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Magnetic Fields, Plasmas, and Coronal Holes: The Inner Solar System

L. F. Burlaga

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Goddard Space Flight Center
Greenbelt, Maryland 20771

MAGNETIC FIELDS, PLASMAS, AND CORONAL HOLES:
THE INNER SOLAR SYSTEM

by

L. F. Burlaga
NASA/Goddard Space Flight Center
Laboratory for Extraterrestrial Physics
Greenbelt, MD 20771

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ABSTRACT

This paper reviews the recent results concerning streams and magnetic fields in the inner solar system. Specifically, it discusses in situ magnetic field and plasma observations within 1 AU which describe MHD stream flows and Alfvénic fluctuations, and it discusses the latest theories of those phenomena. Observationally, there have been significant advances in our understanding of streams and fluctuations as the result of acquiring nearly complete sets of high resolution plasma and magnetic data simultaneously at two or more points by IMPs 6, 7, and 8, Mariner-Venus-Mercury, HELIOS 1, and HELIOS 2. HELIOS and IMP observations and coronal hole observations demonstrated that streams can have very thin boundaries in latitude and longitude near the sun. This has necessitated a revision of earlier views of stream dynamics, for it is now clear that magnetic pressure is a major factor in the dynamics of stream in the inner solar system and that nonlinear phenomena are significant much closer to the sun than previously believed. Simultaneous IMP 6, 7, and 8 observations of Alfvénic fluctuations have shown that they are probably not simply transverse Alfvén waves; they suggest that Alfvénic fluctuations are better described as nonplanar, large-amplitude, "general Alfvén" waves moving through an inhomogeneous and "discontinuous" medium, and coupled to a compressive mode.

1. INTRODUCTION

During the last few years, new measurements of the interplanetary medium and sun have produced exciting and important changes in our knowledge of interplanetary phenomena. This review discusses two of these phenomena which are of fundamental importance for solar-terrestrial physics, viz., recurrent streams and "alfvénic fluctuations" within 1 AU. Due to space restrictions, only selected highlights are presented. No attempt was made to be comprehensive or to review work prior to 1975. For recent reviews of earlier work on streams, see Hundhausen (1972), Burlaga (1975), and Wu et al. (1977). Fluctations have recently been reviewed by Hollweg (1975a) Völk (1975) and Barnes (1978).

2. STREAMS

Prior to 1975, it was assumed that near the sun the velocity and temperature vary slowly with longitude (e.g., sinusoidally) and that streams steepen as they move away from the sun toward 1 AU. Indications that this might not be so first came from attempts to project speeds measured at 1 AU back to their source at the sun, using the assumption that a volume element moves at a constant speed through the interplanetary medium. Usually, this projection shows that material in the trailing part of a stream comes from a very small range of longitudes near the sun (Roelof and Krimigis, 1973; Lazarus, 1975).
Nolte et al. (1977) interpreted this as a sharp boundary of the stream near the sun, and they estimated that the width of the boundary in the high corona is 4^{o} to 6^{o}. The concept of a sharp boundary of a stream

near the sun is consistent with (and actually implied by) the idea that recurrent streams originate in coronal holes which themselves have very sharp boundaries (Pneuman, 1973; Krieger et al., 1973; Neupert and Pizzo, 1974; Krieger et al., 1974; Nolte et al., 1976, Hundhausen, 1978)

The first definitive evidence that streams have sharp boundaries near the sun came from the plasma observations of Rosenbauer and Schwenn made on HELIOS 1 as it moved from 1 AU to 0.3 AU. Figure 1 presents their observations of density (n), temperature (T), and speed (V) for two recurrent streams at (0.96 - 0.85) AU and at (0.54 - 0.31-0.43) AU two solar rotations later. This shows three basic results: 1) the streams are steeper near the sun, 2) the temperature profiles tend toward "mesa-like" structures as the sun is approached, and 3) the density profiles tend toward "inverse-mesa" structures near the sun (Rosenbauer et al., 1977). The large gradients in n, T, and V near 0.3 AU clearly indicate that the streams have relatively sharp boundaries there, and that the front of a stream (the "interaction region", Burlaga and Ogilvie, 1970) broadens as the stream moves away from the sun. The signature of the forward boundary--a decrease in density, increase in temperature, and an increase in speed--identifies it as a stream interface (Belcher and Davis, 1971; Burlaga, 1974; Burlaga, 1975).

The mesa-like profiles near 0.3 AU are shown in more detail in Figure 2 from Burlaga et al. (1978b), which includes magnetic field observations made by the Rome-GSFC magnetometer on HELIOS 1 and coronal hole observations made from the He 10830Å data by J. Harvey. The hot, narrow, low-density stream, A3, with negative magnetic polarity, apparently originated in a lobe of the south polar coronal hole in which the photospheric polarity was also predominantly negative. The mesa-like profiles are presumably the consequence of the sharpness of the boundaries of the coronal holes (these are determined to $\approx 10^{\circ}$ by the He 10830Å observations). No changes in magnetic polarity were observed near the stream, possibly because the coronal hole was in a larger "unipolar" region from which slow plasma was being emitted (Bohlin, 1976). The large, abrupt increase in speed at the front of A3 was evidently the result of a velocity shear. The speed changed by 350 km/s in 2° heliographic longitude. If the velocity shear were predominantly longitudinal, as suggested by the projection of the HELIOS trajectory over the coronal hole shown in Figure 2, then the shear is $\gtrsim$ 130 km/sec/deg at $\simeq$ 0.3 AU (Burlaga et al., 1978b). The shear at the rear boundary is found to be $\gtrsim$ 20 km/sec/deg at $\approx$ 0.3 AU. Burlaga et al. (1978b) attribute the difference in width of the front and rear boundaries to kinematic steepening between the sun and $\approx$ 0.3 AU, and they estimate that both of the boundaries had a width of $\approx 7.4^{\circ} \pm 4.5^{\circ}$ at $\approx 2.5\ R_{\odot}$. Assuming a longitudinal divergence factor of 3 between the lower corona and $2.5\ R_{\odot}$, they estimate that the width of the boundary at the coronal hole was $\approx 2.5^{\circ} \pm 1.5^{\circ}$. On the other hand, Gosling et al. (1978) argue that kinematic steepening may not occur near the sun, and they suggest that the width of the forward boundary (or interface) is generally much less than estimated by Burlaga et al. (1978b), i.e., they suggest that often the stream interface is a tangential discontinuity extending from the sun to $\gtrsim$ 1 AU. They do not provide any direct observations or calculations in support of this view, but it deserves to be considered further.

Figure 2 shows that HELIOS passed $\approx 15^{\circ}$ northward of the edge of the south polar coronal hole extension between March 15 and 17 but no fast stream was observed by HELIOS on HSR 3.26 to 3.31 in association with this hole. This implies that the latitudinal width of the northern boundary of the stream <u>between the sun and 0.35 AU</u> was $\leqslant 15^{\circ}$. By comparing HELIOS observations near 0.3 AU with IMP 7/8 observations at 1 AU, Schwenn *et al*. (1978) have shown that the latitudinal width of the northern boundary of the stream <u>between $\approx$ 0.3 AU and 1 AU</u> was $< 10^{\circ}$, corresponding to a latitudinal shear of $\geqslant$ 30 km/sec/deg in that region. These results are shown in Figure 3, where the stream under discussion is shown at $\approx 140^{\circ}$ on Carrington Rotation 1625. The stream observed by IMP 7, 8 is shown projected to the radial position of HELIOS using the constant speed assumption. The latitudinal gradient is demonstrated by the fact that the stream observed by IMP 7, 8 at -5° latitude is much broader than the stream observed at $+5^{\circ}$ latitude by HELIOS. The K-coronometer data in Figure 3 show a rather broad coronal hole beneath the stream--broader than the HELIOS stream itself. However, these observations are integral measurements of densities at $\approx 2.5\ R_{\odot}$, and while they show the presence of large, stable coronal holes, they cannot be used to define the coronal hole boundaries.

The evidence, then, is clear. Near the sun, streams can have sharp boundaries in which there are large velocity shears. These are the result of the sharp boundaries of the coronal holes which are their sources.

Rosenbauer *et al*. (1977) suggested several possible dynamical consequences of the large gradients near the sun: 1) The interaction regions will broaden rapidly near the sun because of the high magnetoacoustic speed there (which implies that the magnetic field plays an important role even in the region ≈ 0.3-0.5 AU, in contrast to earlier models; this was suggested again by Gosling et al., 1978). 2) MHD waves might be generated by the velocity shears. 3) Quasi-viscous interactions might be important in shear layers which are nearly parallel to the ecliptic. 4) Waves crossing the interface between fast and slow flows might exchange significant momentum with the flows. 5) Adjacent streams might interpenetrate near the shear layer.

The role of the magnetic field in the dynamics of stationary streams with large (but not discontinuous) longitudinal velocity gradients near the sun was evaluated quantitatively by Pizzo and Burlaga (1977), using a 2-dimensional, 1-fluid, MHD code. They took the inner boundary at 0.3 AU and they assumed the V, N, T, and flow angle (ϕ) profiles shown in Figure 4a. Note that the stream has a relatively thin shear layer (ΔV = 300 km/s in ~ 7° longitude), a high temperature, and a low density, approximating the mesa-like profiles described by Rosenbauer et al. (1977). The magnetic field intensity and the total pressure were assumed to be constant at 0.3 AU. The computed stream profiles at 1 AU are shown in Figure 4b. The stream steepens in transit to 1 AU, producing a thinner interface and a broad pressure pulse. The pressure pulse broadens rapidly near the sun because of the high magnetoacoustic speed there, thus delaying the formation of a shock pair which would develop if there were no magnetic field. The temperature is enhanced in the interaction region primarily by the compression but also as a result of the temperature profile at the inner boundary. Gosling et al. (1978) erroneously stated that such temperature enhancements in similar models (e.g., Hundhausen, 1973; Burlaga et al., 1971; and Hundhausen and Burlaga, 1975) are due to the assumed high temperature at the source. Their "alternate" explanation of the temperature jump is simply the inclusion of the effect of low densities in streams near the sun. (In the absence of measurements near the sun, most of the early models assumed constant density versus longitude.) When the density is lower in the stream, the pressure (nkT) is still increased by the tendency of the stream to steepen, but the energy is distributed among fewer particles and hence they are heated more than if the initial density profile were uniform at the source. This effect was discussed earlier by Siscoe (1976), Goldstein and Jokipii (1977) and Pizzo (1977), and it is implicit in the models of Burlaga et al. (1971) and Hundhausen and Burlaga (1975).

The dynamical evolution of a stream depends sensitively on conditions ahead of the stream, because the interaction depends on the relative momentum flux of the two flows. This was shown explicitly in simulations by Pizzo and Burlaga (1977). It is significant that the material ahead of the stream is usually relatively dense and thus has a high inertia (Belcher and Davis, 1971). These high-density regions are called NCDE's (non-compressive density enhancements) by Gosling et al. (1977). Burlaga et al. (1978b) have shown that some streams are preceded by regions of exceptionally high magnetic field intensity and low temperature. An example of one of these regions, called cold magnetic field enhancements (CME's) is shown in Figure 5. The origin of CME's is not known. They might be related to NCDE's, but the density is not always high in a CME, and the magnetic field intensity is not always high in an NCDE.

Although it has been shown that coronal holes produce high speed streams and that solar magnetic field lines are open in coronal holes, it does not follow that all recurrent flows originate in coronal holes. Levine (1978) (also see his review in this volume) has shown that open magnetic field lines also occur near separatrices in active regions. Those regions are potential sources of interplanetary plasma. Burlaga *et al.* (1978a) have shown examples of fast plasmas which were associated with open field lines on the sun, but not with coronal holes.

3. ALFVÉNIC FLUCTUATIONS IN STREAMS

The subject of interplanetary fluctuations is very complex, because there are several types of fluctuations which can occur in many combinations and interact in numerous ways. Observations from one spacecraft are generally insufficient to identify all the modes that are present. Coleman (1966, 1967) and Belcher and Davis (1971) observed that fluctuations in solar wind velocity are often correlated with fluctuations in the magnetic field, with a preferred phase and with relatively little change in magnetic field intensity and density. Belcher and Davis (1971) introduced the useful term "Alfvénic fluctuations" to describe these disturbances, because they have some characteristics in common with linear Alfvén waves. Their amplitude is usually not small, however (e.g. Belcher *et al.*, 1969; Burlaga and Turner, 1976). Large amplitude Alfvén waves were first discussed by Walen (1944a, 1944b) and were reviewed by Alfvén and Falthamer (1963). The theory of plane, non-linear

Alfvén waves was recently developed in some important papers by Barnes and Hollweg (1974), Barnes and Suffolk (1971), and Barnes (1976). They identified an exact solution of the compressible MHD equations which they called the "transverse Alfvén wave", and they suggested that Alfvénic fluctuations can be regarded as transverse Alfvén waves to good approximation.

A plane transverse Alfvén wave has the following properties:

(1) $\delta \underset{\sim}{V} = A\, \delta \underset{\sim}{B}$;

(2) $A \equiv V_A/B_o$, where V_A is the Alfven speed, and B_o is the unperturbed magnetic field intensity;

(3) $\delta \underset{\sim}{B}(t)$ fluctuates parallel to a plane;

(4) Planarity implies that the wave is one-dimensional, $\delta \underset{\sim}{B} = \delta B(x - V_A t)$. The $\hat{k}$ vector is normal to $\delta \underset{\sim}{B}$ and it is parallel to the minimum variance direction, $\hat{\lambda}_{min}$, of $\delta \underset{\sim}{B}(t)$. $\hat{\lambda}_{min}$ does not change in the directions normal to $\hat{k}$.

(5) $|\underset{\sim}{B}|$ is constant in the wave, $\delta|\underset{\sim}{B}|/B_o = 0$.

WKB calculations predict the following additional properties of plane transverse Alfvén waves in the solar wind:

(6) $|\delta \underset{\sim}{B}(r)| \sim \rho^{\frac{1}{4}}(r)\ [V/V_A \cos \varphi) \pm 1]^{-1}\ \xi^{-3/4} \approx r^{-3/2}$, where ρ is the solar wind density and ξ is a function of the temperature anisotropy (Whang, 1973; Barnes and Hollweg, 1974; Hollweg, 1975a; Barnes (1978); Jacques (1977).

(7) In the absence of velocity gradients, $\hat{k}$ (and $\hat{\lambda}_{min}$) will lie close to the radial direction at 1 AU (Barnes, 1969; Vӧlk and Alpers, 1973).

(8) At the front of a stream, $\hat{k}$ will point toward the west of the earth-sun line, and at the rear of the stream, $\hat{k}$ will point toward the east (Barnes and Hollweg, 1974; Hollweg, 1975b; Richter and Olbers, 1974; Richter, 1975).

Now let us consider how recent observations of Alfvénic fluctuations compare with the theoretical properties of transverse Alfvén waves listed above.

(1') Alfvénic fluctuations are defined as fluctuations for which $\delta \underset{\sim}{V}$ is highly correlated with $\delta \underset{\sim}{B}$ (correlation coefficient $\rho \gtrsim 0.6$ or ≥ 0.8). However, this is not a sufficient condition for Alfvén waves. In fact tangential discontinuities and other convected structures can occur among Alfvénic fluctuations, i.e., Alfvénic fluctuations are not necessarily just Alfvén waves. This is demonstrated in Figure 6 which shows a train of Alfvénic fluctuations containing several discontinuities (vertical lines) that were shown to be tangential by a minimum variance analysis of accurate, high resolution data (Burlaga et al., 1977). Denskat and Burlaga (1977) have also identified convected structures among Alfvénic fluctuations, using measurements of the time delay of discontinuities passing between two spacecraft. Similar results for higher frequency fluctuations were obtained by Neugebauer et al. (1978). The occurrence of convected structures among Alfvénic fluctuations might be the result of Alfvén waves moving through an ensemble of stationary structures. In any case, it is clear that Alfvénic fluctuations are not necessarily just Alfvén waves.

(2') It is generally found that A is $\approx V_A/B_o$ on average, but there is scatter about this value which is not fully explained.

(3') Condition (3) is a fundamental characteristic of transverse Alfvén waves. This is approximately satisfied locally, in the sense that measurements of $\delta\underset{\sim}{B}(t)$ do tend to lie near a plane perpendicular to $\underset{\sim}{\bar{B}}$. Nevertheless, Burlaga and Turner (1976) found that there is a measurable fluctuation along $\hat{\lambda}_{min}$, $\delta B_n/\bar{B} \approx 0.08$. Sari and Valley (1976), Sari and Behannon (1978) and Neugebauer et al. (1978) likewise found fluctuations parallel to $\hat{\lambda}_{min}$ and $\underset{\sim}{\bar{B}}$. Furthermore, Sari and Behannon (1978) found that $\delta\underset{\sim}{B}_{\parallel}$ along $\underset{\sim}{B}_o$ is correlated with $\delta B_{\perp}$ normal to $\underset{\sim}{B}_o$ (Figure 7).

(4') If Alfvénic fluctuations are plane waves, then the normal $\hat{n}$ determined from the time for the fluctuations to be convected between two spacecraft should be the same as the normal $\hat{\lambda}_{min}$ determined by the minimum variance method from data obtained at one spacecraft. Denskat and Burlaga (1977) found that this was not the case for Alfvénic fluctuations observed by two spacecraft separated by a distance L $\approx$ (20 to 70) $R_{\oplus}$; i.e., they concluded that Alfvénic fluctuations are not necessarily plane waves on a scale of $\approx 50\ R_{\oplus}$ (Figure 8 bottom).

(5') $|\underset{\sim}{B}|$ is not constant in Alfvénic fluctuations. Burlaga and Turner (1976) found that $\frac{\delta B}{B} \approx 0.06$ for Alfvénic fluctions in 15 min. intervals. This is a small change, but it is real. Sari and Valley (1976) and Sari and Behannon (1978), and Neugebauer et al. (1978) found significant fluctuations in $|\underset{\sim}{B}|$ with cross-spectra consistent with the presence of magnetoacoustic modes during most of the "Alfvénic" periods that they examined. Since magnetoacoustic waves are expected to damp quickly, even a small δB perturbation might indicate a significant transfer of energy. The cause of the δB perturbations is not known, but one possibility is that it results from the decay of nonlinear Alfvén waves (Goldstein, 1978).

(6') The radial variation of the amplitude of Alfvénic fluctuations has been investigated by Belcher and Burchsted (1974) (between 0.7 AU and 1.6 AU), by Behannon (1978) (between 1 AU and 0.46 AU), and by Mariani et al. (1978) (between 1 AU and 0.3 AU). All of the results are consistent with the predictions for transverse Alfvén waves given by (6) above. However, the same formula holds for more general Alfvén waves (Whang, 1973). Furthermore, Mariani et al. (1978) found that the fluctuations in slow flows, which are presumably not Alfvén waves, also satisfy (6) (Figure 9). We conclude that while the observations show a radial variation for the intensity of Alfvénic fluctuations which is consistent with the predictions for plane transverse Alfvén waves, this does not imply that they necessarily are plane transverse Alfvén waves.

(7') The minimum variance direction, $\hat{\lambda}_m$, is generally found to be close to the mean field direction at 1 AU, i.e., it tends to be close to the average field direction rather than to the radial direction. Solodyna and Belcher (1976) have shown that this is true of all fluctuations in the Mariner 5 data that they examined, including the Alfvénic fluctuations (Figure 10). Denskat and Burlaga (1977), using observations from two spacecraft to determine phase found that in most cases the phase direction was not consistent with $\hat{k}$ parallel to the radial direction, $\hat{x}$ (Figure 8 top).

(8') Solodyna and Belcher (1976), Figure 10, and Burlaga and Turner (1976) found no tendency for the most probable value of $\hat{\lambda}_{min}$ to be oriented differently in the leading and trailing parts of streams. In all cases, $\hat{\lambda}_{min}$ was nearly parallel to $\underset{\sim}{B}_o$. Denskat and Burlaga found that generally the normal to the phase plane was not normal to $\underset{\sim}{B}_o$ (Figure 8, middle).

We conclude that the theory of plane transverse Alfvén waves does not account for several observed properties of Alfvénic fluctuations (viz., (1'), (3'), (4'), (5'), (7'), and (8')), and it is not a unique explanation of the other observed properties of Alfvénic fluctuations ((2') and (6')). Clearly, more general concepts are needed to explain the observed characteristics of Alfvénic fluctuations.

Whang (1973) and Goldstein et al. (1974) have shown that large amplitude Alfvén waves need not be plane transverse waves. In particular, they showed that there exist large-amplitude fluctuations with $\delta\underset{\sim}{V} = (V_A/B_o)\ \delta\underset{\sim}{B}$ and $|\underset{\sim}{B}|$ = constant which satisfy a linear wave equation. These "general" Alfvén waves have a large amplitude, but they are nevertheless linear. Wave packets can be formed by linear superposition of waves moving in one direction, because all Alfvén waves propagate at the same speed and along $\underset{\sim}{B}_o$. The perturbation vector, $\delta\underset{\sim}{B}$, of a general Alfvén wave moves on the sphere $|\underset{\sim}{B}|$ = constant. (A transverse Alfvén wave is the special case when the perturbation vector moves on a great circle of this sphere.) Thus, $\delta\underset{\sim}{B}_{||}$ along $\underset{\sim}{B}_o$ need not be zero, and it will be correlated with $\delta B_{\perp}$, as observed ((3') above). It is possible that locally the waves are nearly traverse with $\delta\underset{\sim}{B}$ nearly normal to $\underset{\sim}{B}_o$, but that they are not plane waves. Then $\delta\underset{\sim}{B}(t)$ fluctuates in one plane of one point and in a different plane of another point. The observation that tangential discontinuities exist among Alfvénic fluctuations can be explained as the result of general Alfvén waves moving through an inhomogeneous magnetic field. The observations that $|B| \neq$ constant and that $\delta|\underset{\sim}{B}|$ is correlated with $\delta B_{\perp}$ suggest the presence of a compressive mode. This might be the result of the decay of Alfvén waves (Goldstein, 1978), but this hypothesis must be examined further and other explanations should be considered.

In conclusion, the observations suggest that Alfvénic fluctuations are nonplanar Alfvén waves moving through an inhomogeneous and/or "discontinuous" medium and possibly coupled to a compressive mode. Of course, this view must be developed more quantitatively and tested against new observations, just as was done for plane transverse Alfvén waves. Hopefully this will be equally fruitful and exciting.

4. SUMMARY

Recent observations have shown that streams are bounded by thin shear layers within 1 AU, probably because they originate in coronal holes which have sharp boundaries. This has a number of dynamical implications which must be explored.

The properties of Alfvénic fluctuations in streams cannot be fully explained on the hypothesis that they are plane, transverse Alfvén waves. A more complete and accurate description might be that they represent nonplanar, "general Alfvén waves" weakly coupled to a compressive mode and moving through a medium containing tangential discontinuities and other convected inhomogeneities. These concepts must be examined more thoroughly both theoretically and observationally.

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FIGURE CAPTIONS

Figure 1 HELIOS 1 observations of streams near 0.9 AU and 0.4 AU.

Figure 2 HELIOS 1 observations of a stream (A3) and magnetic fields near 0.3 AU, and a map of coronal holes.

Figure 3 IMP observations at -5° latitude (projected to ≈ 0.3 AU) and HELIOS observations at $+5^{\circ}$ latitude, showing the existence of large latitudinal gradients in a stream between 0.3 AU and 1 AU.

Figure 4 A 1-fluid, 2-dimensional MFD model of a stream with steep boundaries at 0.3 AU. The inner boundary conditions are shown in the left panel. The calculated variations at 1 AU are shown in the right panel.

Figure 5 A cold magnetic enhancement in front of a recurrent stream.

Figure 6 Alfvénic fluctuations containing several tangential discontinuities (vertical lines).

Figure 7 General Alfvén waves. Fluctuations perpendicular to $\langle \underset{\sim}{B} \rangle$ are correlated with non-zero fluctuations along $\langle \underset{\sim}{B} \rangle$. In some cases there are correlated fluctions in $|\underset{\sim}{B}|$ as well, suggesting some coupling to a compressive mode.

Figure 8	Top: The phase plane normal, projected in the ecliptic, $\hat{n}$, with respect to the radial direction, $\hat{x}$; middle: $\hat{n}$ with respect to the magnetic field; bottom: $\hat{n}$ with respect to the minimum variance direction.
Figure 9	HELIOS 1 observations of the variance σ^2 over 3-hour intervals versus r between 1 AU and 0.3 AU for high speeds and low speeds.
Figure 10	The minimum variance direction for Alfvénic fluctuations in Mariner 5 data.

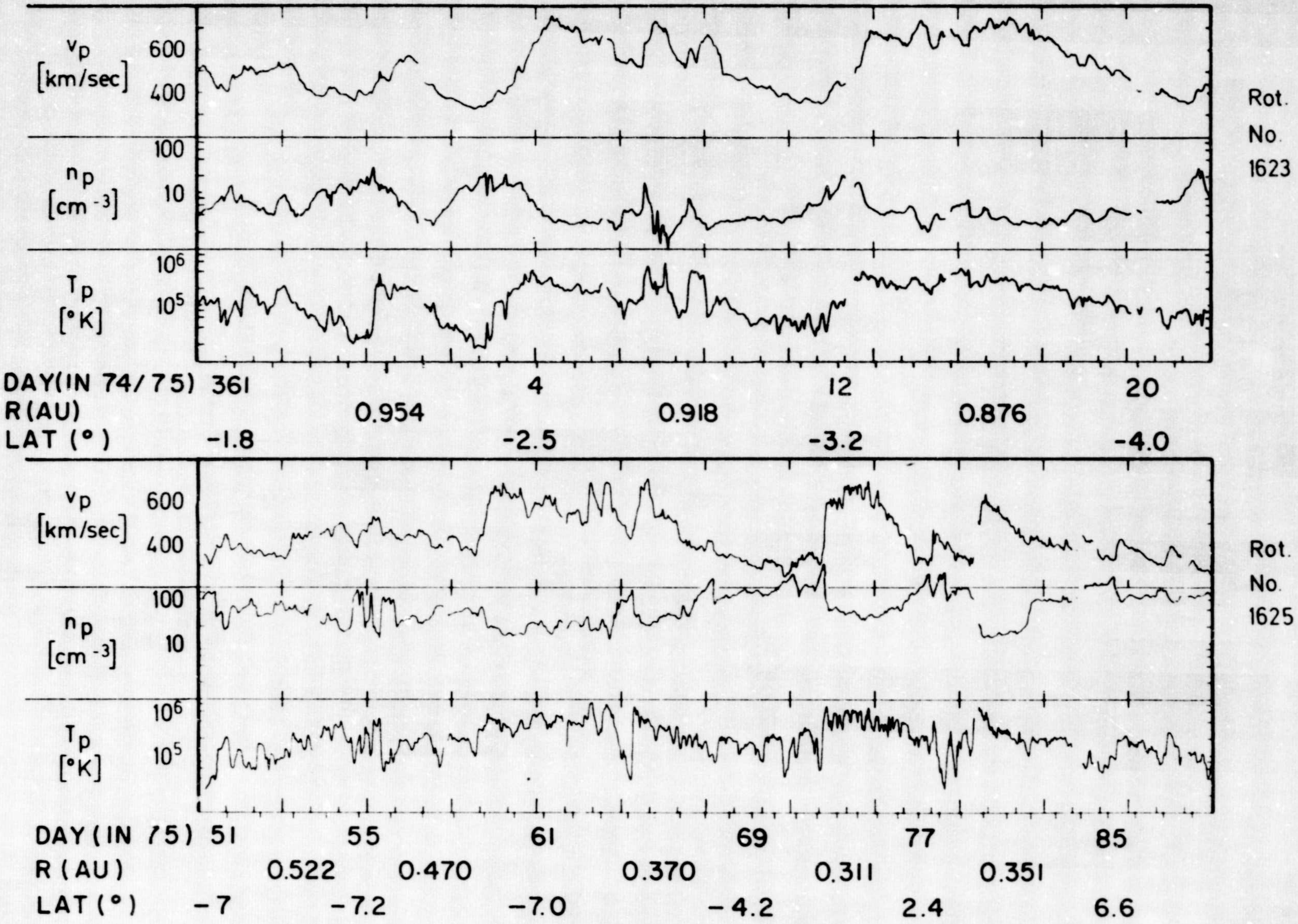

vp [km/sec]
600
400
np [cm-3]
100
10
Tp [°K]
10^6
10^5
DAY(IN 74/75) 361 4 12 20
R(AU) 0.954 0.918 0.876
LAT (°) -1.8 -2.5 -3.2 -4.0
Rot. No. 1623
vp [km/sec]
600
400
np [cm-3]
100
10
Tp [°K]
10^6
10^5
DAY(IN 75) 51 55 61 69 77 85
R (AU) 0.522 0.470 0.370 0.311 0.351
LAT(°) -7 -7.2 -7.0 -4.2 2.4 6.6
Rot. No. 1625

Figure 1

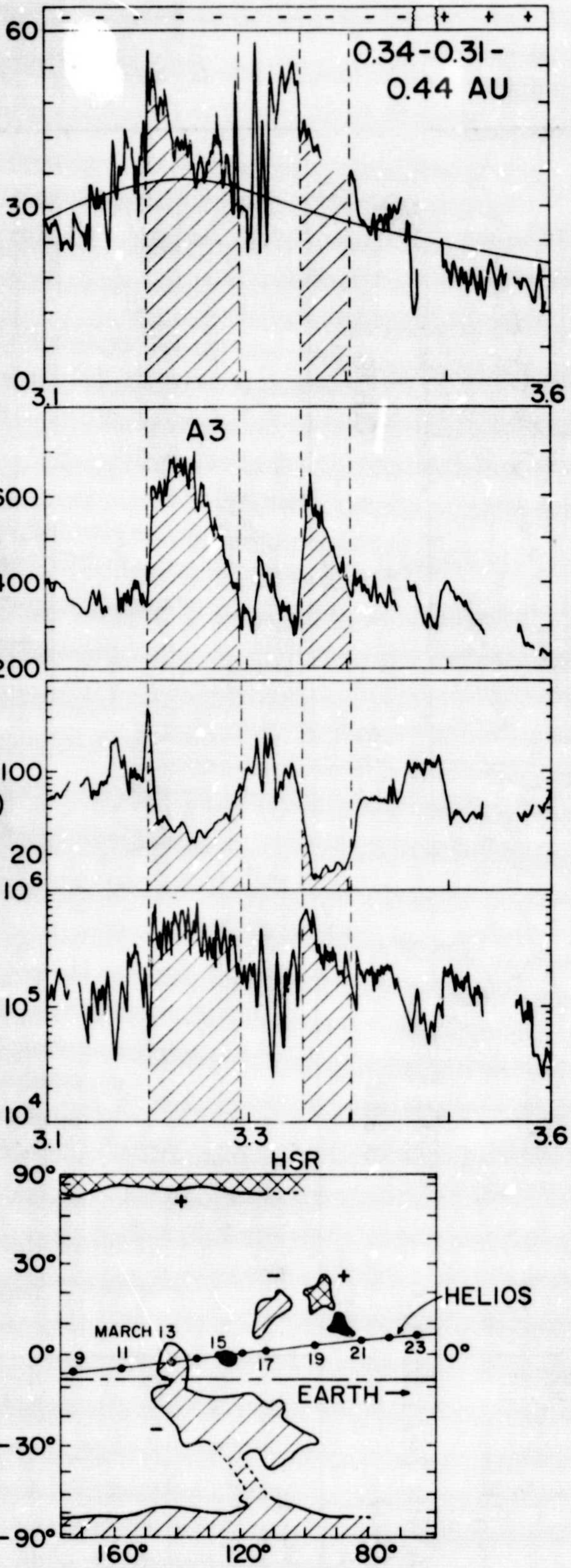

0.34-0.31-
0.44 AU
60
30
0
B(γ)
3.1
3.6
A3
600
400
200
V(km/s)
100
20
n(cm-3)
10^6
10^5
10^4
T(°K)
3.1
3.3
3.6
HSR
90°
30°
0°
-30°
-90°
+
-
+
-
HELIOS
MARCH 13
9
11
15
17
19
21
23
0°
EARTH →
160°
120°
80°

Figure 2

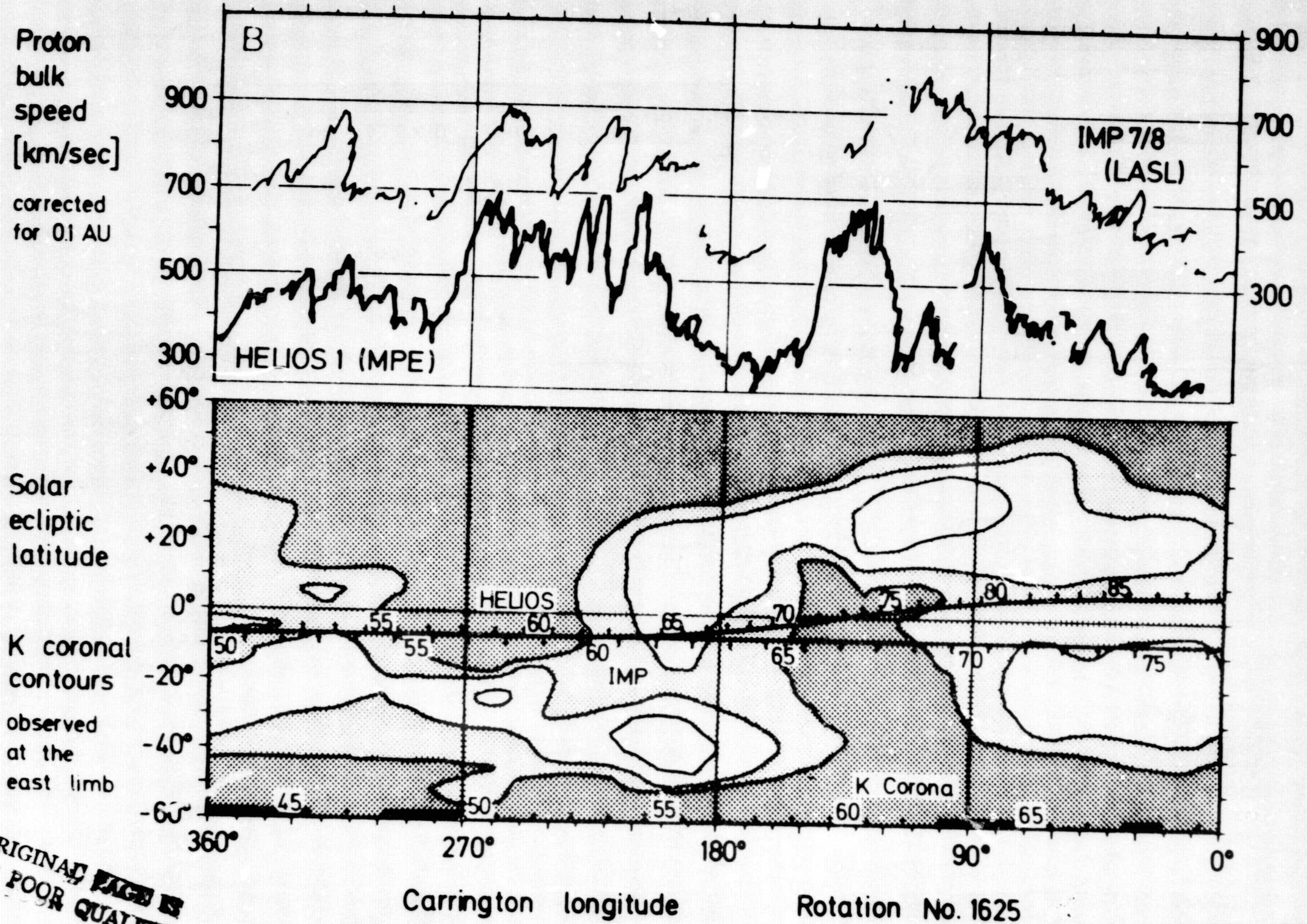

B
Proton bulk speed [km/sec]
corrected for 0.1 AU
900
700
500
300
HELIOS 1 (MPE)
IMP 7/8 (LASL)
900
700
500
300
Solar ecliptic latitude
K coronal contours
observed at the east limb
+60°
+40°
+20°
0°
-20°
-40°
-60°
HELIOS
IMP
K Corona
50
55
60
65
70
75
80
85
45
360°
270°
180°
90°
0°
Carrington longitude
Rotation No. 1625

Figure 3

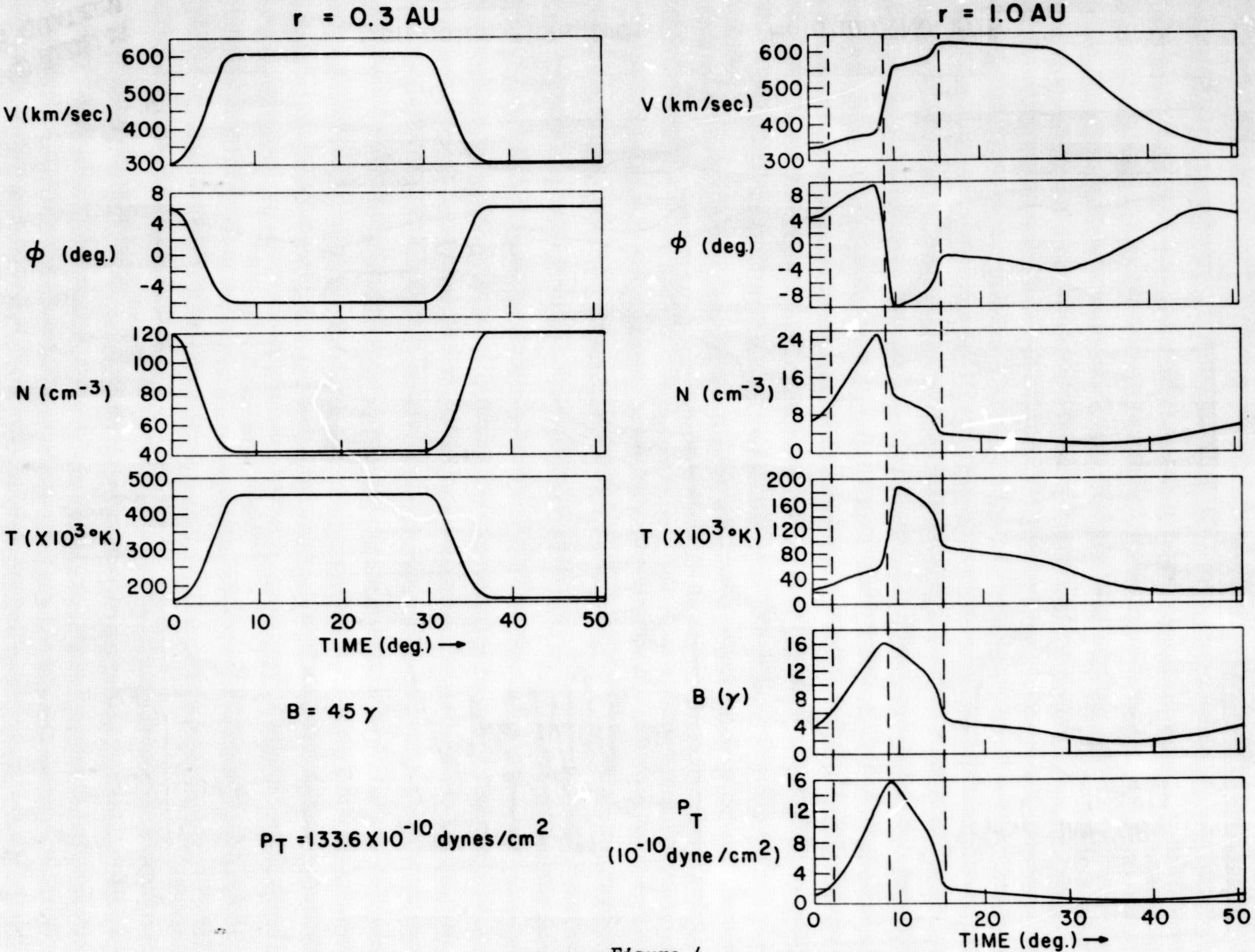

r = 0.3 AU
V (km/sec)
600
500
400
300
ϕ (deg.)
8
4
0
-4
N (cm-3)
120
100
80
60
40
T (X10³ °K)
500
400
300
200
0
10
20
30
40
50
TIME (deg.) →
B = 45 γ
P_T = 133.6 X 10^-10 dynes/cm²
r = 1.0 AU
V (km/sec)
600
500
400
300
ϕ (deg.)
8
4
0
-4
-8
N (cm-3)
24
16
8
0
T (X10³ °K)
200
160
120
80
40
0
B (γ)
16
12
8
4
0
P_T
(10^-10 dyne/cm²)
16
12
8
4
0
0
10
20
30
40
50
TIME (deg.) →

Figure 4

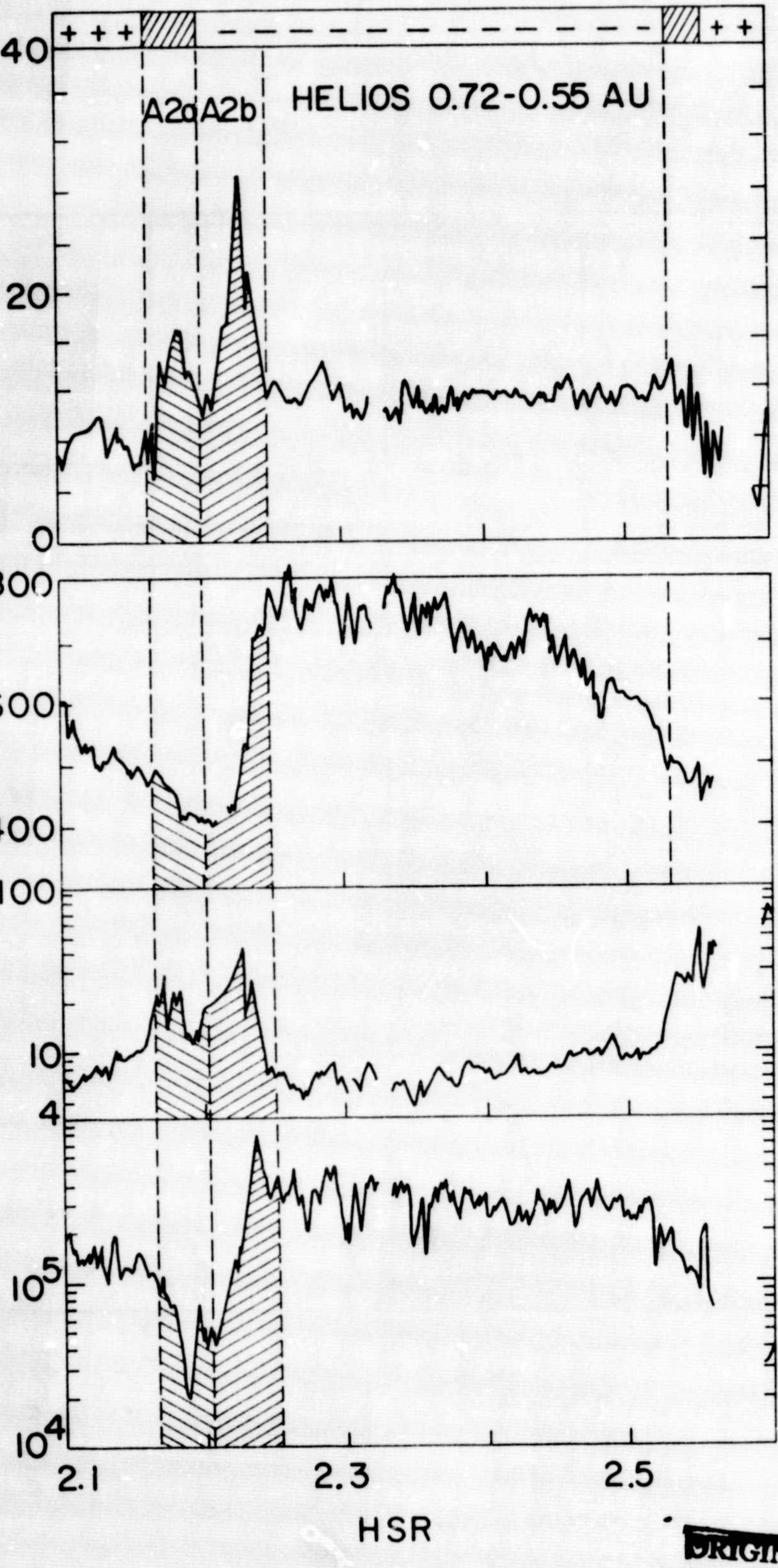
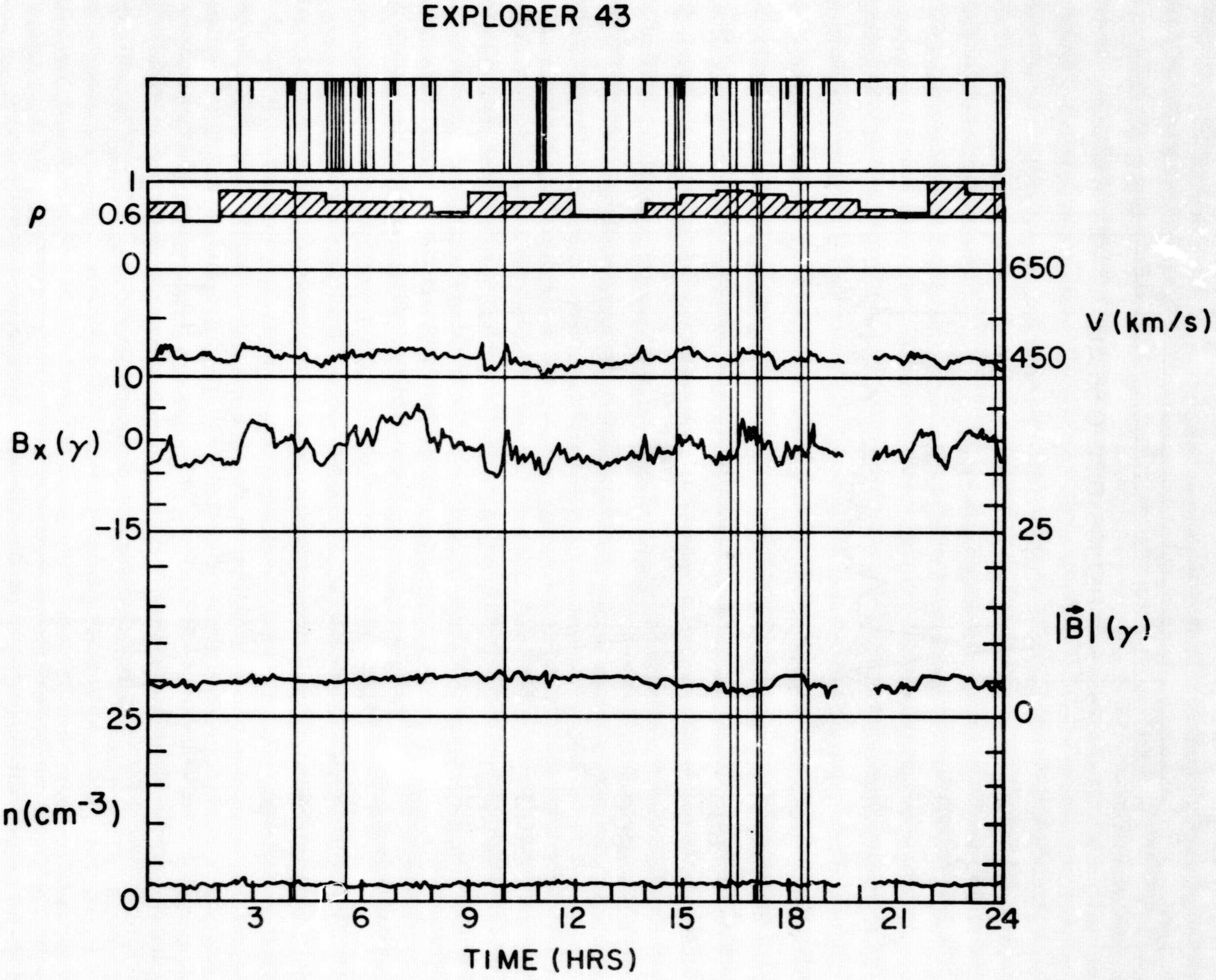

+ + +
- - - - - - - - - - - -
+ +
A2a
A2b
HELIOS 0.72-0.55 AU
B(γ)
40
20
0
V (km/s)
800
600
400
n(cm-3)
100
10
4
T(°K)
10^5
10^4
2.1
2.3
2.5
HSR

Figure 5



DAY 95, APRIL 6, 1971

Figure 6

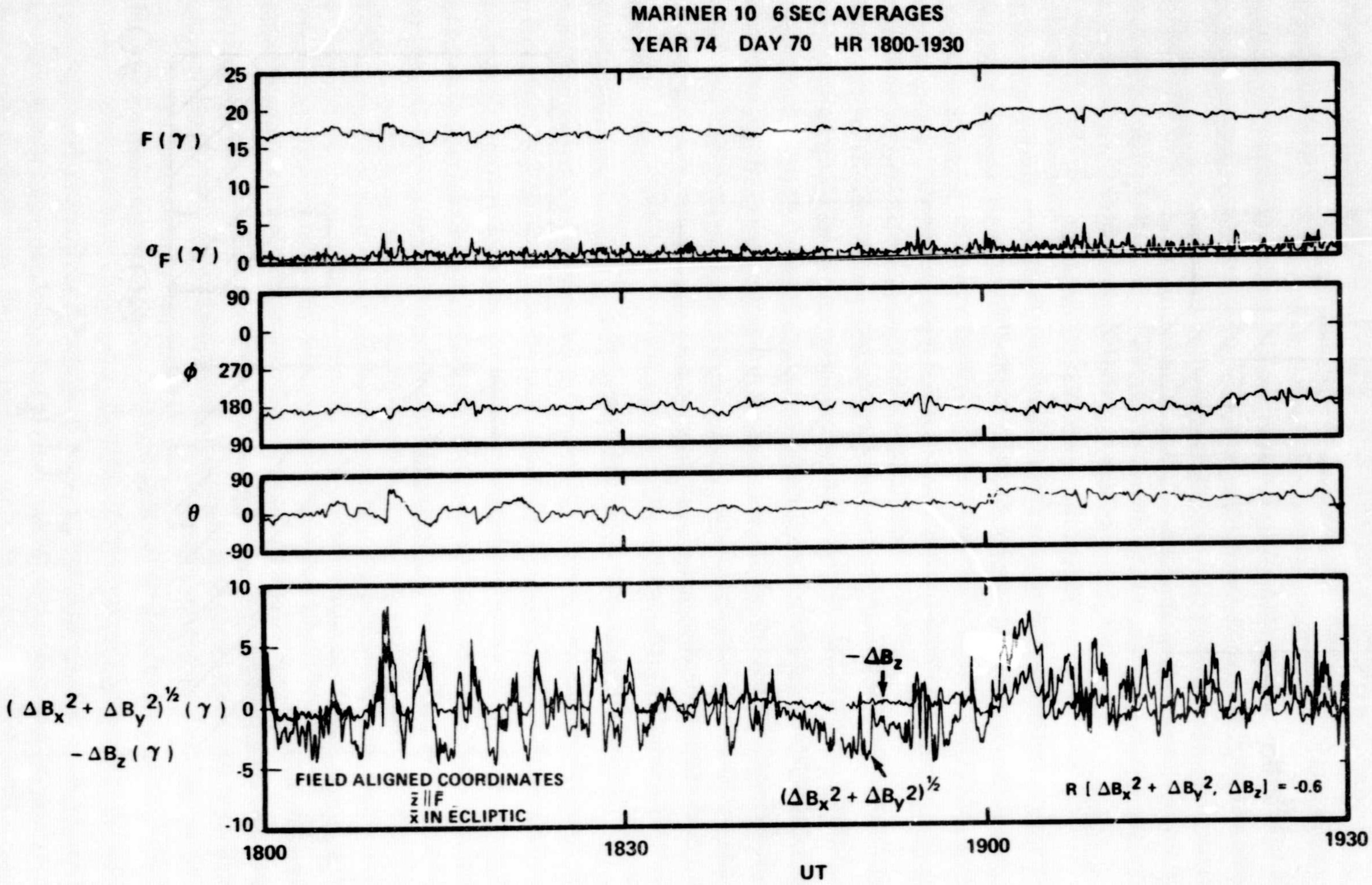

MARINER 10 6 SEC AVERAGES
YEAR 74 DAY 70 HR 1800-1930
F (γ)
25
20
15
10
5
0
σF (γ)
90
0
φ 270
180
90
θ
90
0
-90
(ΔBx2 + ΔBy2)½ (γ)
− ΔBz (γ)
10
5
0
-5
-10
− ΔBz
(ΔBx2 + ΔBy2)½
FIELD ALIGNED COORDINATES
z̄ ∥ F̄
x̄ IN ECLIPTIC
R [ΔBx2 + ΔBy2, ΔBz] = -0.6
1800
1830
1900
1930
UT

Figure 7

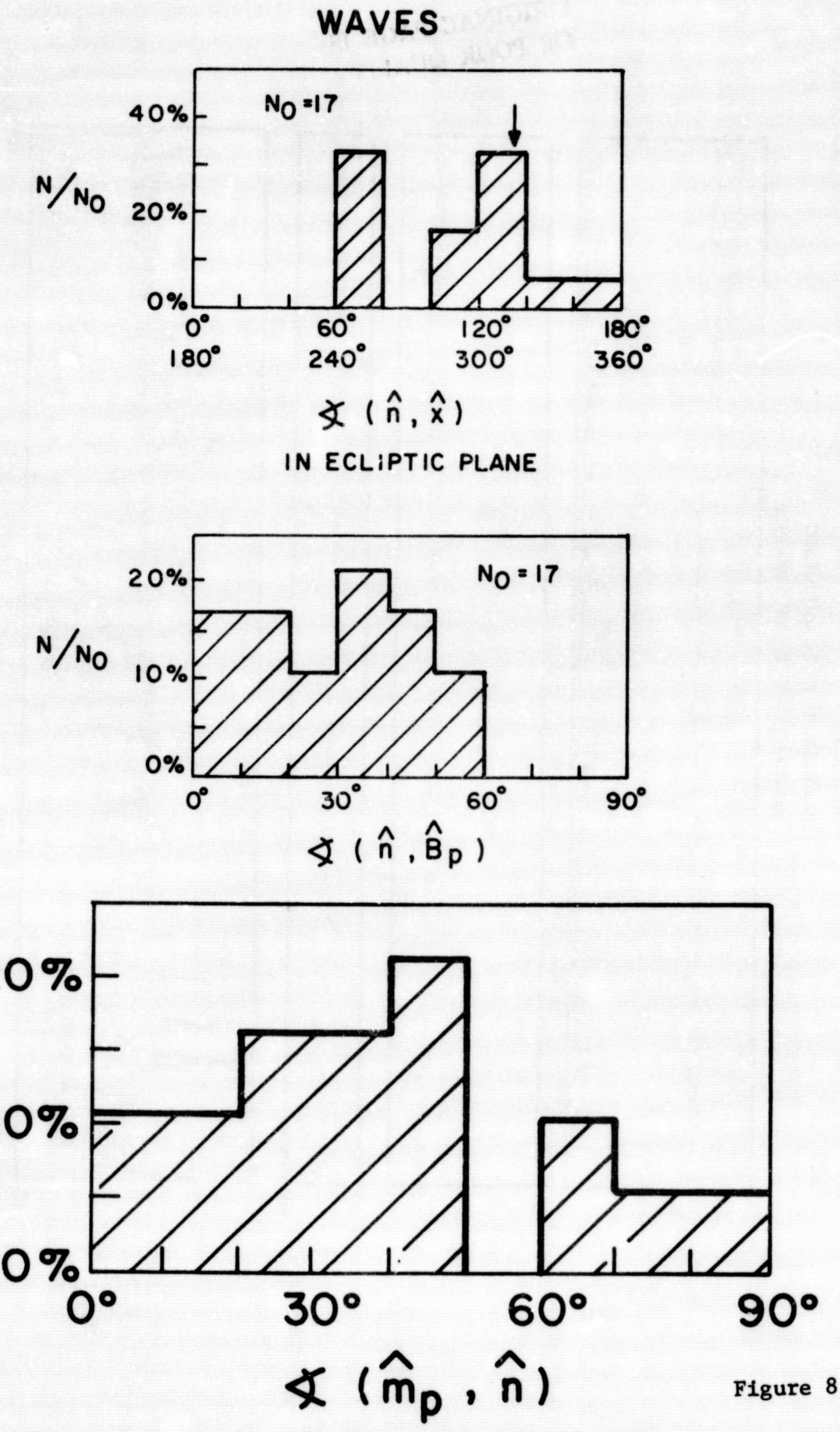

WAVES
N_O = 17
40%
20%
0%
N/N_O
0°
180°
60°
240°
120°
300°
180°
360°
∢ (n̂, x̂)
IN ECLIPTIC PLANE
N_O = 17
20%
10%
0%
N/N_O
0°
30°
60°
90°
∢ (n̂, B̂p)
20%
10%
0%
N/N_O
0°
30°
60°
90°
∢ (m̂p, n̂)

Figure 8

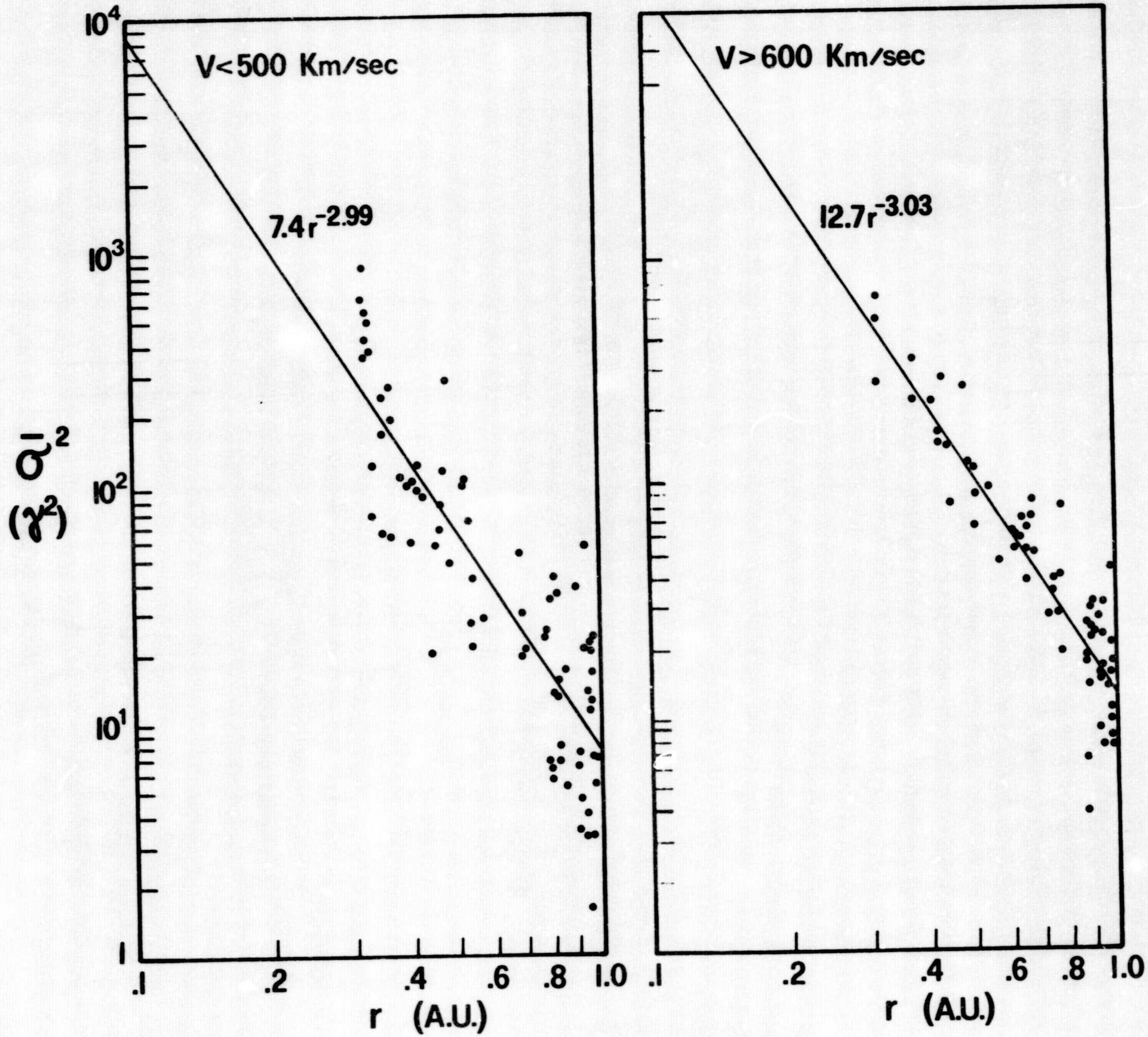
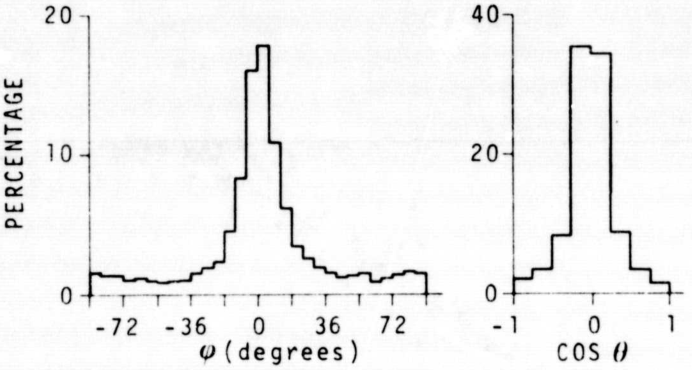
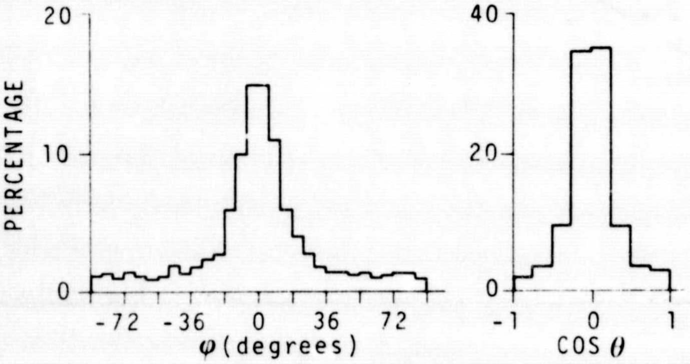

10^4
10^3
10^2
10^1
1
σ̄²
(γ²)
V<500 Km/sec
7.4r^-2.99
V>600 Km/sec
12.7r^-3.03
.1
.2
.4
.6
.8
1.0
r (A.U.)

Figure 9

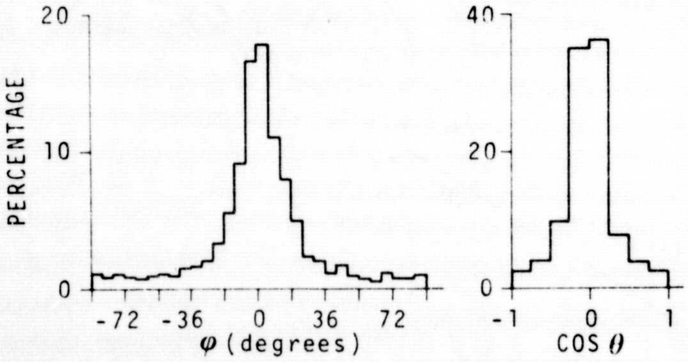
a) WHOLE MARINER 5 MISSION (22.5m)



b) LEADING EDGE OF HIGH SPEED STREAMS (168.75s)



c) TRAILING EDGES OF HIGH SPEED STREAMS (168.75s)



d) PREDOMINANTLY ALFVÉNIC PERIODS (168.75s)

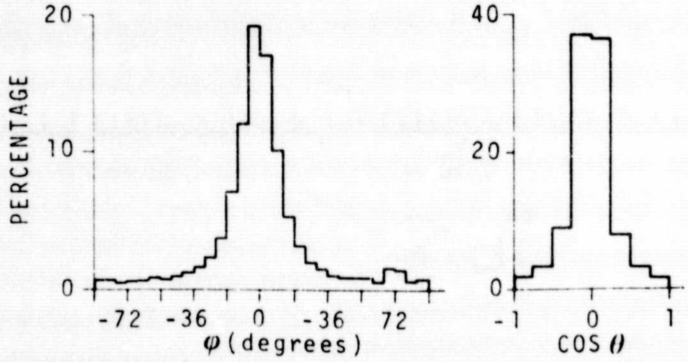


Figure 10

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16. Abstract

This paper reviews the recent results concerning streams and magnetic fields in the inner solar system. Specifically, it discusses in situ magnetic field and plasma observations within 1 AU which describe MHD stream flows and Alfvénic fluctuations, and it discusses the latest theories of these phenomena. Observationally, there have been significant advances in our understanding of streams and fluctuations as the result of acquiring nearly complete sets of high resolution plasma and magnetic data simultaneously at two or more points by IMPs 6, 7, and 8, Mariner-Venus-Mercury, HELIOS 1, and HELIOS 2. HELIOS and IMP observations and coronal hole observations demonstrated that streams can have very thin boundaries in latitude and longitude near the sun. This has necessitated a revision of earlier views of stream dynamics, for it is now clear that magnetic pressure is a major factor in the dynamics of stream in the inner solar system and that nonlinear phenomena are significant much closer to the sun than previously believed. Simultaneous IMP 6, 7, and 8 observations of Alfvénic fluctuations have shown that they are probably not simply transverse Alfvén waves; they suggest that Alfvénic fluctuations are better described as nonplanar, large-amplitude, "general Alfvén" waves moving through an inhomogeneous and "discontinuous" medium, and coupled to a compressive mode.

17. Key Words (Selected by Author(s))
Solar wind, interplanetary magnetic field, Alfvén waves, coronal holes

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