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INTERPLANETARY MAGNETIC FIELD MEASURED BY PIONEER 8 DURING THE 25 FEBRUARY 1969 EVENT*

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1 - INTRODUCTION.

In this paper we present preliminary results from the magnetic field experiment on the space probe Pioneer 8 in interplanetary space during the 25 February 1969 event.

The spacecraft was injected into a solar orbit on December 13, 1967. During the time interval in which we are interested, the sun to Pioneer line was pointing 23° east of the sun-earth line. The heliocentric distance of the probe was 1.52×10^{8} km, i.e., slightly larger than the corresponding sun-earth distance of 1.48×10^{8} km. The Pioneer 8 - earth distance was about 6×10^{7} km.

Magnetic measurements were made by a single sensor mounted at an angle of 54° 45' with respect to the spin axis of the probe. Vector components were then obtained by three consecutive measurements at 120° intervals from each other during the rotation of the spacecraft, which is 1.0 seconds. Thus one complete vector measurement is obtained in 0.67 seconds.

The quantization uncertainties were $\pm 0.125\gamma$ and $\pm 0.375\gamma$, respectively in the two possible ranges of operation, $\pm 32\gamma$ and $\pm 96\gamma$. Due to the low total bit rate of 16 bits/sec from the probe, one field vector is telemetered on the average each 7 seconds. Each vector component is the average of four consecutive measurements which are obtained by the instrument and computed on-board the spacecraft by a special computer, the Time-Average-Unit (Scearce et al., 1968). Because the reception of telemetry data was intermittent, unfortunately long gaps are present in the data. However, an approximate picture of the time evolution of the event in the distant interplanetary space can be given.

Results from the simultaneous plasma measurements on the same probe and comparison with those obtained by other near earth satellites will improve the interpretation of this discontinuous data.

2 - EXPERIMENTAL RESULTS.

A summary of the results is shown in Figure 1 where averages over 10 minute intervals of the usual magnetic field parameters are plotted: φ is the azimuth on the ecliptic plane ($\varphi = 0$ when field points to the sun); θ is the elevation relative to the ecliptic plane (positive when the field has a component pointing toward the north pole); $\overline{F}$ is the average field strength as computed by the averages of individual components; $\overline{\overline{F}}$ is the average of the individual field strengths. Short period (i.e. $<10^m$) variations of the field are present when

$$\overline{\overline{F}} - \overline{F} > 0$$

The main features seen in an inspection of Figure 1 are the following:

a) A rather steady field is observed in the early hours of February 25 with an average intensity of 4 to 6 γ and an azimuth of 120°-130°.

b) A rapid increase of the field occurs shortly after 2000: the variation from the pre-increase value to the compressed field near 10 γ occurs in a few minutes, between 2000 and 2022. After that the field slowly increases to a maximum value of about 14 γ; sporadic coherent fluctuations are present when individual values are compared.

c) Significant long period variations are seen between 0200 and 0500 February 26 for each of the three magnetic parameters and also short period variations as the difference $\overline{\overline{F}} - \overline{F}$ occasionally becomes very large.

d) A very quiet field of about 6γ is observed between 2000 February 26 and 0500 the next day. Also, short term variations are absent.

e) At 2149 February 27, when data are again telemetered the field is already at a high level of more than 10 γ. These high values are maintained for several hours. Between 2310 and 2320 a rapid, large azimuth variation occurs. Several polarity variations of the field occur as shown by the 180° variation of the azimuth.

f) In the last time interval, between 2000 February 28 and 0500 February 29 the average field strength is $5.5 \pm 1.5\gamma$, an approximately average interplanetary value, Quasi-periodic variations with period ≈ 1.5 hours are found in the field strength and the inclination θ. Also several polarity changes are present.

A higher time-resolution plot of the field increase after 1957 February 25 is shown in Figure 2, where 10 second averages of the field elements $\bar{\bar{F}}$, θ, φ are given. The structure of the field variation appears quite complicated: the field azimuth φ and the elevation θ change abruptly at 2008; however, a gradual increase of θ was already going on several minutes earlier. The field intensity is slowly varying during the time interval preceding a 5 minute gap in the data coverage; it is steady but at a higher level at 2022, after the data gap. This last field increase is associated with a slight variation in direction.

3 - DISCUSSION

A number of correlated events occurred in the period considered. A summary is given in Figure 3 where the timing sequence of the different events is illustrated. Several important and long lasting flares were observed on the sun, one cosmic ray proton event and three sudden commencement geomagnetic storms were observed on earth and sudden ionospheric disturbances were detected. A very active region, McMath No. 9946, was present in the northern hemisphere of the sun (Central Meridian Passage ≈ 1200 February 23). The flares indicated by solid arrows all originated in the above perturbed region. The flare indicated by a dotted arrow (Figure 3) originated in the region McMath No. 9957 located in the eastern hemisphere of the sun.

Although neither of the last two flares is the source of the increased field observed on Pioneer 8, they can help to build the right time sequence of the event. It seems reasonable to associate the flares of February 24, 25 and 26 with the three s.s.c. on the ground, 25 hours apart from each other. This interpretation is confirmed by the time variations of cosmic rays on the earth and in cislunar space. A solar proton event on the ground was indeed detected by several radiation monitors, as well as by several satellites and space probes; its first appearance is put around 0911 February 25. The Deep River neutron monitor indicated a strong intensity increase starting at 0925. The following Forbush decrease on the ground started during the first few hours of February 27 in association with the s.s.c. observed at 0307. The average velocities of the perturbation responsible for the s.s.c., as estimated by the sun-earth transit time, are given in Table 1, which includes the approximate origin time of the parent flare assumed to be responsible for the s.s c.

TABLE 1

flare at			s.s.c. at	Sun Earth transit time	Estimated average velocity
time	Heliographic Long.	Lat.			
2300 Feb. 24	30°W	11°N	0158 Feb. 26	27 hours	1540 km/sec
0900 Feb. 25	37°W	13°N	0307 Feb. 27	42 hours	1000 km/sec
0418 Feb. 26	46°W	13°N	0423 Feb. 28	48 hours	860 km/sec
1040 Feb. 27	27°E	15°S			
1350 Feb. 27	65°W	13°N			

It seems reasonable to interpret the field strength increase observed by Pioneer 8 as having begun at approximately 2003 UT February 25 and to be due to the effect of the flare of 2300 February 24 which occurred about 21 hours before. If the scaling factors derived from the velocities of Table 1 are used, the next magnetic field increases would have been expected on Pioneer 8 about 33 and 37 hours after the corresponding flares, i.e., around 1800 February 26 and 1700 February 27 respectively, during the data gap period. Measurements taken between 2000 February 26 and 0500 February 27 do not show any significant perturbation: in the next data period, starting at 2200 February 27, the field is already at a steady, high value which indicates that the perturbation was already present at the location of Pioneer 8.

The directional change at 2008 February 25 appears to be a tangential discontinutiy with the field vector rotating around a direction approximately perpendicular to the field lines. The increase in the intensity a few minutes later, although it cannot be studied in detail due to the data gap, might be due to the effect of a fast shock discontinuity.

Actually two worldwide geomagnetic storms were observed on February 26 and 27. Presence of shocks in the interplanetary medium can be expected to be associated with them (Burlaga and Ogilvie, 1969). Unfortunately the data gaps prevent unique identification of the field variation associated with the shock. The results presented in Figure 2, with the additional feature of a very steady field in the second half of the time interval 2000 to 2100, when the fastest field variation occurs, lead us to suggest that a shock wave passed by Pioneer 8 around 2020.

Previous evidence of interplanetary shocks is due to several authors. (At the time this paper was prepared, the relevant review presented by A. J. Hundhausen (1969) at the same symposium was not available.) Evidence for a shock wave in deep interplanetary space onboard Mariner 2 was presented by Sonett et al. (1964) who found an impulsive field change from 6 to 16γ in a time interval less than 3.7 minutes. The average shock velocity between the spacecraft location and the earth was estimated at 510 km/sec assuming a spherical wave front from the sun. The resulting velocity referred to the traveling plasma was about 130 km/sec. Van Allen and Ness (1967) detected an interplanetary shock onboard Explorer 33 at a geocentric radial distance of about 70 R_E on July 8, 1966. The field abruptly changed from 12 to 20 γ with a rise time of 5 to 10 seconds. The estimated near earth velocity of the shock was 890 $\pm$ 40 km/sec as compared with an average sun-satellite velocity $\bar{v}$ = 950 km/sec and the shock normal was pointing in the direction $\varphi = 182^\circ \pm 5^\circ$, $\theta = -27^\circ \pm 5^\circ$. Plasma data is not yet available to determine the shock wave velocity properly.

More recently, from the Vela 3 data, Gosling et al. (1968) have identified two shock-like structures in the deep interplanetary medium, on October 5, 1965 and January 20, 1966. The average velocity from the sun to the spacecraft in the two events was respectively 2500 and 1670 km/sec; corresponding velocities past the spacecraft were 410 and 420 km/sec, which means 70 and 90 km/sec with respect to a reference system moving with the plasma. These results also indicate clearly a slowing down of the shock as it propagates away from the sun.

Ness and Taylor (1968) also studied this same event using, in addition, the magnetic field data from Pioneer 6, deep in interplanetary space. Unfortunately data gaps also precluded unique indentification of the event on Pioneer 6.

Taylor (1968) using data from Explorer 28 (IMP-3) was able to study the geometry of many shocks in near earth interplanetary space and associated terrestrial disturbances which occurred between June 1965 and January 1967. Unambiguous identification of the parent flare for each event was not possible so that a statistical study of shock velocity was not conducted.

Ogilvie and Burlaga (1969), using magnetic and plasma data from Explorer 34 identified 7 interplanetary shocks between May 67 to January 68. They found that the Rankine-Hugoniot conditions are satisfied at the shock fronts and that all the events were the cause of s.s.c. geomagnetic storms. Shock velocities with respect to the moving plasma were of the order of tens of km/sec.

In our case, the observed perturbation has also been interpreted as a shock, although until plasma data are available not all the features of the shock can be uniquely found. The high average velocity of the shock may well be an effect of the long duration of the generating flare. An important question arises from the association of solar and magnetic events outlined above, and it is: why the field increase is detected on the spacecraft 6 hours earlier than on the ground?

The time sequence of magnetic field variations on Pioneer 8 and on the earth does not favor a spherically propagating shock. The Pioneer-Sun distance was larger than the sun-earth distance; even a very high velocity, 1000 km/sec, shock wave would imply about a one hour delay between earth and Pioneer for field perturbations. One possible interpretation of the time sequence of field variations is that the disturbance emitted from the sun was traveling with different velocities at different azimuthal orientations. Evidence for non-spherical propagation has been given by Hirshberg (1968), Taylor (1969) and others. In this interpretation, the average velocity would be significantly higher toward the Pioneer 8 position, i.e. the isotime curves, which are those points in space reached by the perturbation at a given time, should not be spherical around the point where the flare originated.

The azimuthal distribution of the velocity should exhibit a maximum in a direction east of the sun earth line. If the shock actually occurred in the data gap between 2017 and 2022 February 25, the normal to its surface car be estimated by consideration of the B vector variation ahead and behind the shock. Using 5 minute averages of the data on each side of the gap we obtain the SE components (γ) as : ahead, $B_x = -1.6$, $B_y = 3.8$, $B_z = 6.0$, and behind $B_x = -2.3$, $B_y = 5.1$, $B_z = 7.5$.

Corresponding field intensities and orientations are $B = 7.3$, $\theta = 55^\circ$, $\varphi = 113^\circ$ and $B = 9.4$, $\theta = 53^\circ$, $\varphi = 115^\circ$. Determination of the shock normal based on use of continuity of the normal component of the field and the coplanarity theorem may contain a large error due to the very small difference in direction of the field vectors ahead of and behind the shock.

The normal to the shock front, as estimated by the above field values, corresponds to $\theta = -35^{\circ}$ and $\varphi = 155^{\circ}$. This direction has a large component aligned with the average field, which suggests that a high velocity shock wave was propagating toward Pioneer 8 approximately along the interplanetary magnetic field lines. The angular relative position of the solar region where the flares took place and Pioneer 8, as well as the spiral geometry of the interplanetary magnetic field support this hypothesis.

With the available data we cannot state how long the perturbation persisted, nor are we able to say whether or not an effect of the flare at 0900 UT February 25 was detected by the spacecraft. However, a similar azimuthal distribution of the velocity can be inferred from the 27 February field increase which also occurred on the spacecraft at least 6 hours before the 0423 s.s.c. on the ground. In this case the required propagation velocity in the direction of Pioneer 8 is definitely lower, between 1300 to 1000 km/sec. A sketch of a possible interpretation of the geometry of the events initiated on February 25 in interplanetary space is given in Figure 4.

In conclusion, the observations on Pioneer 8 suggest, but cannot uniquely determine, the passage of two fast shocks, one on February 25 the other sometime on February 27 between 0500 and 2200. The lack of information on the solar plasma onboard the same spacecraft prevents complete determination of the physical properties of the shocks. The estimated average velocities of these shocks, especially for the first one, appear quite high although comparable to those found by Gosling et al (1968). As the plasma data from Pioneer 8 become available, and simultaneous magnetic field and plasma data from other spacecraft, an improved analysis of this event shall be possible.

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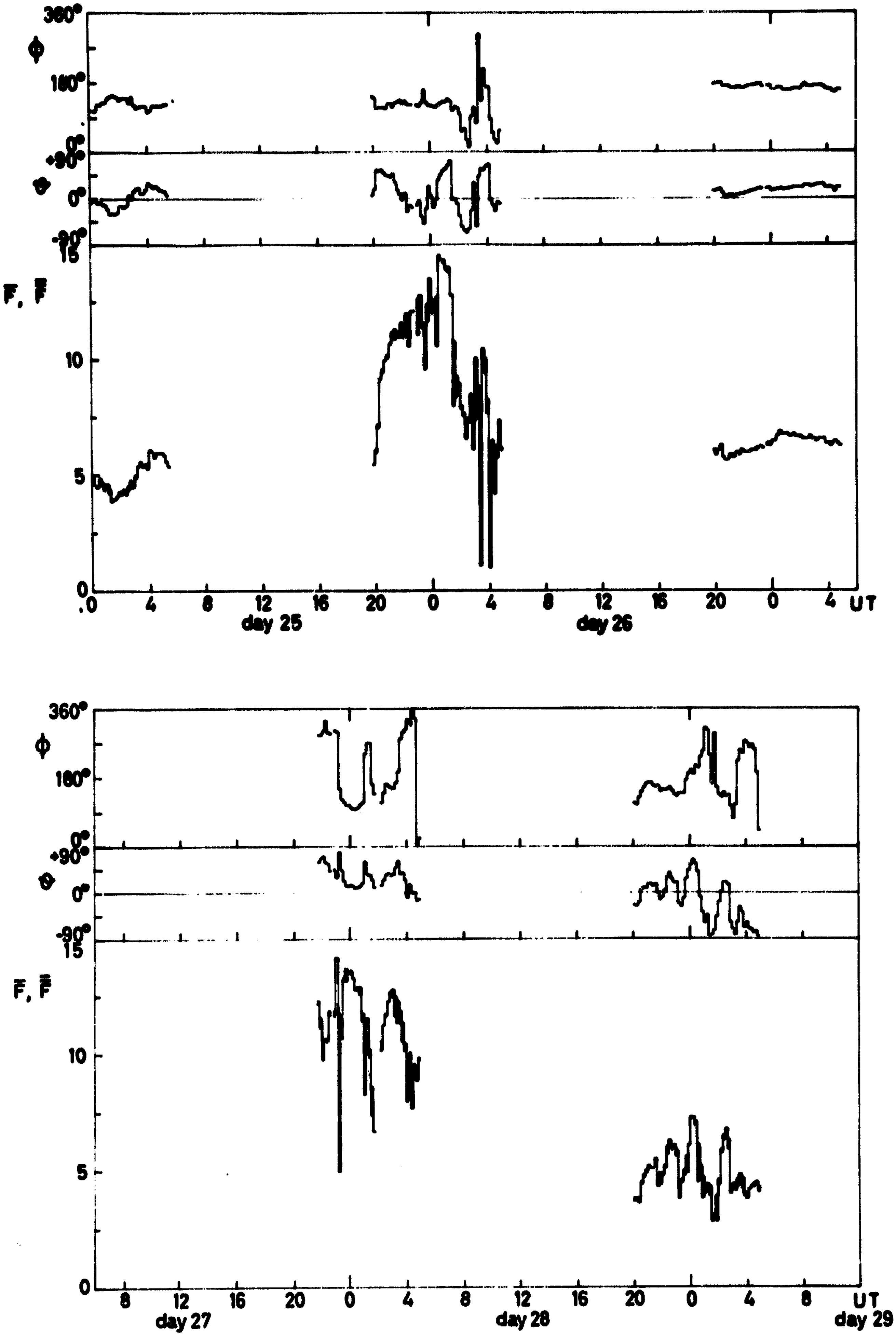
FIGURE CAPTIONS

Figure 1 Pioneer 8 10-minute averages of the interplanetary magnetic field elements $\bar{F}$, $\bar{\bar{F}}$, θ and φ for the period February 25 to 29. (See text).

Figure 2 Pioneer 8 10-second averages of the interplanetary magnetic field elements $\bar{\bar{F}}$, θ and φ, during the initial phase of the field increase on 25 February 1969.

Figure 3 Time sequence of the events on the sun, Pioneer 8 and on the earth. The data gaps are defined by the times t_1 to t_2, t_3 to t_4 and t_5 to t_6.

Figure 4 A sketch of the magnetic field lines (left) and of the shock front propagation into the interplanetary medium (right); P is the position of Pioneer 8. Solid and dashed lines on the left hand represent the field configuration immediately before the time t_2 and between t_4 to t_5, as defined in Figure 3.



360°
Φ
180°
0°
+90°
Θ
0°
-90°
15
F, F̄
10
5
0
0 4 8 12 16 20 0 4 8 12 16 20 0 4 UT
day 25
day 26
360°
Φ
180°
0°
+90°
Θ
0°
-90°
15
F, F̄
10
5
0
8 12 16 20 0 4 8 12 16 20 0 4 8 UT
day 27
day 28
day 29

FIGURE 1

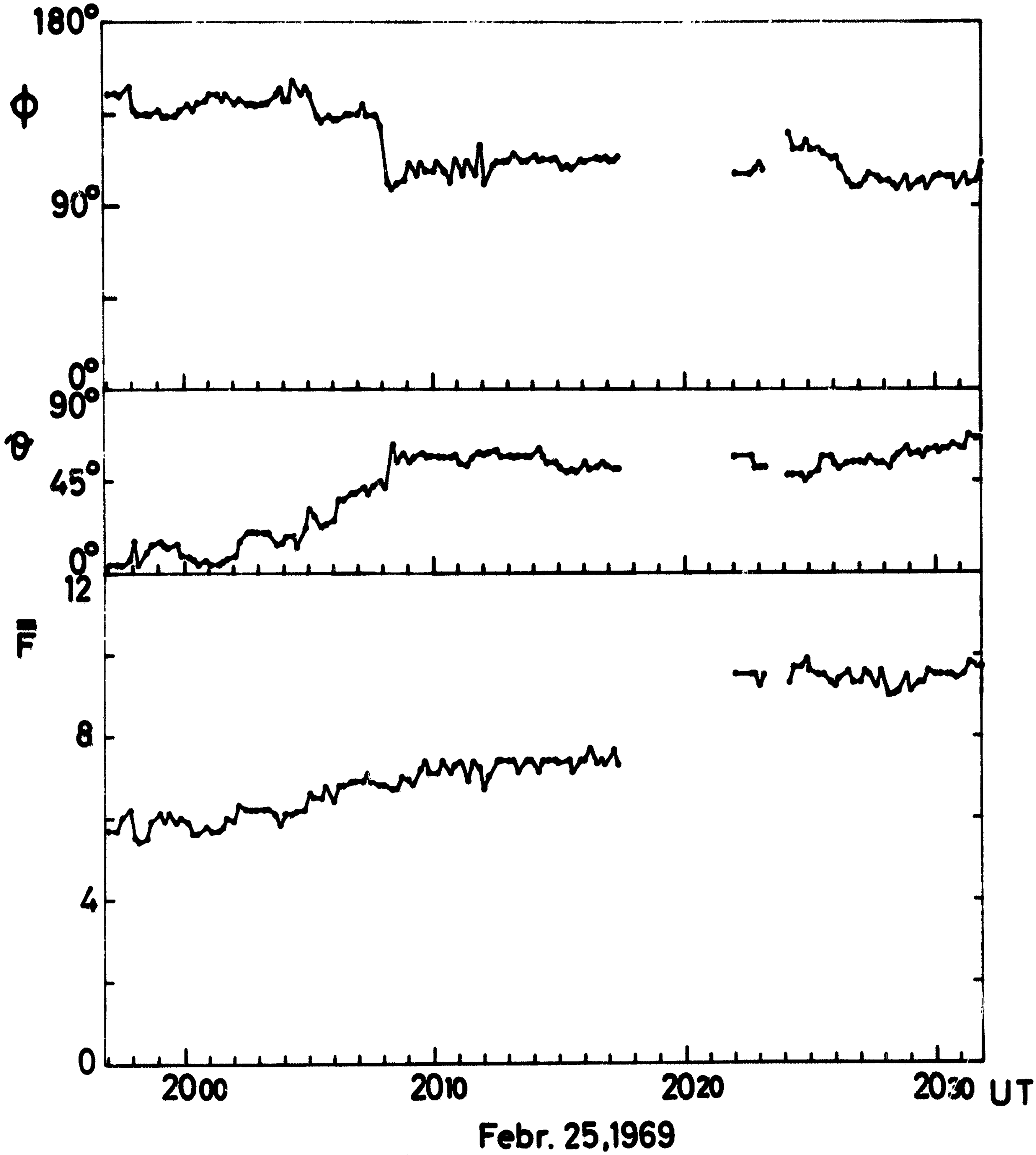
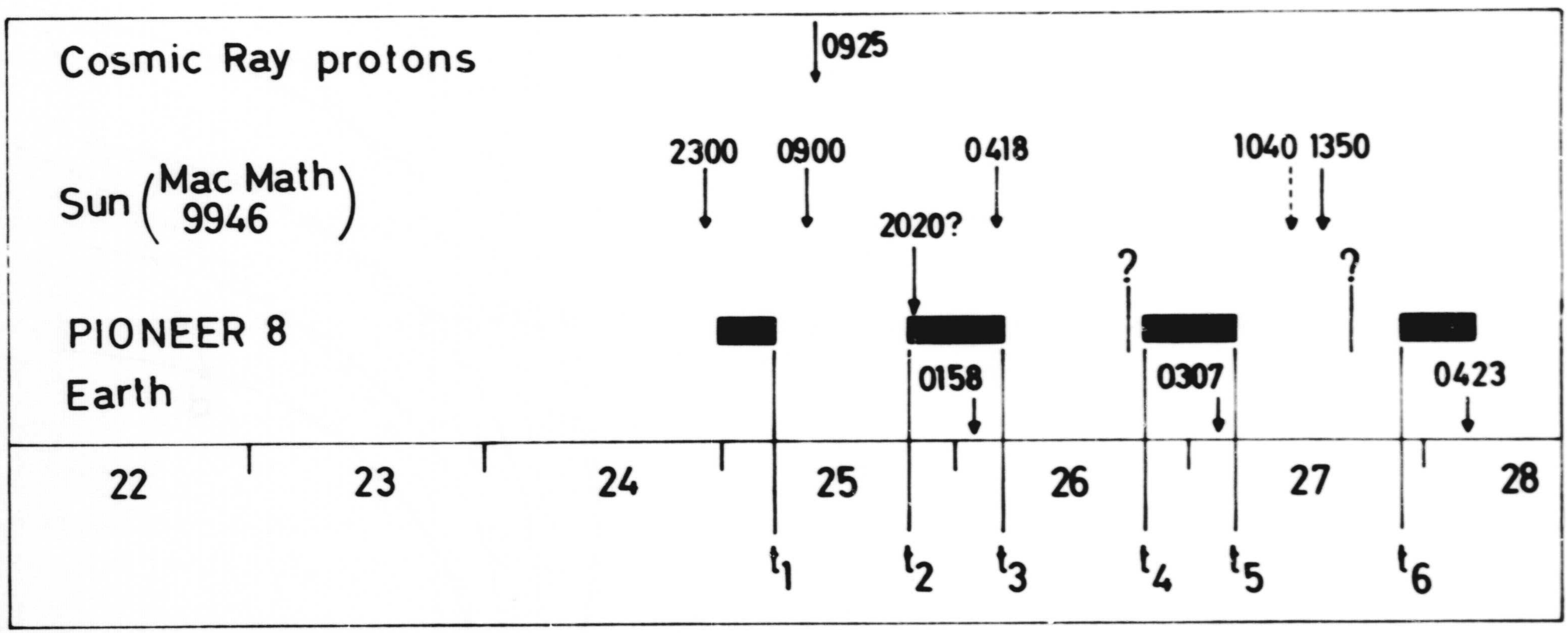


FIGURE 2



Cosmic Ray protons
0925
Sun (Mac Math 9946)
2300
0900
2020?
0418
1040
1350
?
?
PIONEER 8
Earth
0158
0307
0423
22
23
24
25
26
27
28
t1
t2
t3
t4
t5
t6

FIGURE 3

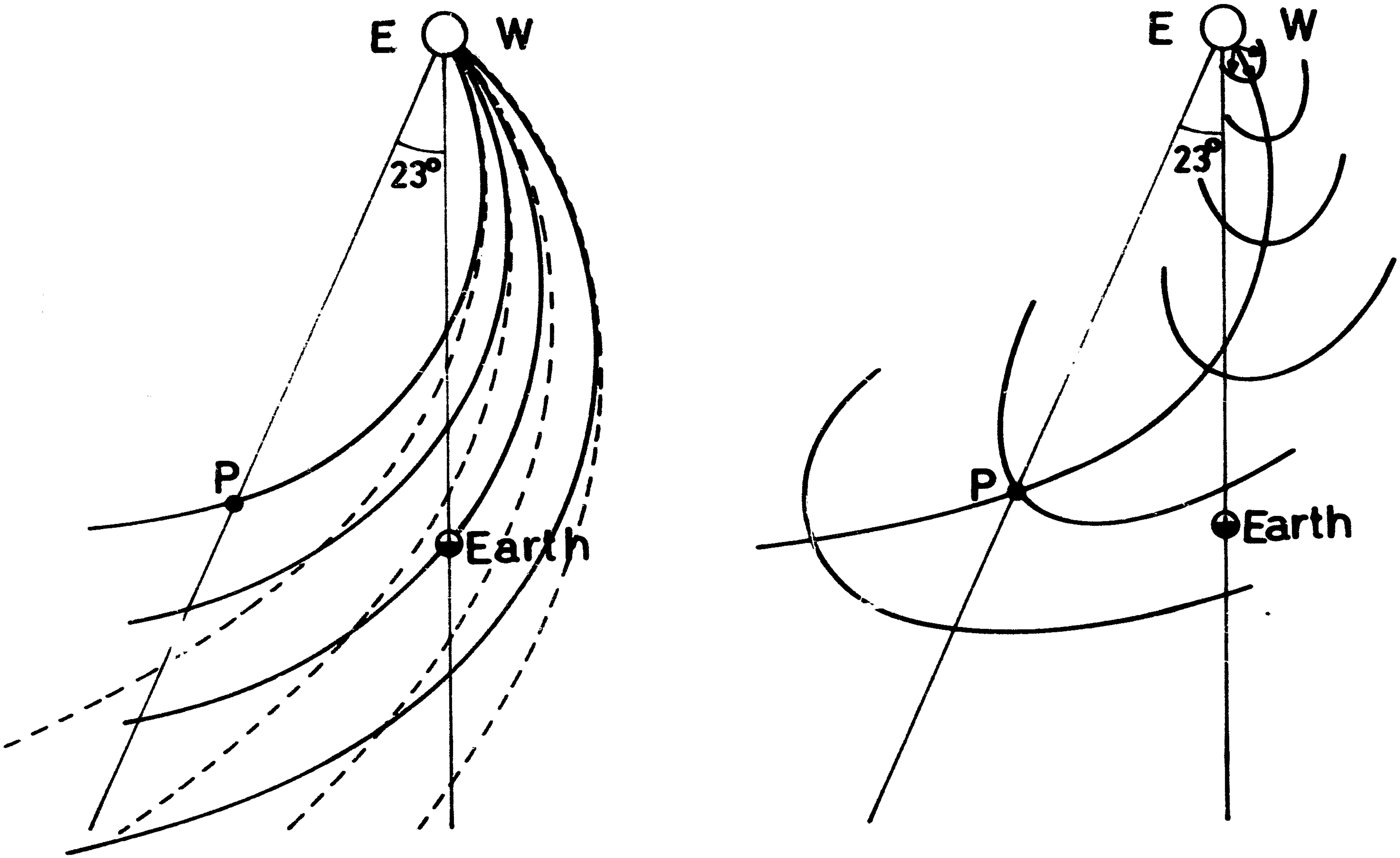


FIGURE 4