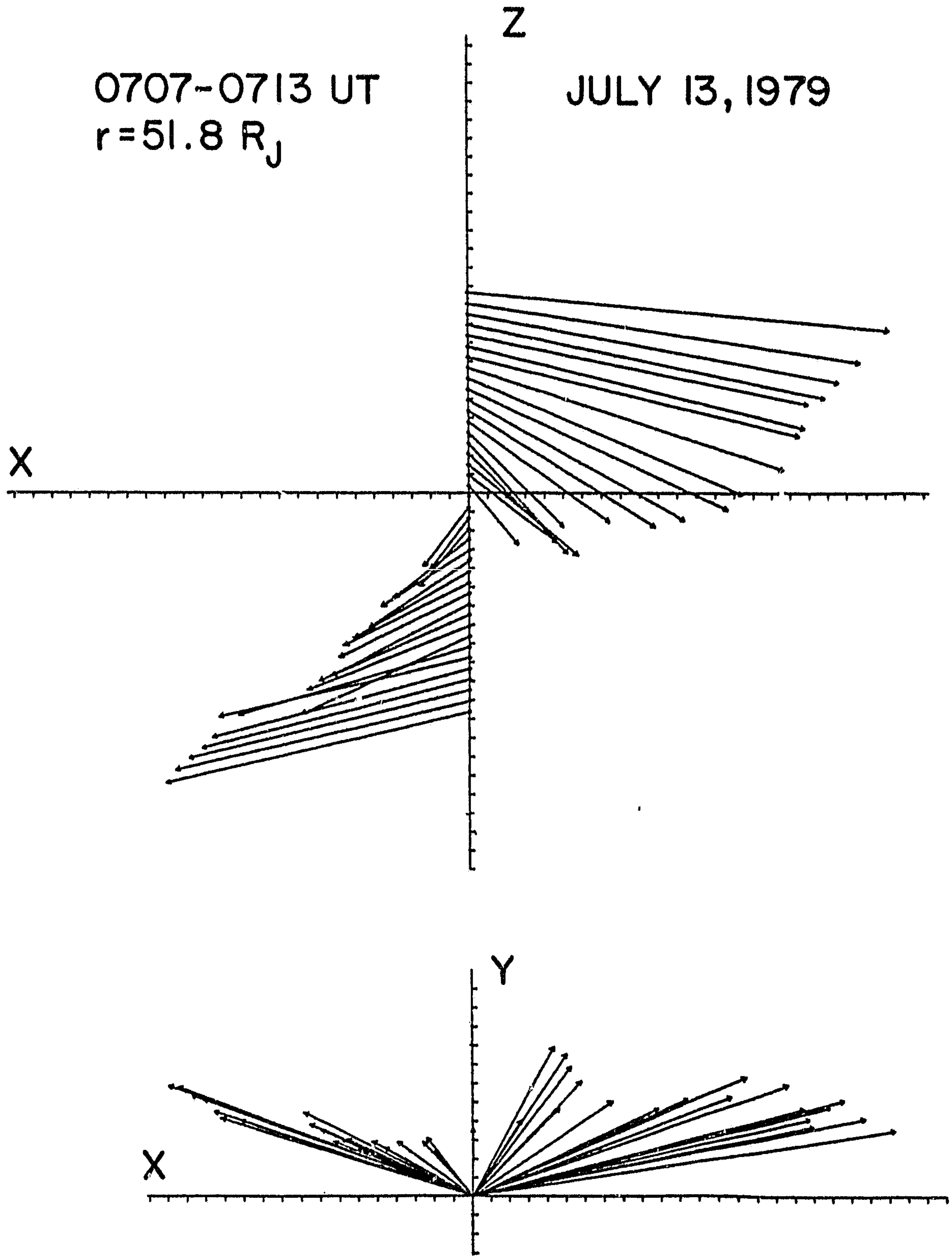


Figure 2

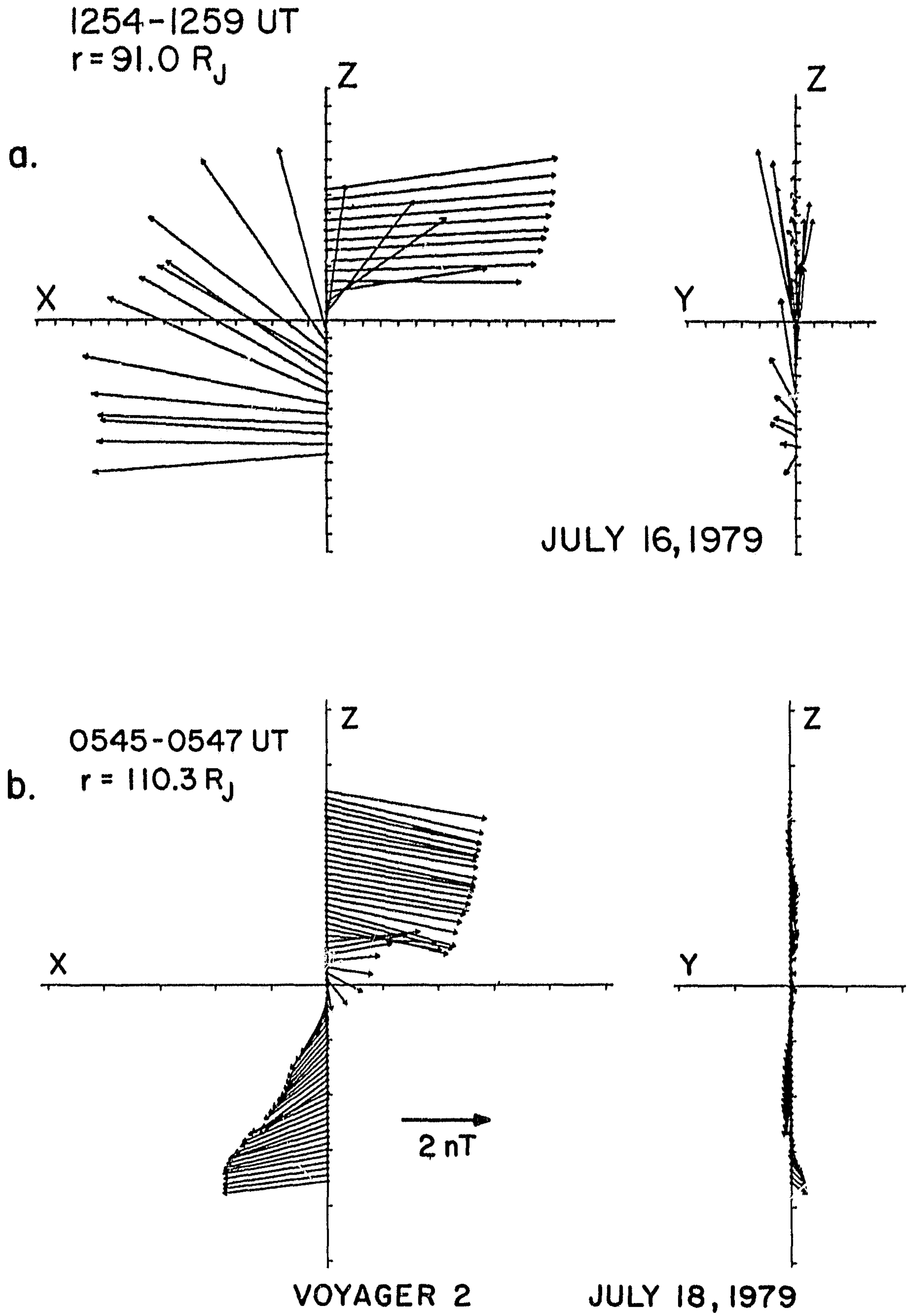

1254-1259 UT
r = 91.0 R_J
a.
Z
X
Y
Z
JULY 16, 1979
0545-0547 UT
b.
r = 110.3 R_J
Z
X
Y
Z
2 nT
VOYAGER 2
JULY 18, 1979

Figure 3

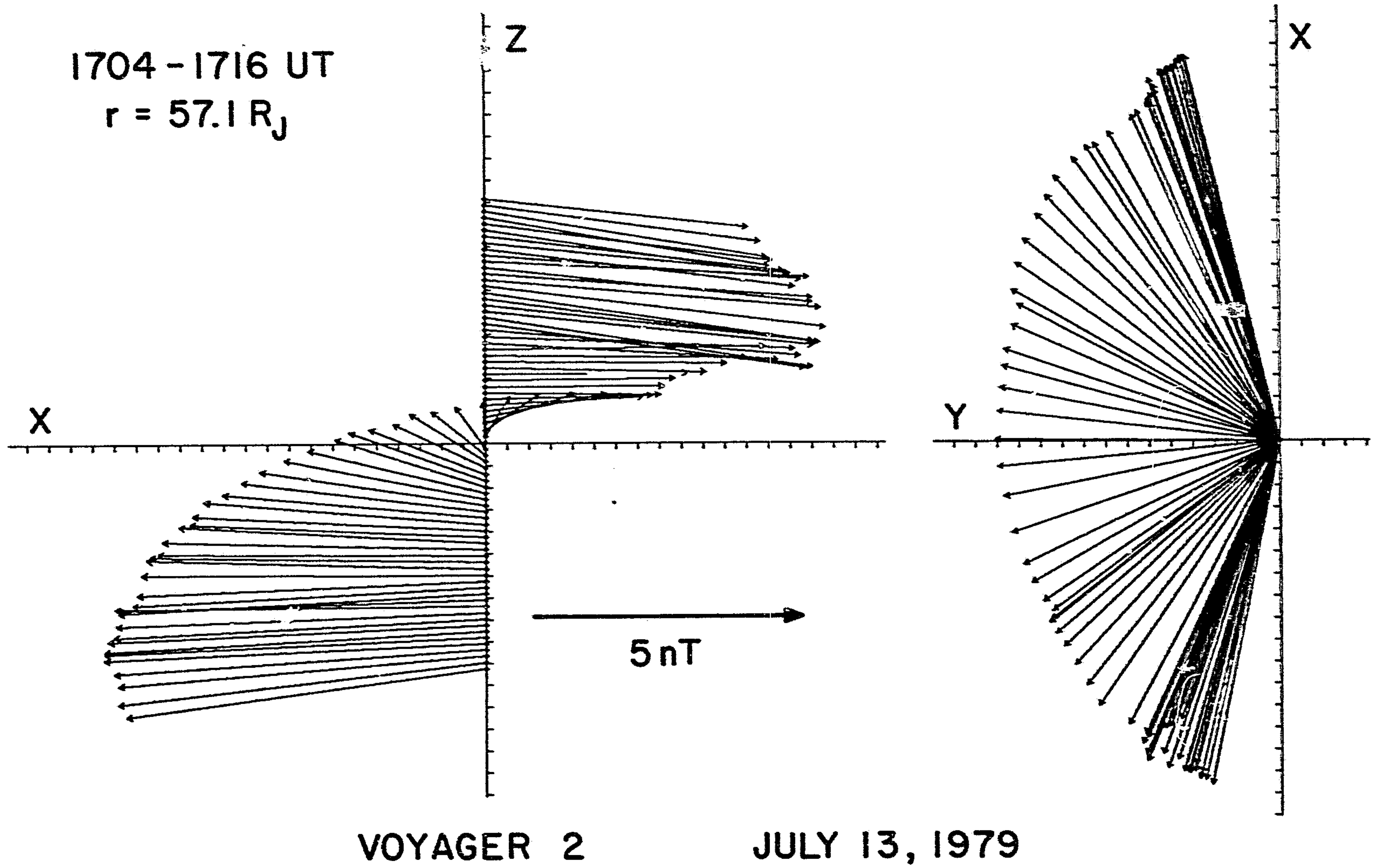


Figure 4

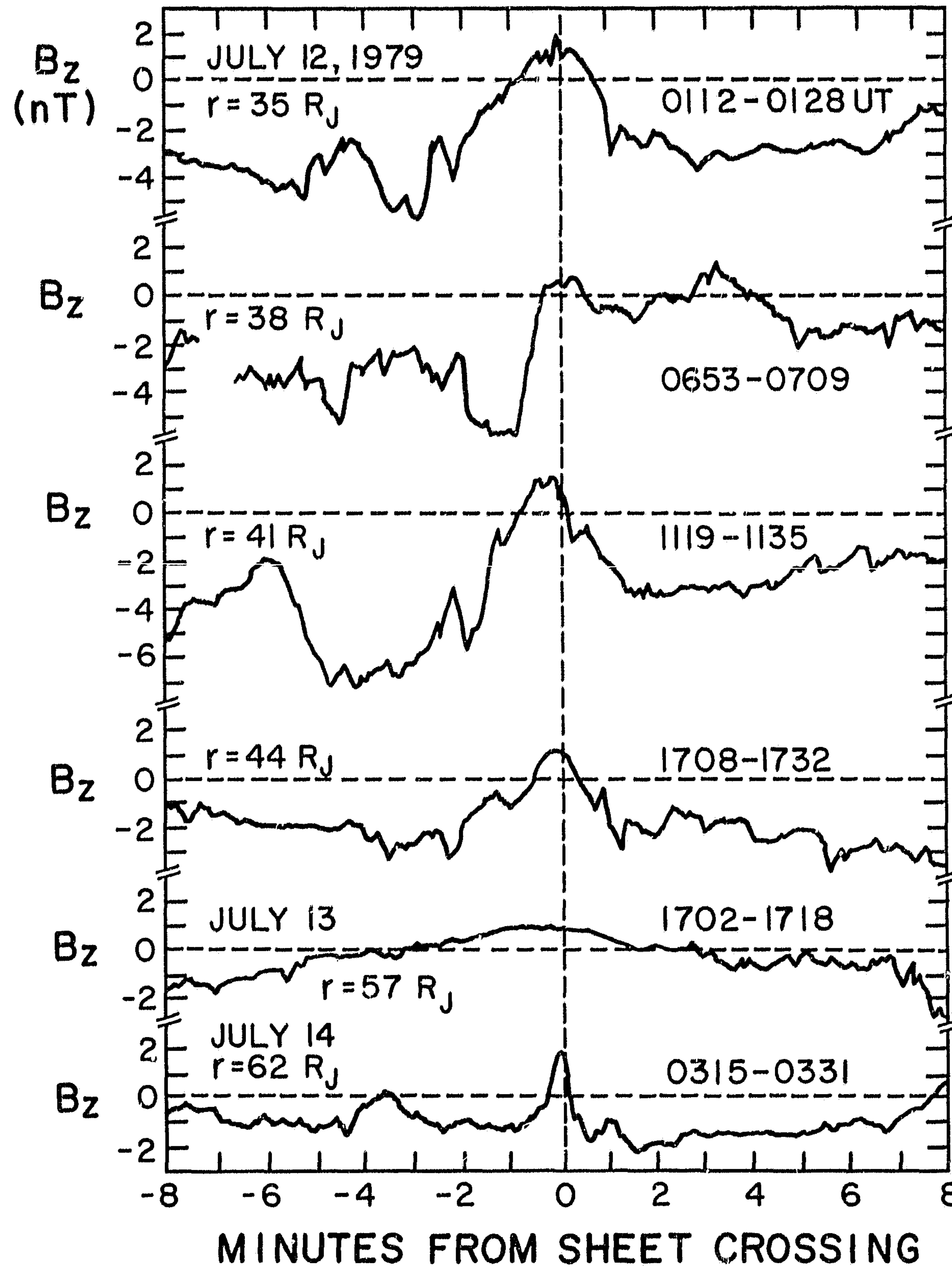
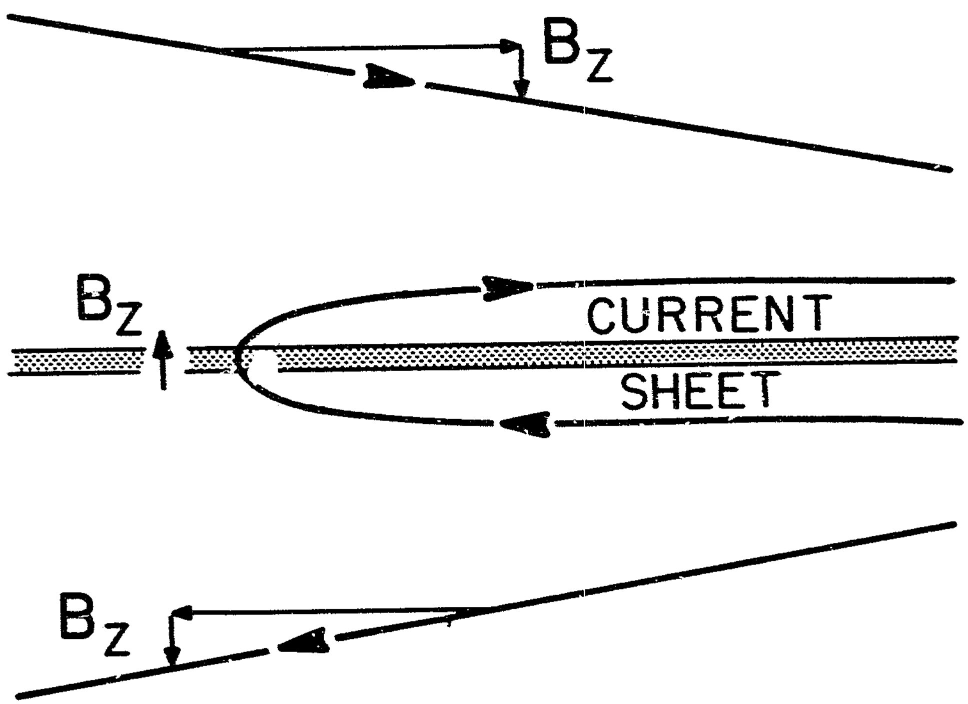

Bz (nT)
JULY 12, 1979
r = 35 RJ
0112-0128 UT
r = 38 RJ
0653-0709
r = 41 RJ
1119-1135
r = 44 RJ
1708-1732
JULY 13
r = 57 RJ
1702-1718
JULY 14
r = 62 RJ
0315-0331
Bz
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
8
MINUTES FROM SHEET CROSSING

Figure 5



(DESSLER & HILL, 1970)

Figure 6

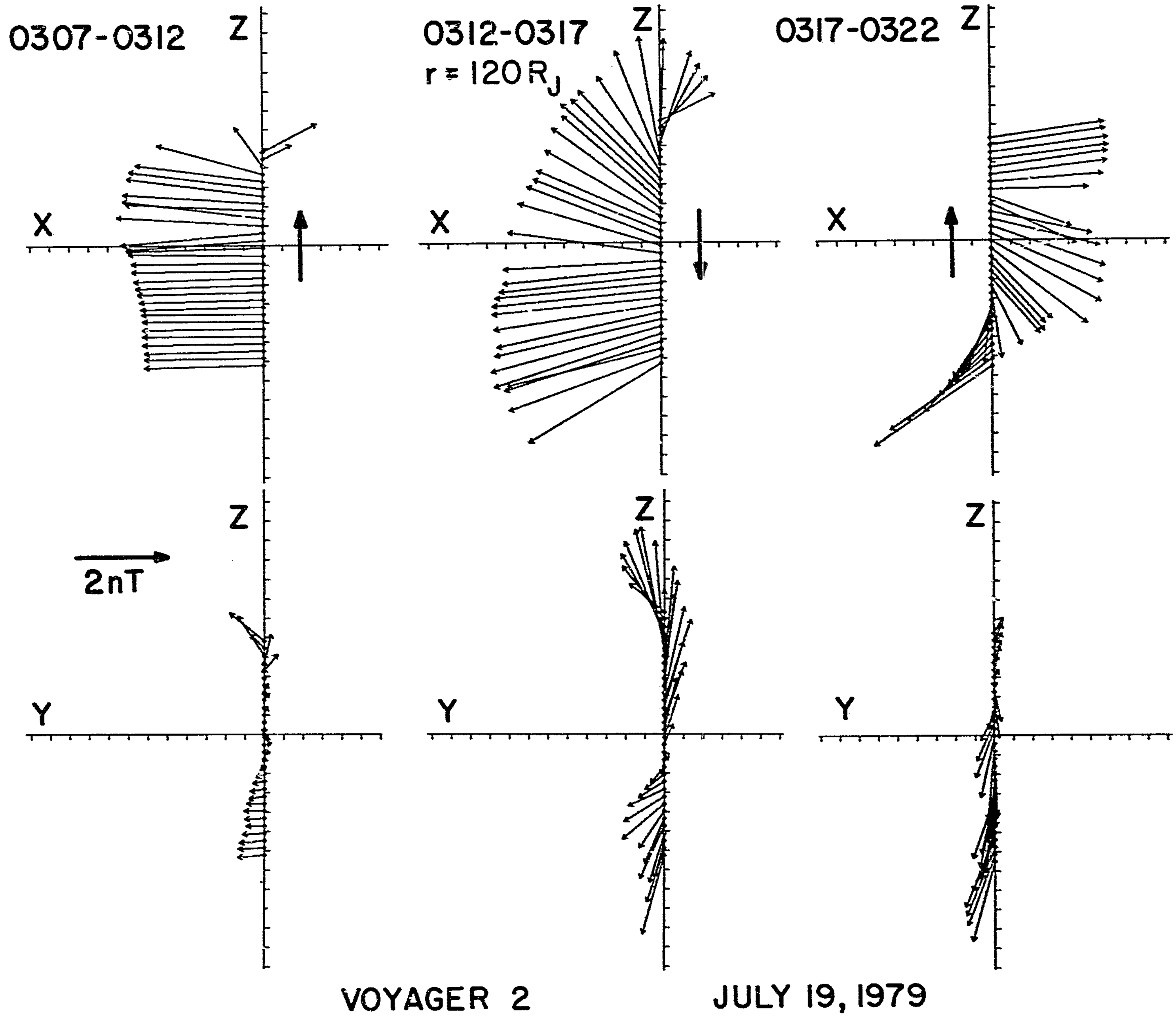

0307-0312
0312-0317
r = 120 R_J
0317-0322
Z
X
Y
2nT
VOYAGER 2
JULY 19, 1979

Figure 7

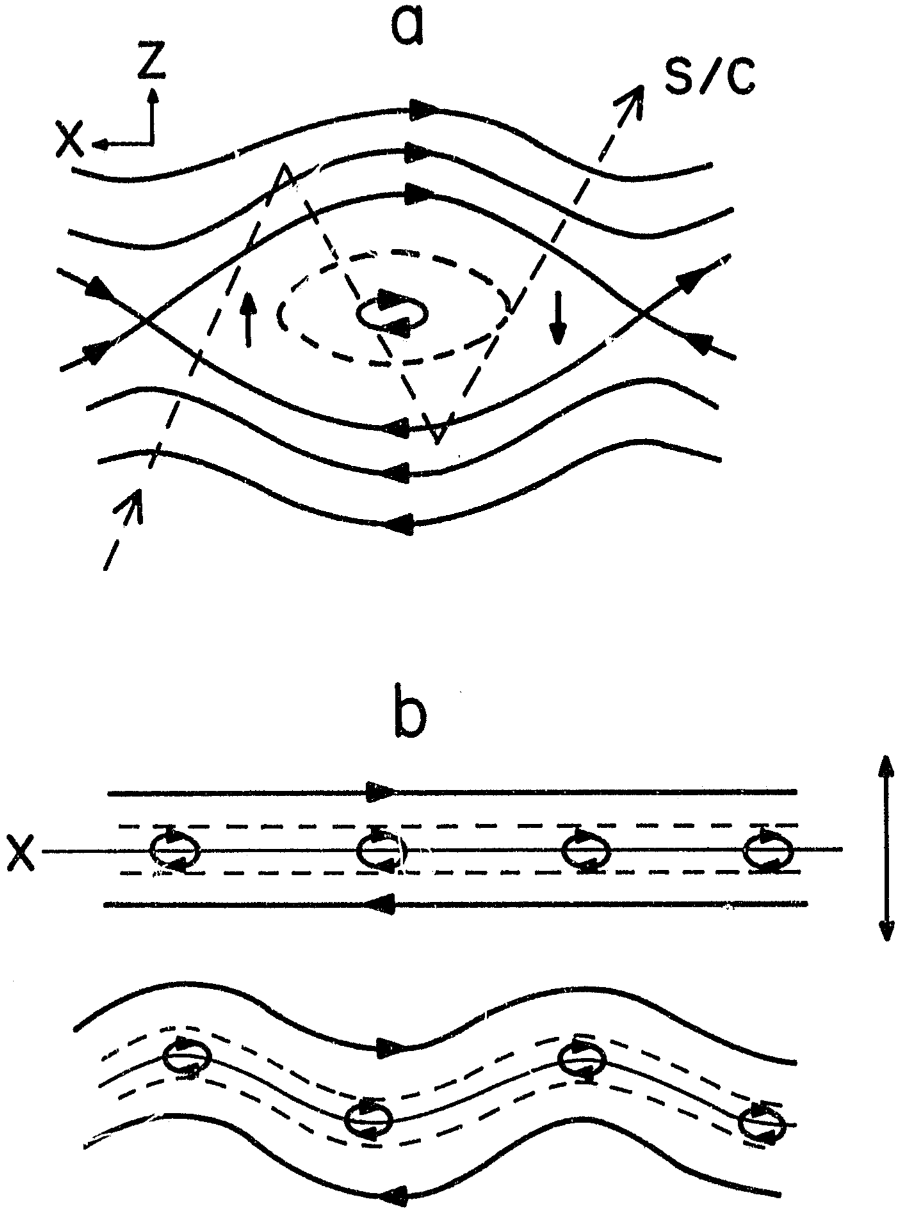
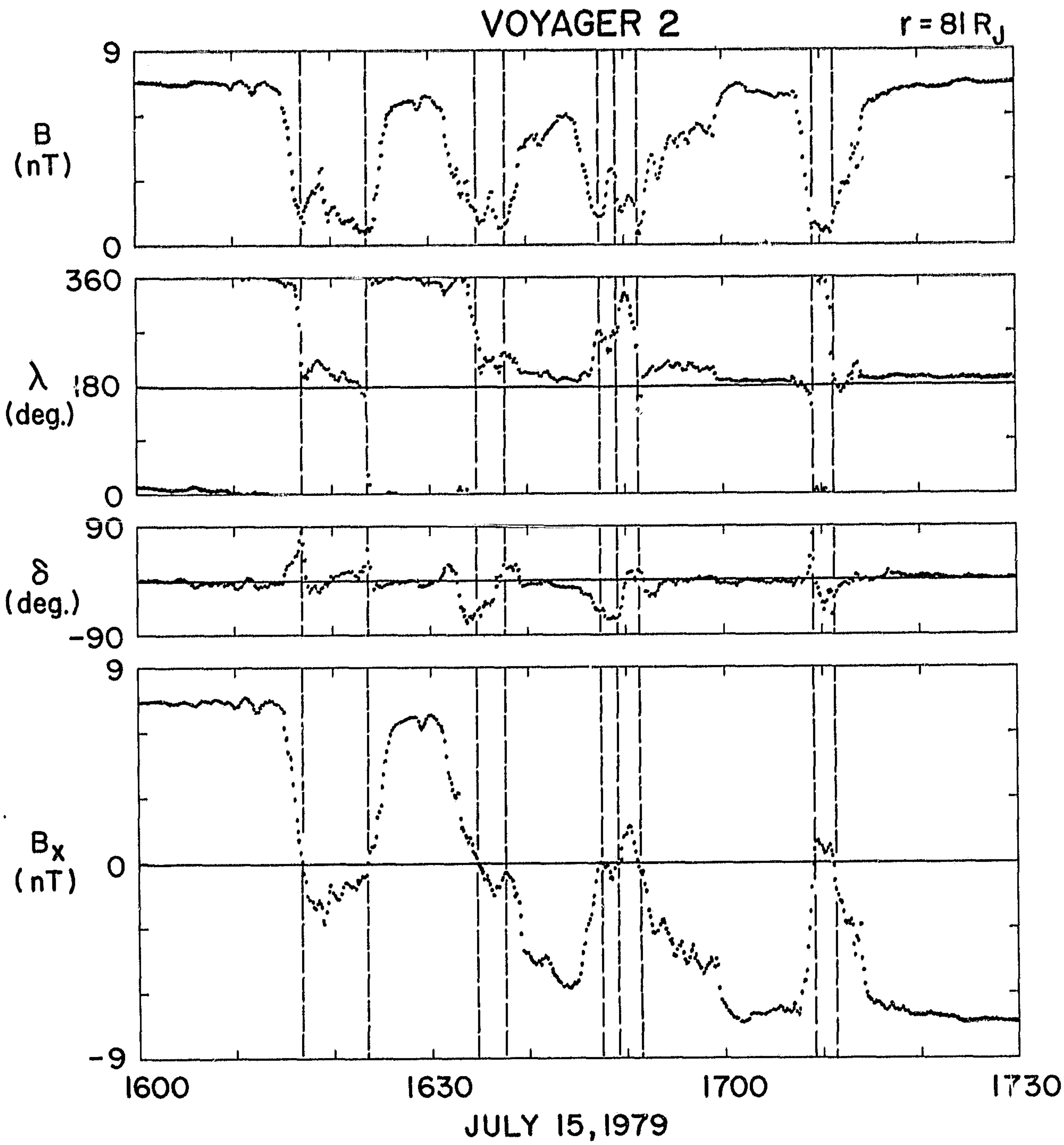


Figure 8



VOYAGER 2
r = 81 R$_J$
9
B
(nT)
0
360
λ
(deg.)
180
0
90
δ
(deg.)
-90
9
B$_X$
(nT)
0
-9
1600
1630
1700
1730
JULY 15, 1979

Figure 9

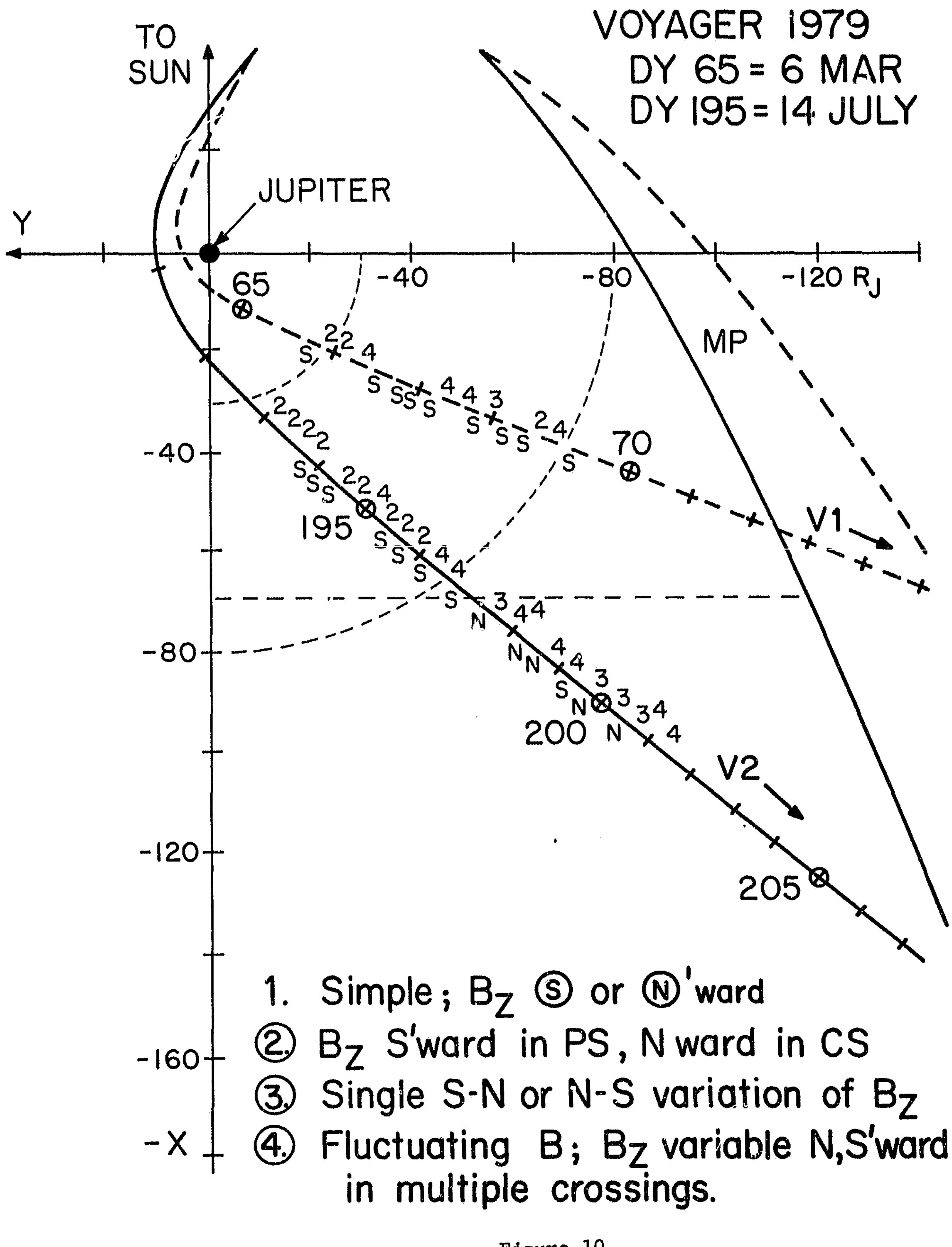

VOYAGER 1979
DY 65 = 6 MAR
DY 195 = 14 JULY
TO SUN
Y
JUPITER
-40
-80
-120 R_J
MP
65
70
V1
195
200
205
V2
-40
-80
-120
-160
-X
1. Simple; B_Z Ⓢ or Ⓝ'ward
② B_Z S'ward in PS, N ward in CS
③ Single S-N or N-S variation of B_Z
④ Fluctuating B; B_Z variable N,S'ward in multiple crossings.

Figure 10

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