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ON THE COMPLEX STATE OF THE INTERPLANETARY MEDIUM OF JULY 28-29, 1977

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ABSTRACT

Plasma and magnetic field variations observed on July 28-30, 1977, in the near-Earth solar wind are presented and discussed. Both a corotating stream and a driven shock are present. The driver gas seems to be enveloped in the rising speed phase of this stream; this appearance is attributed to a convoluted surface separating the two plasma domains. The magnetic field in the post shock flow (0030-1230 UT of July 29) has a large and geoeffective southward component at times; the energy coupling coefficient "ε" reaches $\sim 5.4 \times 10^{19}$ ergs/s. In the driver gas (1230 UT of July 29 to 0110 of July 30) the magnetic field is dominantly northward. The density and dynamic pressure decrease by almost two orders of magnitude ($\gtrsim$ 100 to $\lesssim$ 2 cm^{-3}) from just behind the interplanetary shock to $\sim$ 3 hours into the driver gas flow. The dominant magnetic field variation in the driver gas is modeled by a cloud-like structure. Significant plasma parameter variations within the driver gas are attributed to structure in the parent solar mass ejection event and to interplanetary kinematics.

INTRODUCTION

The solar wind flow which enveloped the Earth's magnetosphere on July 28-29, 1977, was very unusual in a number of aspects. The solar wind variations during this period and the magnetospheric response to these variations have been the subject of a Coordinated Data Analysis Workshop within the framework of the International Magnetospheric Study. This paper, which deals primarily with the interplanetary aspects of this event, is one of a series of related papers to result from that Workshop.

The objectives of this paper are: (1) to describe the disturbed solar wind flow in terms of temporal variations of basic interplanetary plasma and magnetic field parameters and of secondary parameters derived therefrom; and (2) to discuss some features of the interplanetary physics implicit in the data. The first objective is required not only in anticipation of the second, but also to provide the causal input functions needed by workers investigating the July 29 magnetospheric processes.

As will be seen, the interplanetary medium on July 29, 1977, is marked by a solar wind stream and associated interface, and by a shock and associated plug of driver gas. These features, which are related to differing solar sources, give rise to extreme density and pressure variations and to complex magnetic field structures which sometimes have strong and durable southward field components.

The paper addresses, in sequence: (1) salient characteristics of the spacecraft and experiments from which the data come; (2) construction of the data plots; (3) identification of the principal variations apparent in the data; (4) the stream associated and shock/driver gas associated phenomena responsible for the observed variations.

THE DATA SOURCES

The data used in this analysis come from the IMP-7 and IMP-8 spacecraft. On July 29, 1977, IMP-7 was $\sim 34\ R_E$ distant from the earth, near the noon meridian and $\sim 10\ R_E$ above the ecliptic plane; thus IMP-7 was well upstream of the average location of the Earth's bow shock (Fairfield, 1967). IMP-8 was at a similar distance from the earth, in the local time range 1820 to 2020, and $\sim 22\ R_E$ above the ecliptic plane. IMP-8 crossed the bow shock into the magnetosheath at 0638 UT on the 29th, reemerged into the solar wind during a data gap, went back into the magnetosheath at 1110 UT, and remained in the magnetosheath until at least 0600 of July 30. In this paper, data are plotted as functions of IMP-8 observing times, with appropriate time shifts being made in the data from the upstream IMP-7. For a 412 km/s solar wind flow, characteristic of most of the period of interest, the appropriate time shift is 10 min.

The principal data used are the IMP-8 magnetometer data (PI: N. F. Ness, GSFC) and the IMP-7 and IMP-8 plasma data from two instruments (PI: H. S. Bridge, MIT; PI: S. J. Bame, LASL). Much of the LASL data for this period has already been published by Gosling et al. (1980).

Other data sets examined in identifying boundary crossings are the IMP-8 electric field data (PI: T. L. Aggson, GSFC) and the IMP-7 and IMP-8 LEPEDEA data (PI: L. A. Frank, U. of Iowa). Energetic particle data sets considered in the study of relevant solar events are those of GSFC (PI: F. B. McDonald) and JHU/APL (PI: S. M. Krimigis). Hourly resolution profiles of selected plasma parameters and energetic particle fluxes may be found in Solar Geophysical Data (1978).

OBSERVATIONS

Figure 1 shows one hour resolution profiles of several plasma and magnetic field parameters taken over the interval July 28-July 31, while Figures 2 and 3 show the same parameters at five minute resolution for two periods of special interest. The plasma parameter profiles have been synthesized from the MIT and LASL IMP-7 and IMP-8 data sets, with concern for cross calibration.

Interplanetary magnetic field (IMF) profiles plotted for times when IMP-8 was in the magnetosheath show inferred values. We have used the assumptions that the IMF and magnetosheath field directions are the same, and that the sheath field intensity is twice that of the IMF intensity. The analysis of Behannon and Fairfield (1969) suggests that these are good assumptions at the IMP-8 local time at some reasonable distance from the magnetopause. At the least, we believe the magnetosheath field direction should give reliable inferences of IMF polarity and of the north-south character of the IMF.

In addition to the basic field and plasma parameters of Figures 1-3, interesting derived parameters are plotted in Figure 4, at 5-minute resolution for the period of greatest interest for magnetospheric response. These include the dynamic pressure associated with the bulk solar wind proton flow ($N_p m_p V^2$), the hydromagnetic (HM) pressure of the plasma ($B^2/8\pi$ + NkT; see below), the ratio of the thermal to magnetic pressures (i.e., β), and the energy coupling coefficient "ϵ". This latter is given by Perreault and Akasofu (1978) as $\epsilon = VB^2 \ell_o^2 \sin^4(\theta/2)$, where V = solar wind speed, B = IMF intensity, $\ell_o \lesssim 7 R_E$, and θ is the colatitude of the $(Y\text{-}Z)_{GSM}$ projection of the IMF vector. See Kan et al. (1980) for a discussion of the physical interpretation of ϵ in terms of a dynamo process.

Contributions from alpha particle fluxes were not included in the pressure determination for Figure 4. Gosling et al. (1980) show that over the period July 28 (2000 UT) - July 29 (1230 UT), the He^{++}/H^+ ratio is always < .07, rarely > .05, and typically $\sim$ 0.03. This ratio is enhanced at $\geq$ 1230 UT (July 29), with local maxima of .17 and .21 at $\sim$ 1300 and 1345 UT. Thus, through 1230 UT, the proton dynamic pressure may be an underestimate of the total dynamic pressure by $\sim$ 20% ($m_\alpha N_\alpha/m_p N_p$) or less. The right scale of the dynamic pressure (P) profile of Figure 4 shows the subsolar magnetopause distance (R_{MP}) calculated from the model of Formisano et al. (1979), i.e., R_{MP} (R_E) = .495 $P^{-1/6}$. Due to the sixth root dependence, a 20% underestimate in the total pressure yields only a $\sim$ 3% overestimate in the subsolar magnetopause distance. We note that the Formisano et al. proportionality factor, 0.495, is $\sim$ 10% less than that of the earlier analysis of Fairfield (1971) in which less data were available.

The hydromagnetic pressure (P_{HM}) is computed as $B^2/8\pi + N_p kT_p + N_e kT_e$. Electron density and temperature data are not available to us, so as approximations we take $N_e = N_p$ (change neutrality) and $T_e = 1.1 \times 10^{5}$°K before 0415 UT of July 29 and $T_e = 1.8 \times 10^{5}$°K thereafter. These are characteristic pre- and post-stream interface electron temperatures (Gosling et al., 1978). (Our later discussion identifies a stream interface at $\sim$ 0415 UT.) Figure 4 shows both the observed part of P_{HM}, i.e., $P_{HM}-N_e kT_e$, as well as P_{HM} itself. The values of β given in Figure 4 are defined as $(N_p kT_p + N_e kT_e)/(B^2/8\pi)$. The neglect of alpha particles here is not significant for our purposes.

ENUMERATION OF PRINCIPAL VARIATIONS

We now turn to a brief enumeration of the principal variations visible in Figures 1-4 (and in yet higher resolution data not shown). This enumeration provides solar wind input function information for studies of magnetospheric processes of July 29. Interpretation of these variations in terms of physical, interplanetary processes will be deferred until the next section.

As seen in Figure 1, proton density increases three-fold from 1200 UT of July 28 to 0000 UT of July 29. The IMF turns southward at 2330 UT of July 28. Then at 0030:45 UT of July 29 (vertical line "1" in Figures 1 and 2) the passage of an interplanetary shock causes the following increases: proton density from 30 to 100 cm^{-3}, flow speed from 330 to 410 km/s, temperature from 3.10^4 to $1.5.10^5$°K, and IMF intensity from 6 to 15 nT (1 nT = 1 nanotesla = 10^{-5} Gauss). There is only a minor field direction change at the shock but a significant northward turning two minutes later. Fine scale IMF data reveal that the IMF intensity jump occurred in $\leq$ 2.56 sec. Similarly fine scale plasma data are not available.

From 0030 to 0410 UT of July 29 the solar wind density is extraordinarily high, $\gtrsim$ 100 prot/cm^3. (Of 67,189 hours with density data in the 1963-1978 interplanetary medium compilation, only 8 have averaged densities above 75 prot/cm^3.) The high density gives a dynamic pressure which pushes the subsolar magnetopause in to the unusually low values of

5.9 to 6.3 R_E (cf. Figure 4). (See Knott et al., 1981, for a discussion of GEOS magnetopause observations after shock passage.) The IMF intensity and direction are highly variable. The β spike at 0330 UT (Figure 4) results from the IMF intensity decrease (Figure 2); hydromagnetic pressure balance is little affected since the dominant contribution on either side of 0330 UT is from the plasma. The ϵ function (Figure 4) shows a number of local maxima, with a peak for these hours of 2.4 x 10^{19} ergs/s at 0235 UT.

At 0415 UT (vertical line "2" in Figures 1 and 2) there is a significant drop in density and pressure which continues throughout hour 4. At $\sim$ 0413 UT there begins a significant increase in IMF intensity and a southward turning of the IMF. At 0425 UT, with the IMF vector steeply southward, the IMF polarity shifts from negative to positive. The field remains strong and southward for most of hour 4, which gives rise to the largest value of ϵ, $\sim 5.4 \cdot 10^{19}$ ergs/s, observed during this event. Integrating $\epsilon(t)$ over hour 4 yields a total energy of $1.2 \cdot 10^{23}$ ergs which was transferred from the solar wind to the magnetosphere during this hour. Note from Figure 4 that near 0415 UT the hydromagnetic pressure increases significantly in crossing from the plasma dominated regime to the $\beta \lesssim 1$ regime.

During the rest of the first half of July 29, there are unfortunately significant data gaps in the field data. However, it is clear that during hours 5-6, the IMF remains southward and ϵ remains at levels which are high but reduced relative to hour 4. During hours 9-11, ϵ is observed to be $\lesssim 1 \cdot 10^{19}$ ergs/s through 1110 UT, and then has an inferred peak of $\sim 3 \cdot 10^{19}$ ergs/s at 1135 UT. There are two dynamic pressure pulses ($\sim$ 0505 and $\sim$ 0800 UT) in an otherwise generally declining pressure profile. IMF data are not available to examine the $\sim$ 0800 UT dynamic pressure pulse for hydromagnetic pressure balance. The observed HM pressure (magnetic and proton components) across the 0505 UT pulse is nearly constant, suggesting equilibrium. However inclusion of a reasonable electron contribution suggests a pressure imbalance, such that this fluid element should be trying to expand in the plasma rest frame.

For the second half of July 29 (cf. Figure 3), the IMF, as inferred from magnetosheath observations made between 1400 and 2400 UT, is northward; this corresponds to low values of ϵ and very little energy transfer relative to the first half of the day.

The plasma data show a continuing density drop, a temperature depression, and the previously mentioned He^{++}/H^{+} enhancements during the 1230-1500 UT period (Gosling et al., 1980). Unfortunately the data are sparse for the 1500-1800 UT period. The limited available data (MIT) suggests that densities fell to very low values, perhaps $\lesssim 2$ cm^{-2}. When combined with the inferred IMF intensity of 12γ, we compute a large Alfvén speed and low Alfvén mach number ($\lesssim 2$) for the solar wind flow. These are the conditions under which the bow shock may recede upstream from the magnetopause by unusually large amounts (Spreiter et al., 1966), although there is no theory available to quantify the expected recession.

Although a somewhat enhanced noise level in the IMP-7 telemetry reception precluded continuous determination of bulk flow parameters for the hour 15-18 interval, the MIT energy channel at which the peak flux was being received could be determined nearly continuously (cf. MIT-CSR, 1978, for a discussion of the operation of this instrument.) For the two time periods 1503-1531 and 1659-1728 the peak flux appeared in channels which corresponded to bulk flows about 100 km/s lower than those of the surrounding and intervening times. It is tempting to suggest that in the deeply rarefied, high field flow (very low plasma β), the Earth's bow shock receded beyond the $X_{GSE} \approx 32\ R_E$ location of IMP-7. The IMP-7 LEPEDEA data of the University of Iowa, while too sparse to prove that a bow shock crossing occurred, are consistent with this inference (Ackerson, private communication, 1980). Very few prior observations of such distant bow shocks have been reported (Fairfield, 1971; Ipavich and Lepping, 1975).

We note in Figure 3 an abrupt transition at 1750 UT involving a 40 km/s drop in speed and a large but indeterminate density and pressure jump. The inferred IMF experiences a $\sim$ 40% intensity increase between 1750 and 1755 and a shift (at near constant high latitude angle) of azimuth angle from 135° to 270°. A geomagnetic sudden impulse was observed at this time.

Early in hour 1 of July 30 (vertical line "4" of Figures 1 and 3), the IMF vector moves through southerly inclinations from negative to positive polarity. This polarity is maintained until IMP-8 enters the magnetosphere hours later.

INTERPRETATION OF OBSERVATIONS

We now discuss the observations in terms of physical interplanetary processes. Here we follow a conceptual rather than chronological sequence. Our basic picture is one of a transient plug of gas, driving a shock, superposed on the increasing speed phase of a corotating solar wind stream.

The solar wind stream extends from the speed and density increases of July 28 ($\sim$ 1200 UT), through the peak speed of July 30, to August 3 when a much higher speed stream begins. The July 28 - August 2 range of speeds is characteristic of streams of the same phase of the prior solar cycle (cf. Gosling et al., 1972), although the duration from minimum to peak speed is somewhat longer and the densities considerably greater, in this stream.

That the stream is corotating is evident from the plots of King (1979), where generally similar speed structures are seen 27 days earlier and 27 days later. The source of this corotating stream is believed to be the first long lived ($\sim$ 6 months), low latitude coronal hole of solar cycle 21 (Sheeley and Harvey, 1978). This hole has positive magnetic polarity, as have most appearances of its associated stream. The IMF polarity of July 28 - August 2 is mixed; the significance of this is discussed subsequently.

The field and plasma changes of hour 4 of July 29 (cf. especially 0415-0425 UT; line "2" of Figures 1 and 2) mark the transition from that part of the "stream" which is really the preceding ambient plasma as compressed and accelerated by the following higher speed flow, to the faster material which has emanated from the coronal hole identified above. This identification is made on the basis of the density decrease, the change in flow direction from easterly to westerly, the IMF intensity increase, and the IMF polarity change to the positive values characteristic of the parent coronal hole. We refer to this transition as the stream interface (Belcher and Davis, 1971; Burlaga, 1974; Hundhausen and Burlaga, 1975; Gosling et al., 1978), although we note that the temperature increase usually very prominent in classical stream interfaces is not obvious early in hour 4. On this point we note that (1) passage of the shock through the interface may have disrupted the normal temperature signature, and (2) not all transitions into streams are accompanied by classical stream interfaces (Gosling et al., 1978).

It was shown in the preceding section that the hydromagnetic pressure increases across the stream interface. This implies that, in the solar wind frame, the interface is moving into the plasma ahead. Burlaga (1974) has pointed out that this process is one way tangential discontinuities can form in the solar wind.

We have estimated the direction of minimum variance in the IMF changes in the neighborhood of the interface, using the approach of Sonnerup and Cahill (1967). We have chosen the period 0345-0520 UT, during which the field vector makes a quasi-sinusoidal sweep of the GSE latitude range. For this period we find the minimum variance direction to be $\phi_{GSE} = 195°$, $\theta_{GSE} = 11°$. This indicates that the "extended boundary" between the stream proper and the material in front of it is nearly normal to the ecliptic.

We now shift our focus to the interplanetary shock and associated driver gas. Consider first the shock seen at IMP-8 at 0030 UT of July 29. The changes ($\sim 6°$ and $\sim 18°$) in flow and field directions are modest, although significant increases in density, speed, temperature, and IMF intensity (factors of 2.5, 1.25, 2.8, and 2.5, respectively) are registered, characteristic of a fast forward MHD shock (Burlaga, 1971). To within several degrees, the shock normal is determined to be $\hat{n} = -.98\ \hat{x} + .13\ \hat{y} + .15\ \hat{z}$ (in GSE coordinates); thus the shock appears to be coming from the southwest quadrant, about 12° off the radial direction. However, the large scale configuration of the shock cannot be reliably determined due to distortions caused by passage through the inhomogeneous stream medium (Heinemann and Siscoe, 1974; Hirshberg et al., 1974; Burlaga and Scudder, 1975). The shock speed parallel to the local normal is 450 km/s.

which is $\lesssim$ 50 km/s slower than the average for locally determined speeds of flare associated shocks at 1 AU (Chao and Lepping, 1974).

The driver gas responsible for the shock arrived at ~ 1230 UT July 29, as evidenced by a sharp temperature drop and He^{++}/H^{+} increase (Gosling et al., 1980). Of particular interest was the observation of significant fluxes of singly ionized helium from ~ 1315 to ~ 1430 UT suggesting a cool solar source of the driver gas and also magnetic shielding during coronal passage. Gosling et al. (1980) suggest an eruptive prominence as the cool source. It has been pointed out to us (Joselyn, private communication, 1980) that a filament extending ~ 60° in longitude and located at 50°-60° north latitude disappeared from the solar surface between 1055 UT of July 25 and 1142 UT of July 26. This event may be the eruptive prominence (a disappearing filament when viewed at the solar limb) responsible for the driver gas; if so, considerable latitudinal flow must be involved to have the observed ecliptic plane effect. (See also Joselyn and McIntosh, 1981, and references therein, for studies of eruptive prominence mass ejecta as causative of interplanetary shocks and geomagnetic storms.)

Protons with energies to 35 MeV were observed (Solar Geophysical Data, 1978) at 1 AU at a time (July 26) consistent with their having a solar source simultaneous with the solar source of the He^{+}-rich driver gas. (There is no obvious source flare for these 35 MeV protons.) A determination of possible relations between the sources of these two particle populations is interesting from a solar physics perspective but is beyond the scope of this paper.

The end of the driver gas is best identified in the IMF as inferred from IMP-8 magnetosheath field data. These data are available with only minor gaps from 1430 UT (two hours after driver gas passage began) to ~ 0330 UT of July 30. As illustrated in Figure 3, these data show the IMF swinging slowly from a positive polarity, low inclination state at 1430 UT, through a high inclination state, to a negative polarity, low inclination state by ~ 0030 UT of July 30. As determined by the Sonnerup-Cahill (1967) method, the minimum variance (MV) direction for this change, in GSE coordinates, is ϕ = 216°, θ = - 9°. This direction is well determined (e.g., the minimum-to-intermediate eigenvalue ratio is 7.7), and there is a negligibly small field component along the MV direction ($\langle |B_z| \rangle / \langle |B| \rangle \approx$ 0.067). Since the magnetic profile from $\lesssim$ 1430 UT (July 29) to $\sim$ 0110 UT (July 30) suggests a single structure, it is reasonable to associate the driver gas with this structure.

In a period of $\sim$ 15 minutes (0110-0125 UT) of July 30, the IMF swings through southerly inclination from negative to positive polarity. This change, whose minimum variance direction is virtually the same as for the preceding, much longer variation, probably marks the return to the positive polarity solar wind stream.

The tentatively identified interplanetary structure containing the driver gas thus extends from $\sim$ 1230 UT (July 29) through $\sim$ 0110 UT (July 30), which corresponds to a distance along the line of observation of about 1/8 of an AU.

As is apparent in Figure 3, there is considerable variability in the plasma parameters in this interplanetary structure. It is impossible with data taken along only one line through the structure to uniquely model all the maxima and minima in the plasma parameters. However, we show in Figure 5 a highly idealized and non-unique model which can explain some of the observed variability. This is a modification of the magnetic cloud configuration recently invoked by Burlaga et al. (1981).

Imagine a series of magnetic loops whose common axis has a latitudinal tilt but is otherwise nearly radial. Then as points A, B, and C (cf. Figure 5) convect past the earth, the IMF will appear to shift from low inclination, positive polarity, through high inclination, to low inclination, negative polarity; these changes match the observed IMF directional variations. In this scenario plasma parameter variations are likely to be primarily dependent upon the distance along the structure axis, reflecting both kinematical effects associated with velocity gradients and structure in the parent solar mass ejection event(s). (See Hildner, 1977, for a discussion of mass ejection event structure.)

Naturally occurring deviations from this ideal geometry would provide an explanation of some observed features. For instance, the density and IMF intensity increases at 1750 UT, where the IMF polarity reverses, suggest a pressure ridge which may shear the magnetic structure and cause the structure's equator to move across the observer. Also, low inclination fields could be present at low latitudes at the two ends of the structure; this would eliminate the need to posit entrance into, and exit from, the structure at its top and bottom. Finally, that the structure's minimum variance longitude is 216° (and not $\sim$ 180° as implied in Figure 5) may be accommodated by rotating the structure through 36° about $\hat{Z}_{GSE}$ and stretching it in the direction normal both to $\hat{Z}_{GSE}$ and to the minimum variance direction. This will permit the observer to stay in the region where IMF lines have a northward character.

Taken alone, the 0110-0125 UT transition back to positive IMF polarity falls into the category of "stand alone" current sheets separating regions of opposite magnetic polarity (Burlaga, 1968). However, that both the gradual 1230-0110 UT IMF structure and the rapid 0110-0125 UT variation have the same minimum variance direction suggests a close causal link between these features of disparate time scales. (It is possible that both features properly belong to one IMF structure and that their disparate time scales result not from true spatial asymmetry but from the unique orientation of the line of observation through the structure. Further pursuit of this point without additional data taken elsewhere in the structure is not likely to be fruitful.)

We next construct in Figure 6 an ecliptic plane projection showing the spatial relations, along the line of measurements, of the stream, shock, and driver gas previously discussed individually. The state of the interplanetary medium is frozen at 0000 UT (July 29). Non radial flow, likely to be significant, is not visible. We have constructed corotating stream lines by (1) subtracting the estimated effect of the shock and driver gas from the V (t; 1 AU) profile and (2) assuming radial, constant speed flow back to 0.25 AU. These stream lines are then carried back to the July 29 (0000 UT) longitude range of the parent coronal hole shown at 0.10 AU. (The 0.10 AU and 0.25 AU figures were chosen for illustrative purposes and have no physical content. The apparent asymmetry in divergence of flow is likely real.) The front of the interaction region, the interface, and the peak speed location are shown. The driver gas is shown from ∼ 1230 to ∼ 0100 UT (July 30), and the driven shock with its approximate orientation is also shown. It appears that the shock and the interface intersect a few degrees east of the Earth-sun line. However it is important to note that we have no data on the longitudinal extent of the driver gas or associated shock for this event. Finally, in Figure 6, we have sketched the ecliptic plane projections of the observed/inferred IMF vectors. Recall however, that especially near the middle of the 1230-0100 UT field structure, the field vectors are mostly northward rather than "outward" and "inward" in the ecliptic plane. There is no evidence in the IMP-8 magnetosheath data (available through hour 9 of July 30) or in IMF polarities inferred from high latitude ground magnetograms (and published monthly with 12 hour resolution in this Journal) that negative IMF polarities were encountered in the high speed stream after 0115 UT of July 30.

The most puzzling aspect of Figure 6 is the appearance of the driver gas within the solar wind stream's rising speed phase. Such a situation is hard to understand kinematically, for: (1) the front of the stream, being slower than the driver gas, cannot have overtaken the driver gas; (2) the driver gas, being slower than the peak of the stream, cannot have moved through the stream from behind; and (3) the driver gas is not likely to have emanated from the stream source.

There have been prior cases studied in which driver gas from one source (a flare) is contiguous to a high speed stream and wherein the driven shock propagates through the stream (Burlaga and Scudder, 1975). However, we know of no previous example in which the driver appears to be within the stream.

We believe we have an incursion from a non radial flow of the driver gas into the spatial domain of the stream, such that the envelopment of the driver gas by the stream which emerges from measurements along one dimension is in fact not realized in real three dimensional space.

Unfortunately we have neither definitive flow latitude measurements nor a definitive solar source location to associate with the driver gas. Figure 7 sketches a possible scenario. Note the similarity to Figure 5 of Burlaga and Scudder (1975). The principal difference is that we have added a convolution to the boundary between the corotating stream and shock driver gas. The easterly flow near the arrival of the driver gas and the westerly flow in the bulk of the driver gas are consistent with this scenario. However, we note that the flow is predominantly radial at 1 AU. Thus the principal development of the surface convolution probably occurred closer to the sun (where flows may be less radial) than to the Earth.

Figure 7 implies that the convolution is principally a longitudinal phenomenon, as if the driver gas source were to the west of the stream source. If the driver gas source were predominantly to the north of the stream source (consistent with the $\sim 50°$ north latitude event previously identified as a possible driver gas source), then the convolution would be mainly a latitudinal effect. Such an effect could be visualized by these modifications to Figure 7: (1) straighten the corotating stream; (2) remove the flow longitude arrows (3) consider as a meridional plane projection. If the surface convolution concept is correct, then the most likely situation is for both latitudinal and longitudinal effects to be important.

SUMMARY

We have described in some detail the temporal variations of interplanetary parameters shown in Figures 1-3 for July 28-30, 1977. This description was oriented towards investigators of the July 29 magnetospheric processes who needed to know interplanetary input conditions.

Then we discussed the variations from an interplanetary dynamics perspective. Central meridian passage of a stream-emitting coronal hole, a "hot" solar process responsible for 35 MeV protons, and a "cool" solar process responsible for significant He^{+} fluxes, all occurred during the July 25-26 period. These processes gave rise to a complex state of the interplanetary medium on July 28-30, with attendant geomagnetic effects.

We have interpreted the interplanetary variations as an interplanetary stream on whose rising speed phase is a plug of gas (probably from an eruptive prominence). This plug of gas drives an interplanetary shock; the shock and its driver are on opposite sides of the stream interface, which has many but not all of the classic interface signatures. An idealized model of the IMF structure containing the driver gas was presented.

Some of the key physical questions generated by this analysis are:

(1) How does the driver gas appear to be interior to the corotating stream? We have argued that we may not have a true envelopment by the stream but merely some convolution in the boundary between the non radial stream and driver gas flows which gives the appearance of envelopment along the one direction of measurement.

(2) In what sense is the IMF structure seen between ~ 1230 UT July 29 and ~ 0130 UT July 30 a "cloud?" What are the roles of solar mass ejection inhomogeneities and of interplanetary dynamics in generating the variability of plasma parameters within this structure?

(3) What is the relation, if any, between the hot and cool solar processes responsible for 35 MeV protons and singly ionized helium?

(4) What effect on a stream interface is expected when a shock passes through the interface?

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REFERENCES

Behannon, K. W., and D. F. Fairfield, Spatial variatins of the magnetosheath magnetic field, Planetary Space Sci., 17, 1803-1816, 1969.

Belcher, J. W., and L. R. Davis, Jr., Large-amplitude Alfvén waves in the interplanetary medium, 2, J. Geophys. Res., 76, 3534-3563, 1971.

Burlaga, L. F., Hydromagnetic waves and discontinuities in the solar wind, Space Sci. Rev., 12, 600-657, 1971.

Burlaga, L. F., Interplanetary stream interfaces, J. Geophys. Res., 79, 3717-3725, 1974.

Burlaga, L. F., and J. D. Scudder, Motion of shocks through interplanetary streams, J. Geophys. Res., 80, 4004-4010, 1975.

Burlaga, L. F., and L. Klein, Magnetic clouds in the solar wind, J. Geophys. Res., submitted, 1980.

Burton, R. K., R. L. McPherron, and C. T. Russell, An empirical relationship between interplanetary conditions and DST., J. Geophys. Res., 80, 4204-4214, 1975.

Chao, J. K., and R. P. Lepping, A correlative study of SSC's, interplanetary shocks, and solar activity, J. Geophys. Res., 79, 1799-1807, 1974.

Fairfield, D. H., Average and unusual locations of the Earth's magnetopause and bow shock, J. Geophys. Res., 76, 6700-6716, 1971.

Formisano, V., V. Domingo, and K. -P. Wenzel, The three-dimensional shape of the magnetopause, Planetary Space Sci., 27, 1137-1149, 1979.

Gosling, J. T., A. J. Hundhausen, V. Pizzo, and J. R. Asbridge, Compresssions and rarefactions in the solar wind: Vela 3, J. Geophys. Res., 77, 542-5454, 1972.

Gosling, J. T., J. R. Asbridge, S. J. Bame, and W. C. Feldman, Solar wind stream interfaces, J. Geophys. Res., 83, 1401-1412, 1978.

Gosling, J. T., J. R. Asbridge, S. J. Bame, W. C. Feldman, and R. D. Zwickl, Observations of large fluxes of He^{+} in the solar wind following an interplanetary shock, J. Geophys. Res., 85, 3431-3434, 1980.

Harvey, J. W., and N. R. Sheeley, Jr., Coronal holes and solar magnetic fields, Space Sci. Rev., 23, 139-158, 1979.

Heinemann, M. A., and G. L. Siscoe, Shapes of strong shock fronts in an inhomogeneous solar wind, J. Geophys. Res., 79, 1349-1355, 1974.

Hildner, E., Mass ejections from the solar corona into interplanetary space, in Study of Traveling Interplanetary Phenomena 1977, (eds. M. A. Shea, D. F. Smart, and S. T. Wu), D. Reidel, 3-21, 1977.

Hirshberg, J., Y. Nakagawa, and R. E. Wellck, Propagation of sudden disturbances through a nonhomogeneous solar wind, J. Geophys. Res., 79, 3726-3720, 1974.

Hundhausen, A. J., and L. F. Burlaga, A model for the origin of solar wind stream interfaces, J. Geophys. Res., 80, 1845-1848, 1975.

Ipavich, F. M., and R. P. Lepping, Analysis of the 31 October 1972 interplanetary shock wave and associated unusal phenomena, 14th Int. Cosmic Ray Conf., Proceedings, 5, 1829-1834, 1975.

Joselyn, T. A., and P. S. McIntosh, Disappearing solar filaments: a useful predictor of geomagnetic activity, J. Geophys. Res., in press, 1981.

Kan, J. R., L. C. Lee, and S. -I. Akasofu, The energy coupling function and the power generated by the solar wind--magnetosphere dynamo, Planetary Space Sci. 28, 823-825, 1980.

King, J. H., Interplanetary Medium Data Book, Supplement 1, NSSDC/WDC-A R & S 79-08, 1979.

Knott, K., D. Fairfield, A. Korth, and D. Young, Observations near the magnetopause at the onset of the July 29, 1977 sudden storm commencement, submitted to J. Geophys. Res., 1981.

MIT-CSR Technical Report 78-2, Description of the MIT Plasma Experiment on IMP 7/8, Center for Space Research, MIT, Cambridge, MA 02139, 1978.

Perreault, P., and S. -I. Akasofu, A study of geomagnetic storms, Geophys. J. Roy. Astron. Soc., 54, 547-573, 1978.

Sheeley, Jr., N. R., and J. W. Harvey, Coronal holes, solar wind streams, and geomagnetic activity during the new sunspot cycle, Solar Phys., 59, 159-173, 1978.

Solar Geophysical Data (Comprehensive Reports), 401(II), 19-24, January 1978.

Spreiter, J. R., A. L. Summers, and A. Y. Alksne, Hydromagnetic flow around the magnetosphere, Planetary Space Sci., 14, 223-253, 1966.

FIGURE CAPTIONS

FIGURE 1 Hourly averaged interplanentary plasma and magnetic field data for July 28-31, 1977. The parameters are, from top to bottom, proton density, proton temperature, bulk flow speed, flow azimuth angle (positive for flow from west of sun), IMF magnitude, and IMF latitude and longitude angles in geocentric solar magnetospheric coordinates. The IMF parameters past 1110 UT of July 29 are inferred from magnetosheath observations. The number-labeled vertical lines denote parameter value changes discussed in the text.

FIGURE 2 The same interplanetary plasma and magnetic field parameters as in Figure 1. The data are 5 min averages for the first 6 hours of July 29, 1977.

FIGURE 3 The same as Figure 2, but for the period 1200 UT (July 29) to 0200 UT (July 30). The IMF parameters are inferred from magnetosheath observations as discussed in the text.

FIGURE 4 Top panel: dynamic pressure ($N_p m_p V^2$); nonlinear scale on right shows resultant subsolar magnetopause distance; see text for discussion of alpha particle contribution. Second panel: lower trace is the measured part of the hydromagnetic (HM) pressure ($B^2/8\pi + N_p kT_p$); upper trace is measured HM pressure plus inferred electron pressure ($N_e kT_e$; see text for assumptions). Third panel: plasma β $(8\pi(N_p kT_e + N_e kT_e)/B^2)$. Bottom panel: the energy coupling coefficient ϵ.

FIGURE 5 A schematic of an interplanetary cloud capable of explaining the dominant variations in the driver gas regime.

FIGURE 6 Ecliptic plane projection of the state of interplanetary medium at 0000 UT of July 29 inferred from July 28-August 1 measurements. The vertical line represents the earth-sun line; the heavy dot denotes the Earth's location. The full curved lines represent ideal spiral IMF lines computed from the 1 AU speeds given near the end of each line; we assume the 370 km/s speed would have been observed where shown in the absence of the shock and driver gas; see text for discussion of the solar end of these field lines. The short arrows give the IMF polarity. The labels 1 through 5 denote, respectively: (1) the front edge of the region of ambient solar wind affected by the following stream; (2) the interplanetary shock; (3) the stream interface; (4) the driver gas; (5) the peak speed of the stream. The pictured closure of the driver gas volume (4) off the earth-sun line is merely intended to delimit this region in radial extent and has no physical content.

FIGURE 7 An idealized scenario for the relation of the corotating stream and driver gas. The vertical line denotes the earth-sun line, and the short arrows denote the flow longitude directions (at exaggerated inclinations relative to the vertical).

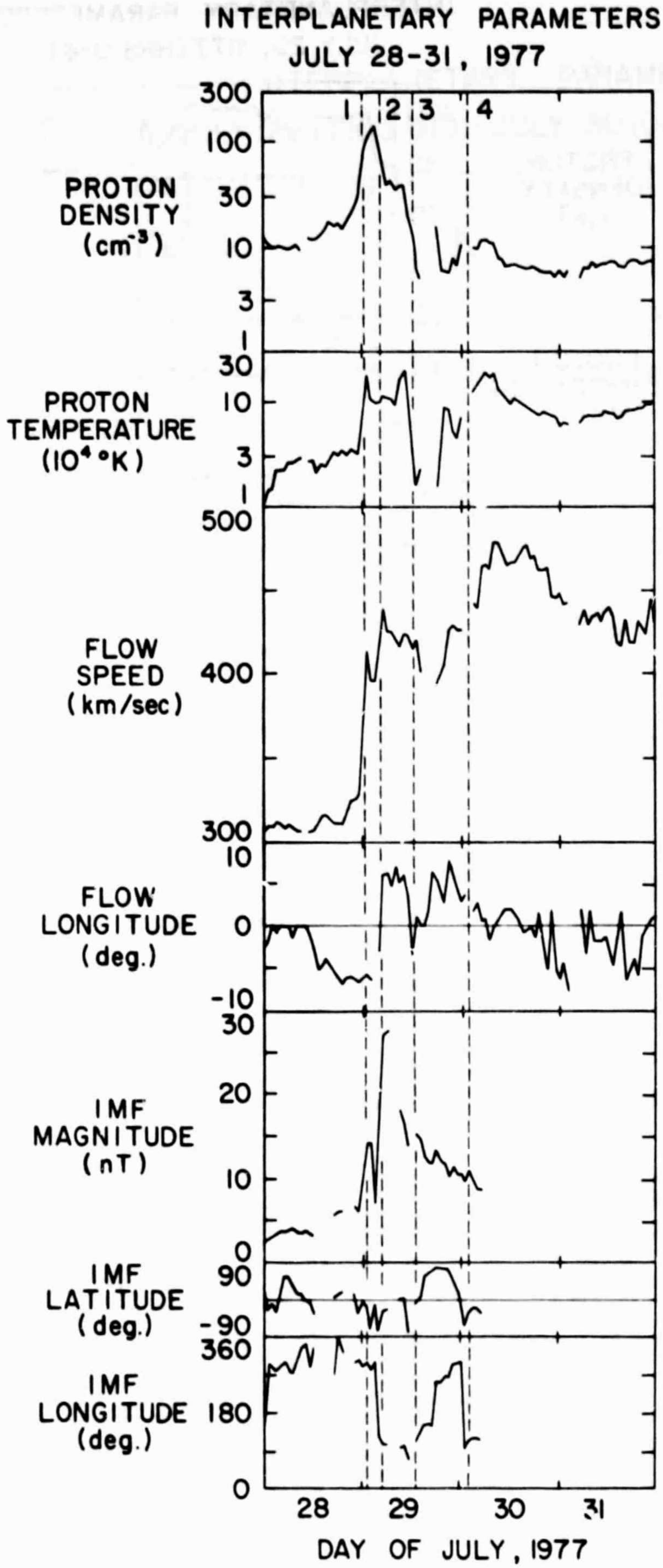
INTERPLANETARY PARAMETERS
JULY 28-31, 1977
1
2
3
4
PROTON DENSITY (cm^{-3})
300
100
30
10
3
1
PROTON TEMPERATURE (10^4 °K)
30
10
3
1
FLOW SPEED (km/sec)
500
400
300
FLOW LONGITUDE (deg.)
10
0
-10
IMF MAGNITUDE (nT)
30
20
10
0
IMF LATITUDE (deg.)
90
-90
IMF LONGITUDE (deg.)
360
180
0
28
29
30
31
DAY OF JULY, 1977

Figure 1

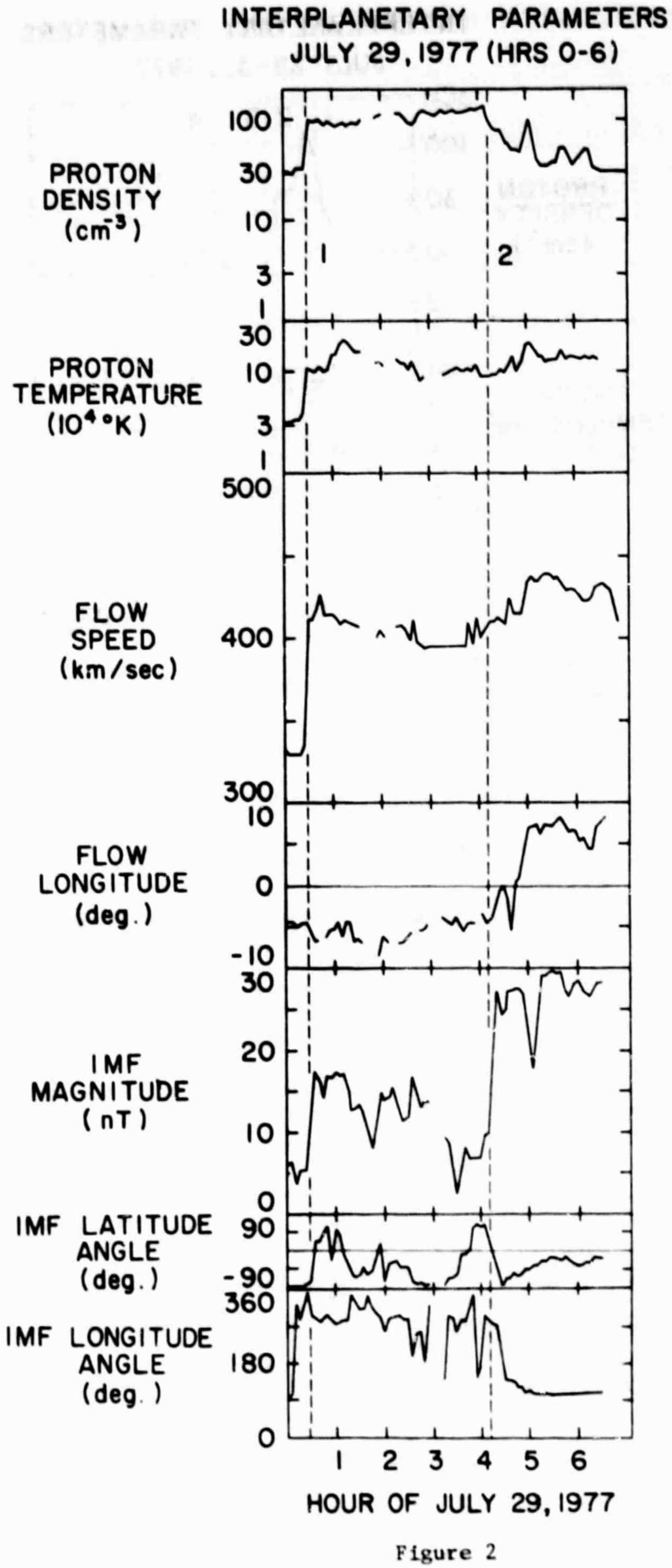
INTERPLANETARY PARAMETERS
JULY 29, 1977 (HRS 0-6)
PROTON DENSITY (cm⁻³)
100
30
10
3
1
1
2
PROTON TEMPERATURE (10^4 °K)
30
10
3
1
FLOW SPEED (km/sec)
500
400
300
FLOW LONGITUDE (deg.)
10
0
-10
IMF MAGNITUDE (nT)
30
20
10
0
IMF LATITUDE ANGLE (deg.)
90
-90
IMF LONGITUDE ANGLE (deg.)
360
180
0
1 2 3 4 5 6
HOUR OF JULY 29, 1977

Figure 2

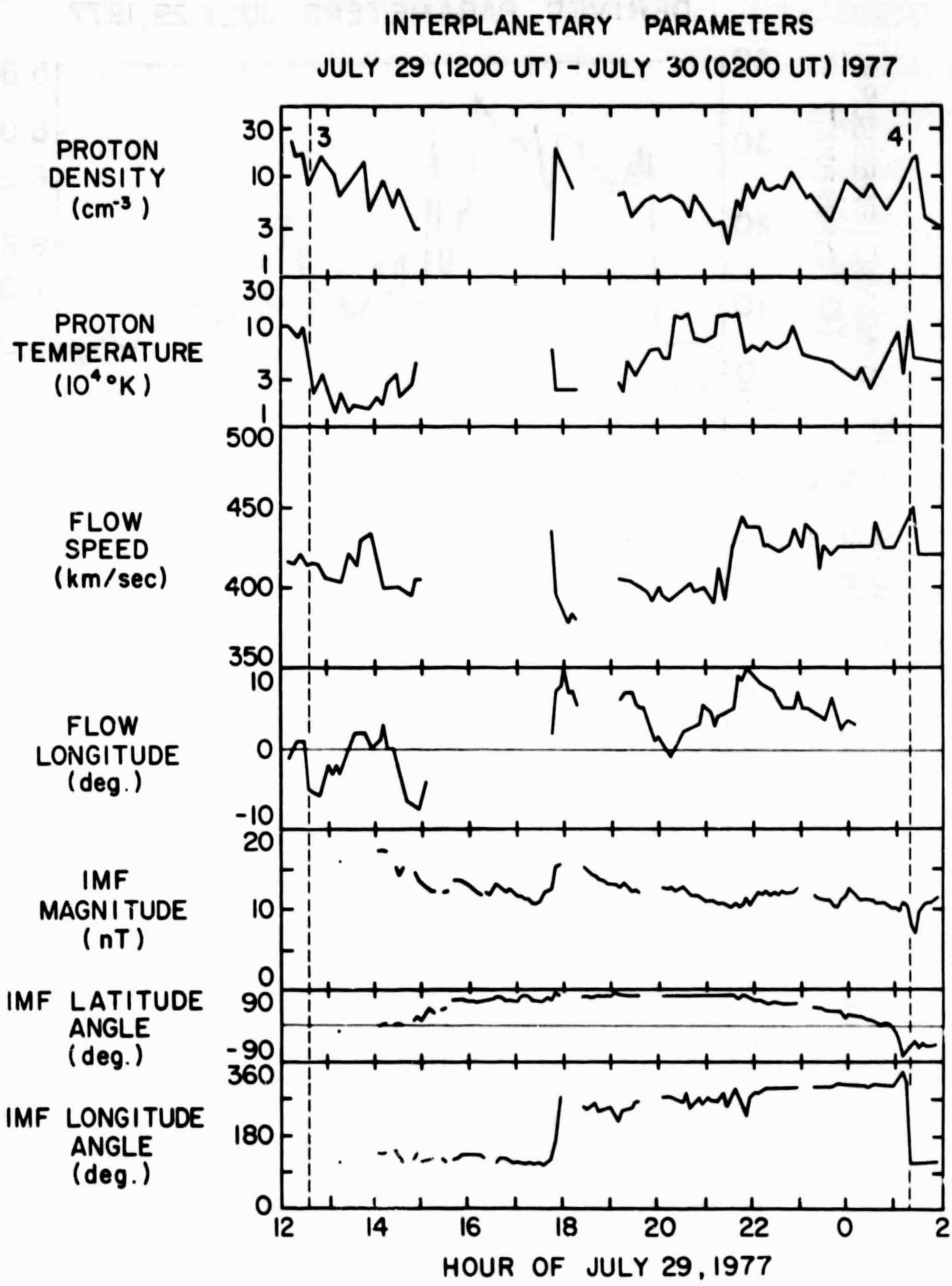
INTERPLANETARY PARAMETERS
JULY 29 (1200 UT) - JULY 30 (0200 UT) 1977
PROTON DENSITY (cm⁻³)
PROTON TEMPERATURE (10⁴ °K)
FLOW SPEED (km/sec)
FLOW LONGITUDE (deg.)
IMF MAGNITUDE (nT)
IMF LATITUDE ANGLE (deg.)
IMF LONGITUDE ANGLE (deg.)
HOUR OF JULY 29, 1977
3
4

Figure 3

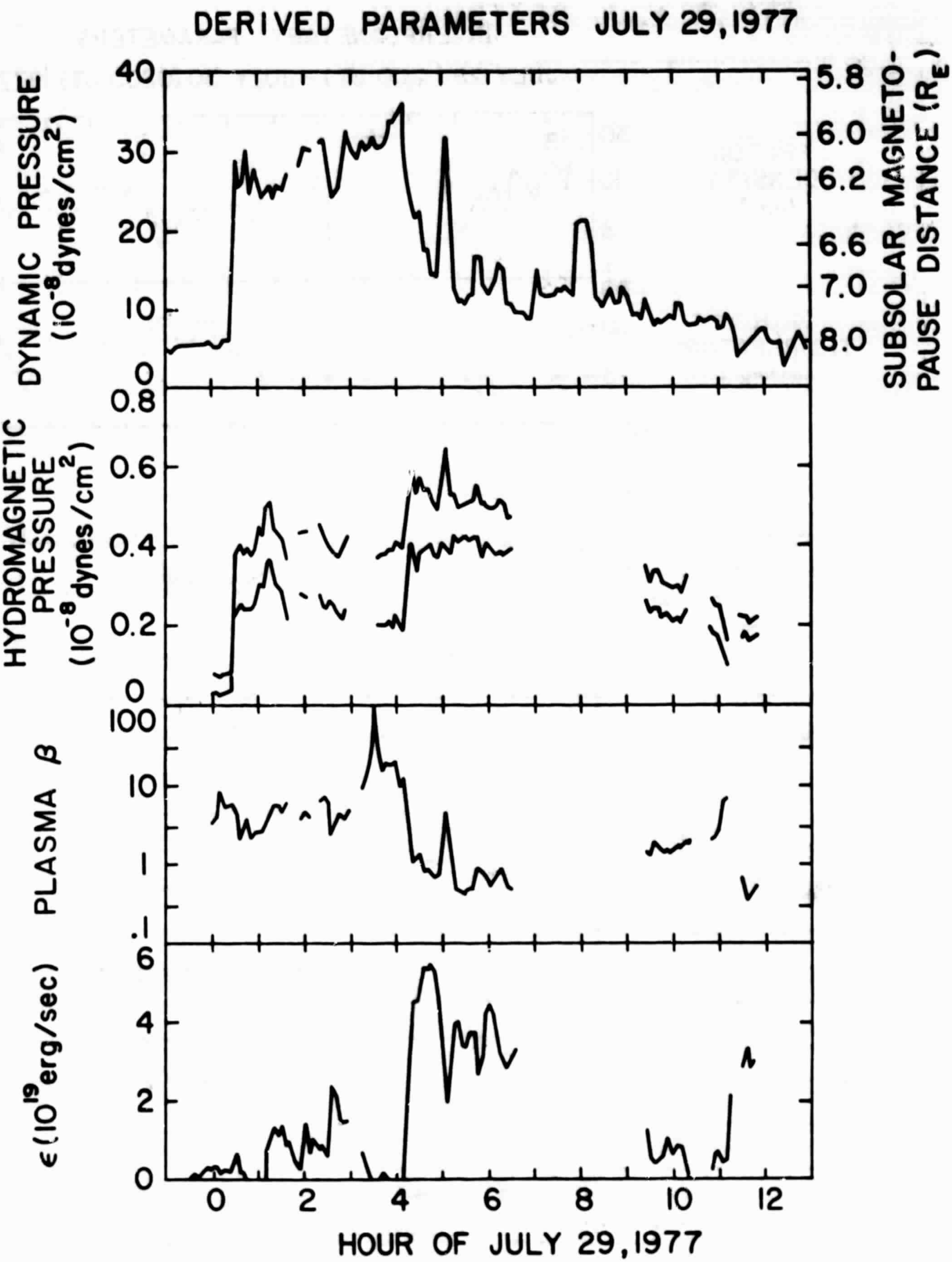
DERIVED PARAMETERS JULY 29, 1977
DYNAMIC PRESSURE
(10^-8 dynes/cm^2)
SUBSOLAR MAGNETOPAUSE DISTANCE (R_E)
40
30
20
10
0
5.8
6.0
6.2
6.6
7.0
8.0
HYDROMAGNETIC PRESSURE
(10^-8 dynes/cm^2)
0.8
0.6
0.4
0.2
0
PLASMA β
100
10
1
.1
ε (10^19 erg/sec)
6
4
2
0
0
2
4
6
8
10
12
HOUR OF JULY 29, 1977

Figure 4

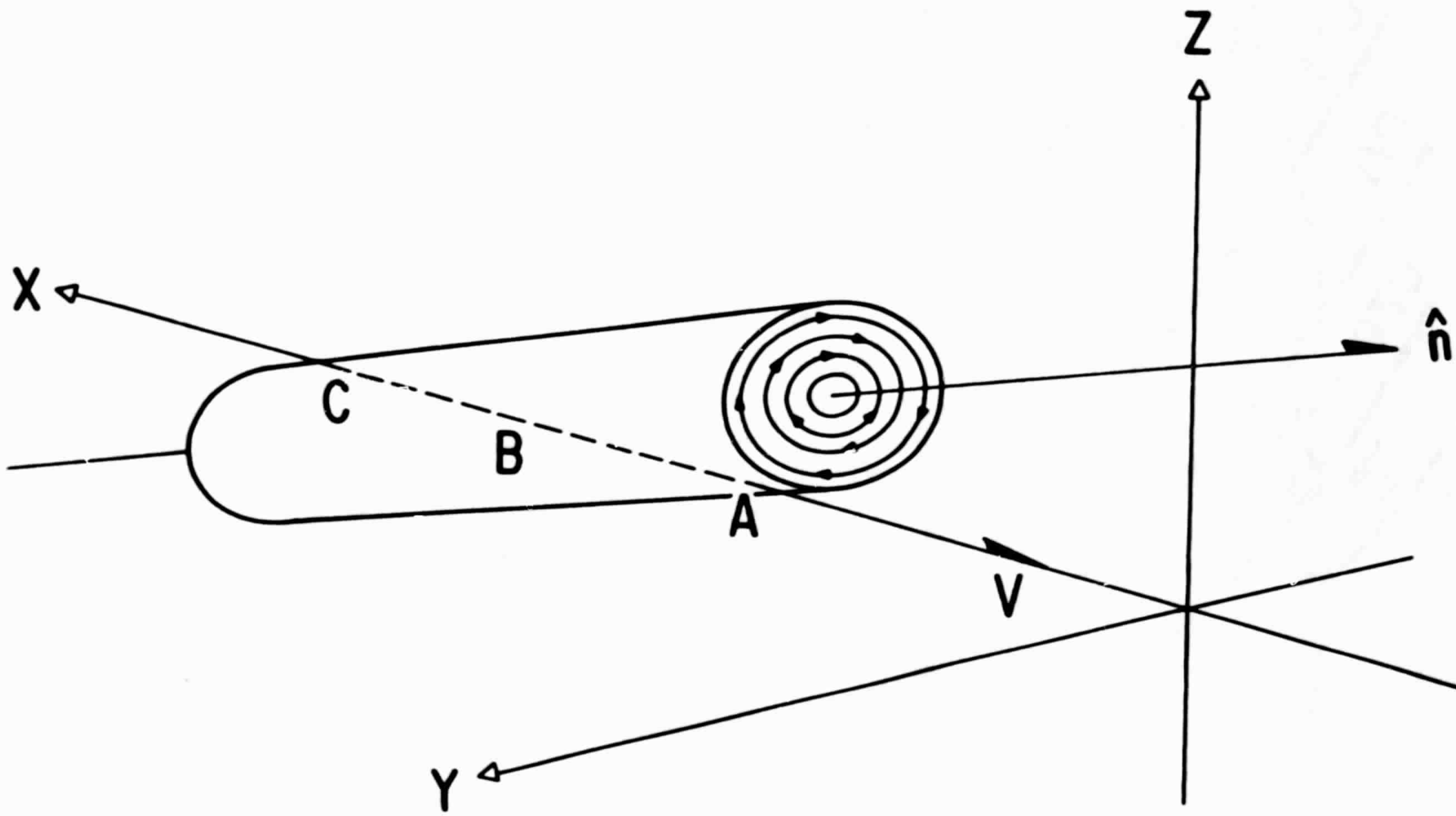

Figure 5

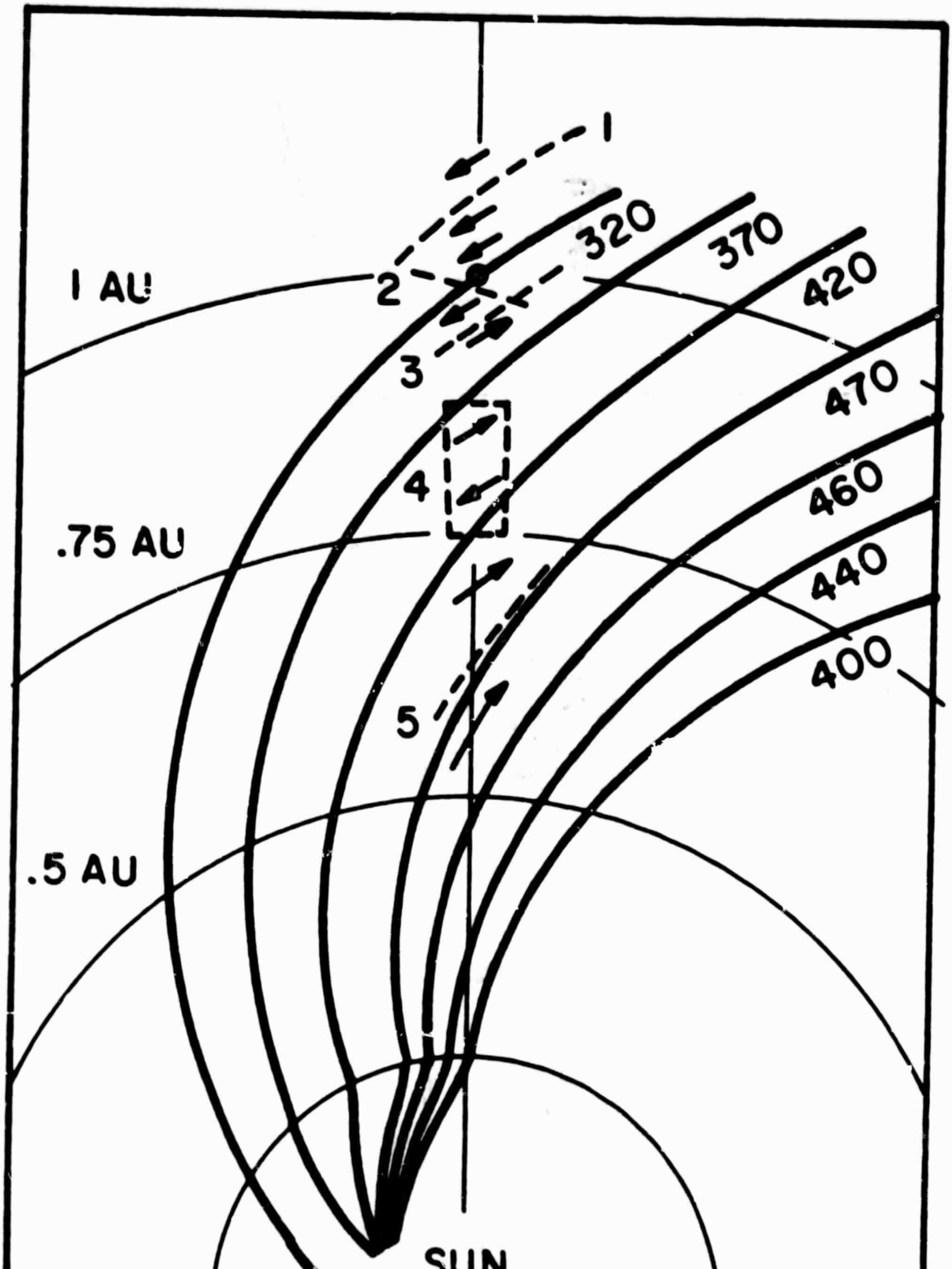

Figure 6

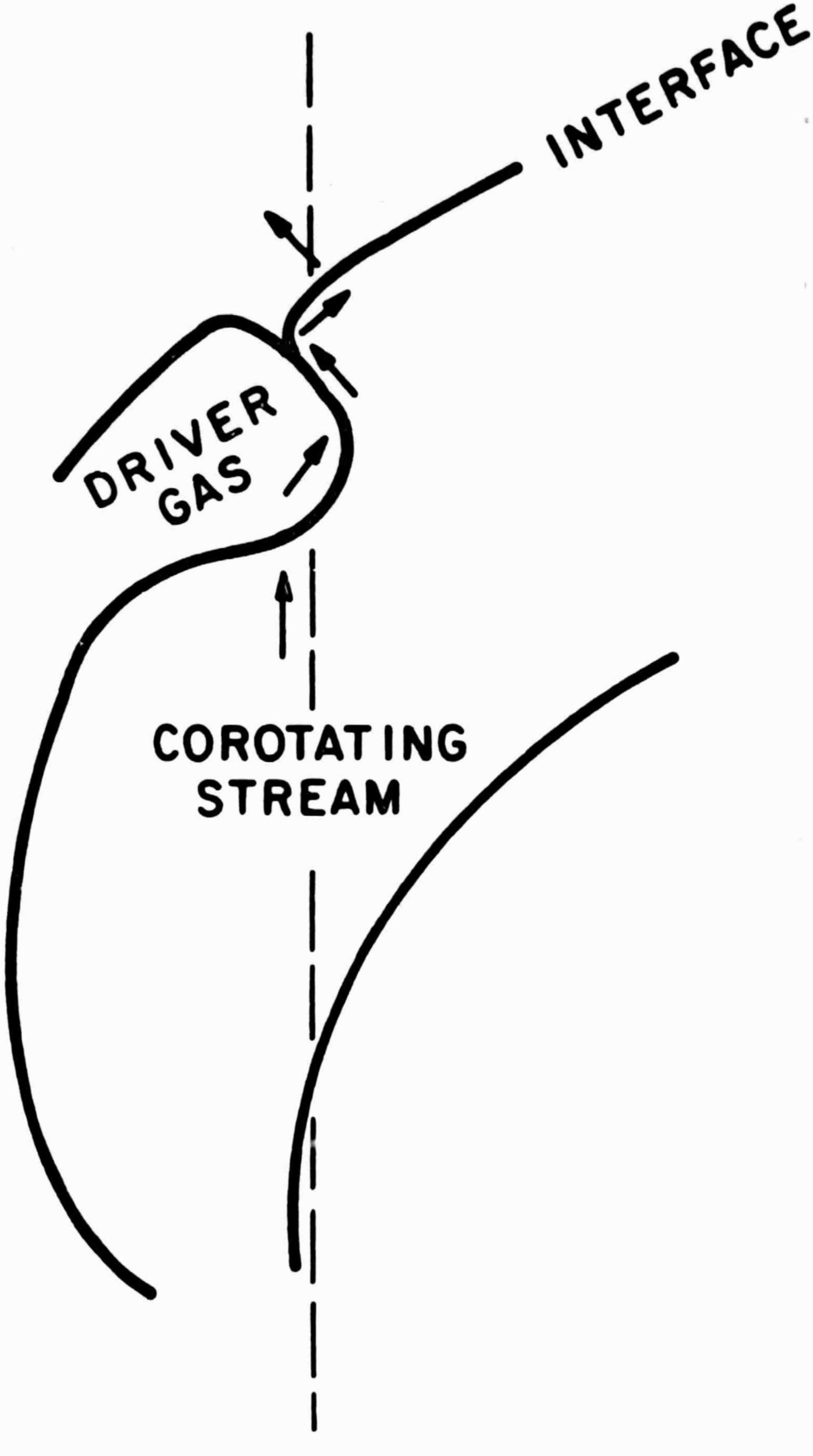

Figure 7