THE INTERPLANETARY MEDIUM

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UNTIL recently, the interplanetary medium was assumed to be devoid of all matter. The earth's magnetic field, which is of the order of 0·5 gauss at its surface, decreases to less than 1 gamma (10^{-5} gauss) within a few earth's radii. The magnetic fields, due to sun and other planets, will also decrease to an insignificant value within a short distance from their surface.

The early evidence to the contrary came from the study of Chapman and Ferraro. They explained the increase of earth's magnetic field in the initial phase of a magnetic storm as due to the compression of the earth's field by plasma emitted from active regions on the sun's surface. From the time delay between the eruptions on the sun and the occurrence of the magnetic storm the velocity of the plasma was inferred to be about 1,000 km./sec. Biermann's[1] results on cometary tails and Blackwell and Ingham's[2] results on the nature of zodiacal light further strengthened the above conclusion.

Starting from Chapman's idea that due to the high thermal conductivity, the corona populated by hot (10^6 degrees K) ionized hydrogen extends to a distance of several solar radii in space, Parker[3] showed that, at large distances from the sun, the thermal energy of the gas will exceed gravitational energy and the gas will be free to escape. Under these conditions, the corona will continually expand. Assuming a coronal temperature of 10^6 K, Parker showed that the solar plasma will attain a streaming velocity of about 500 km./sec. at about 30 solar radii beyond which the velocity will remain practically constant. The magnetic energy density due to sun's dipole field of about 1 gauss at the sun being too small compared to the kinetic energy of the gas except in the low corona, the magnetic field does not exert an appreciable effect on the radially moving solar wind.

According to the concept of the "frozen in" field, which was first proposed by Alfven, the radially outward streaming solar plasma must pull out the solar dipole field. At great distances from the sun, the field lines which are firmly anchored to the plasma will be stretched in the form of a spiral known as "Archimedes Spiral", even though the plasma will move radially outwards. The angle which the corotating spiral field line makes with the sun-earth line at a point in space is given by

$$x = \frac{WR}{V_s}$$

where W is the angular velocity of sun, R is the radial distance of the point of observation and V_s is the velocity of the solar plasma. With a plasma of velocity 400 km./sec. the field lines would make an angle of 45° with the sun-earth line at the orbit of the earth.

The solar wind radially flowing outward from the sun compresses the geomagnetic field as it interacts with it, confining the geomagnetic field to a limited volume of space known as "magnetosphere". The boundary of the magnetosphere, where the kinetic energy of the plasma balances the magnetic energy of the earth's magnetic field, is called the "magnetopause". The magnetopause lies between 10–15 earth radii (radius of earth is about 6,000 km.) on the sunward side. On the dark side of the earth where the forward momentum of the solar plasma is not effective in confining the geomagnetic field, the tail of the magnetosphere is elongated in the form of a tear drop to at least half-way to the moon. Results from Explorer 14[4] showed that the termination of the geomagnetic field at the magnetopause is also coincident with the termination of the trapping of energetic particles as well as the appearance of thermalized plasma.

The magnetic field measurements by Explorers 12 and 14 and IMP satellites clearly show that besides the conspicuous features interpreted as indicative of the magnetospheric boundary, there exists a highly fluctuating weaker magnetic field beyond the boundary to a radial distance of about 17 earth radii (Fig. 1). The termination of this region is characterised by an abrupt change in the magnetic field. Beyond this region, the magnetic field is very uniform and regular. From the analogy of the formation of a shock wave in the supersonic flow of a compressible gas around a solid object, the transition region between the regular but weak interplanetary field, and the highly fluctuating component is considered to coincide with the presence of a shock wave around the magnetosphere. The region between the shock wave and the magnetospheric boundary is called the

"magnetosheath". The magnetosheath having a weak and irregular field is characterised by the presence of thermalized plasma[5,6] and the presence of intense fluxes of electrons[7] with energy greater than 45 Kev. Thus, as shown in
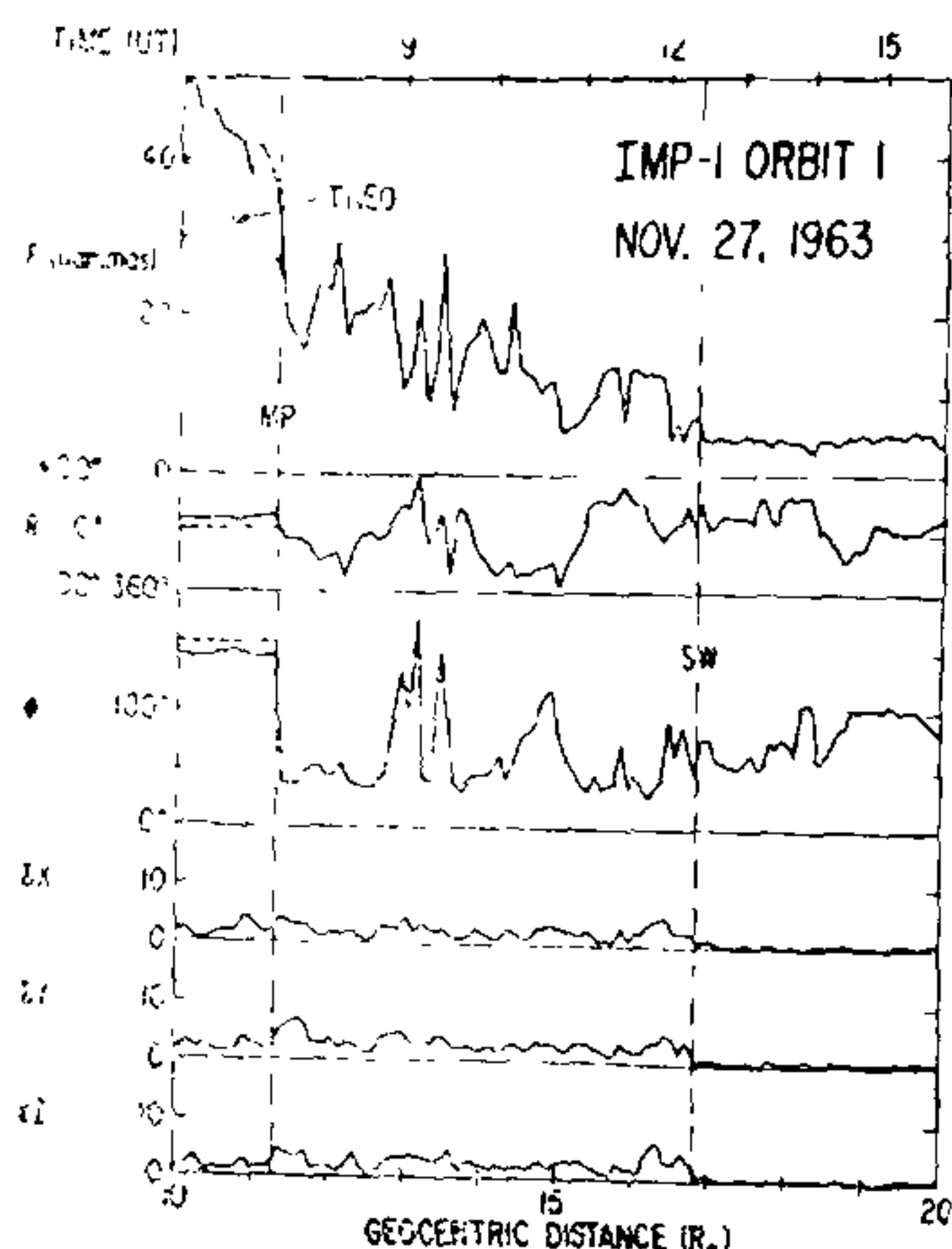

FIG. 1. The interplanetary magnetic field observed by the IMP-1 satellite. The magnetosphere boundary at $11 \cdot 3 \, R_c$ and the shock wave at $16 \cdot 8 \, F_c$ can be clearly seen in the figure.

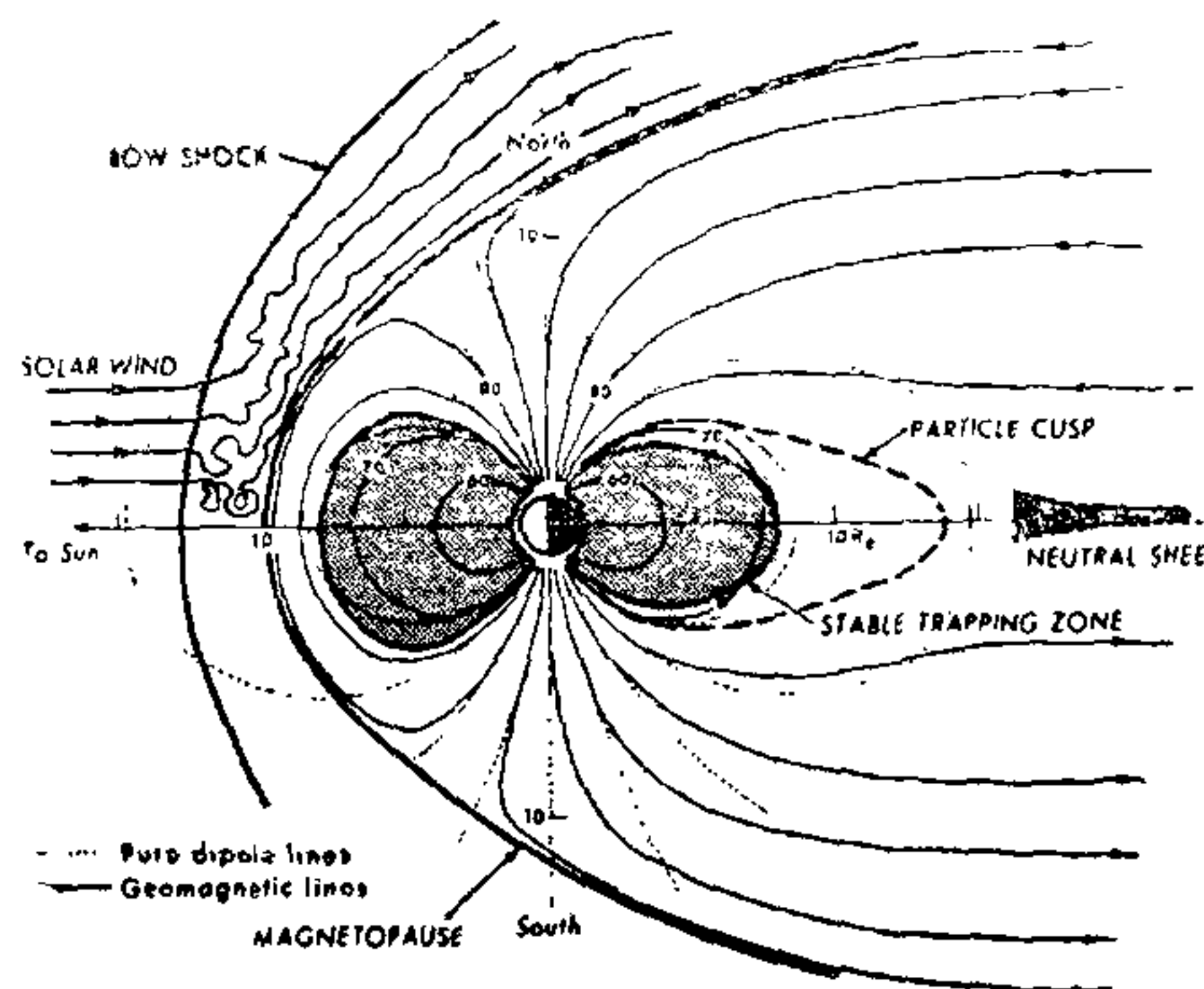Fig. 2, we may consider the extra terrestrial space to be divided into three regions.

FIG 2. Summary of the results on mapping of the terrestrial magnetosphere boundary with the interplanetary medium. The shape and the position of the shock wave and the magnetopause are indicated. The presence of intense fluxes of electrons of energy greater than 45 Kev observed by Anderson in the geomagnetic tail region is also shown.

1. The *interplanetary* region where the properties of the interplanetary medium are undisturbed by the presence of the earth,

2. The *magnetosheath*, associated with the interaction of the solar wind with the geomagnetic field, and

3. The *magnetosphere* within which the geomagnetic field is contained.

In our review, we will concern ourselves only with the interplanetary region, that is not affected by the presence of the earth and its magnetic field.

LARGE-SCALE STRUCTURE OF THE INTERPLANETARY FIELD DURING SOLAR FLARES

The quiet-time interplanetary field structure will be considerably changed at the time of violent solar eruption or flares. The velocity of plasma, emitted from sun at the time of flares, will be considerably greater (about 1,000 km./sec.) than the velocity of quiet-time solar plasma. At the region where the high velocity plasma compresses the field lines of low velocity plasma ahead of it, a blast wave is formed according to Parker.[8] As seen in Fig. 3, the field lines between the sun and the
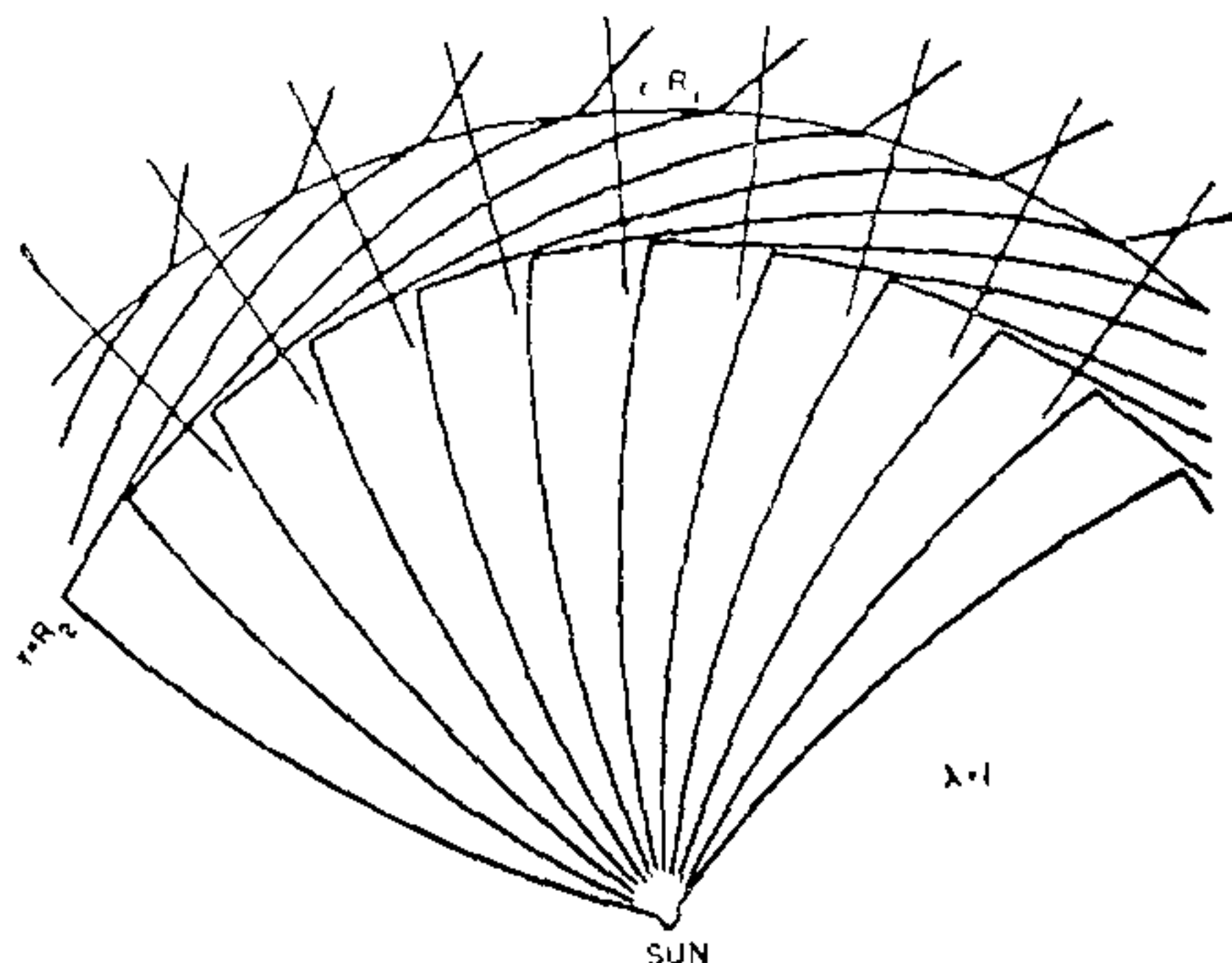

FIG. 3. The blast wave model of Parker as seen from the North ecliptic pole. The field lines are almost radial from the sun to a distance $r = R_2$ due to the high velocity post-flare plasma. Beyond $r = R_1$, the spiral field, due to the quiet solar wind, can be seen. Between these two regions, the field lines are compressed due to the blast wave.

blast wave are very nearly radial due to the very high velocity of the solar plasma emitted during the flare. In the region where the field lines are compressed due to the interaction of high velocity plasma with the low velocity plasma ahead of it, the angle between the field lines and the radial direction is larger.

Convincing experimental evidence for the existence of interplanetary magnetic field structures in the form of spiral pattern emerged from McCracken's study of solar flare increases. Calculating the complex trajectories of cosmic-

ray particles in the geomagnetic field,[10] Mc-Cracken was able to show that each neutron monitor responded to primary cosmic-ray particles arriving from a narrow region of space in the sky. This region called the asymptotic cone of acceptance of the detector scans the entire celestial sphere as the earth spins on its axis. Analysing the data from a number of neutron monitors, McCracken concluded that when the active region producing the flare is located on the western limb of the sun, the spiral magnetic field structure is able to establish a connection between this region and the earth. The relativistic particles produced will thus be guided by the magnetic lines of force and hence will be able to reach the earth in the shortest possible time. The observed increases will also be highly anisotropic in the initial stage, the excess radiation coming mainly from the direction 50° to the west of the sun. With the progression in time, the flare increase becomes completely isotropic which McCracken attributed to the scattering of the cosmic-ray particles by the small-scale magnetic field irregularities of scale size of about 0·01 A.U.

Examining the consequences of an Archimedes spiral field upon which small-scale field irregularities are superimposed, Parker[12] and Axford[13] have predicted that cosmic rays, whose gyroradii are small compared to the dimensions of the ordered component of the interplanetary magnetic field, will corotate with the sun. The corotation effect will produce a diurnal variation of cosmic-ray intensity of about 0·5% in the energy range 1–100 Bev, the maximum flux coming from the 1800 hours direction. The properties of the average diurnal variation derived from a large number of neutron monitors have been shown by McCracken and Rao[14,15] to be consistent with the predictions of Parker-Axford theory. McCracken and Rao[16] have further investigated the properties of the diurnal variation over an entire solar cycle and have concluded that the frequency of occurrence and the characteristics of magnetic field irregularities of scale size 10^{-3}–10^{-1} A.U. are invariant with respect to the phase of the sunspot cycle.

Solar Wind Measurements Using Space Probes

The early attempts to observe the interplanetary plasma directly by the Russian group using Lunik space probes and by Rossi and his group using Explorer 10 established the existence of a radial solar wind. The strongest direct evidence for the existence of a *continuous*

flux of solar wind was obtained by the positive-ion spectrometer on Mariner 2. From approximately 40,000 plasma spectra received during a period of about 5 months in the later part of 1962, Snyder, Neugabauer and Rao[17,18] showed that the solar wind was continually emitted radially from the sun with a velocity ranging between 300–1000 km./sec. and with an average density of about 5–10 protons/cm.^{3} They further showed (Fig. 4) that the solar wind
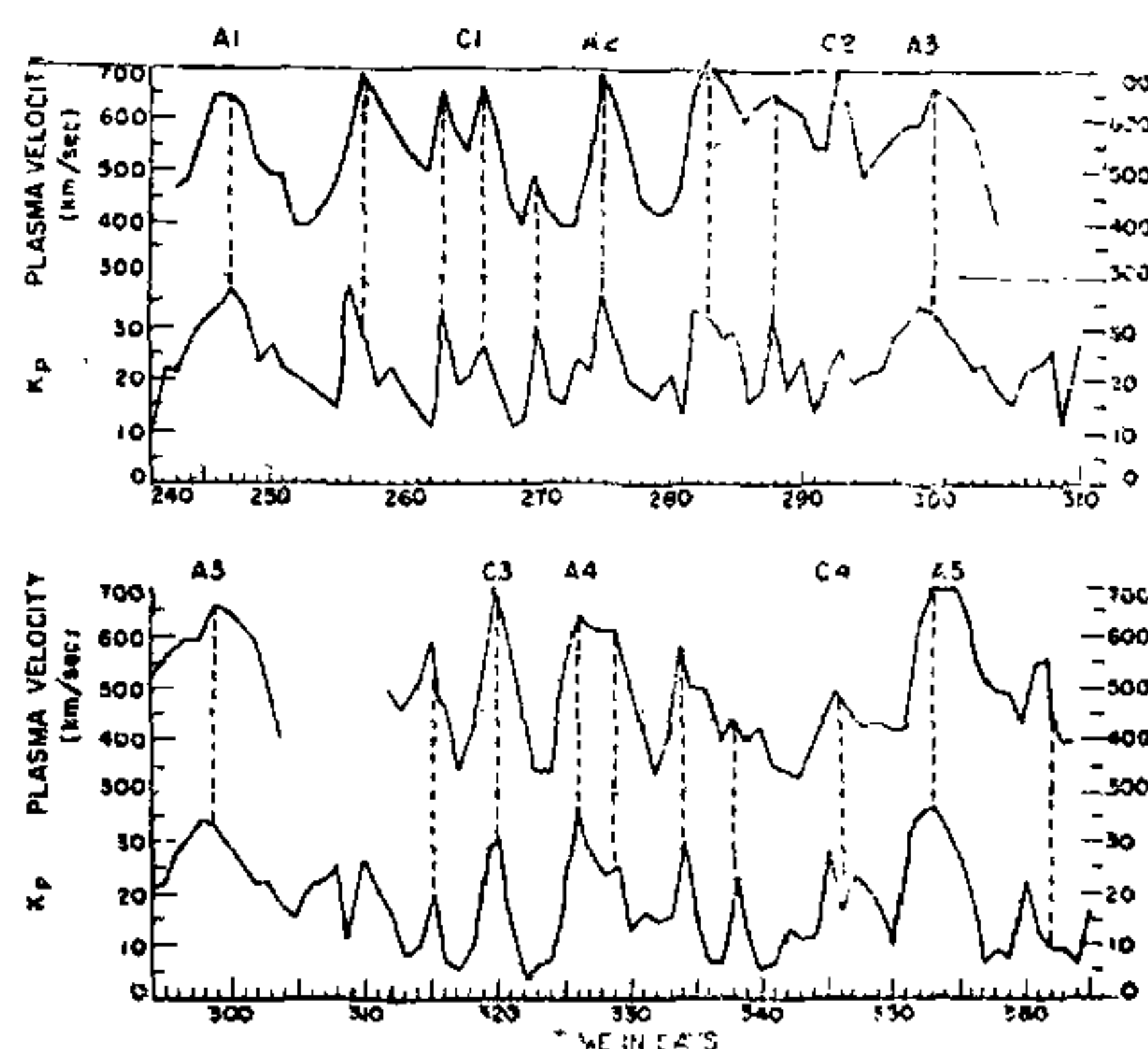

FIG. 4. Daily mean solar wind velocity observed by Mariner 2 during the period August 19 to December 1962. The predominant 27-day recurrence tendency exhibited by solar wind velocity and a one to one correlation with the K_p indices are easily evident from the figure.

velocity exhibited a strong 27-day recurrency tendency, a close association with M region storms, and an extremely good correlation with the K_p indices. The average proton temperature of the plasma was found to be about 2×10^{5} K. The solar wind velocity which was constant between 1·0 to 0·7 A.U. contained about 5% of alpha particles. The average properties of the solar plasma, derived above, have been further verified by the Russian workers[19] using Venus 2 and Venus 3 probes and by Bridge et al.[20] and Wolfe et al.[21] using both IMP satellites and Pioneer 6 and 7 space probes.

The preliminary results of Wolfe et al.[22] obtained from high resolution instrument on board Pioneer 6 deep space probe shows that the previous assumption of radial plasma flow is not completely correct and that the deviation from the radial flow can be as much as 5°. The ion temperature parallel to the magnetic field often exceeds the perpendicular temperature by an order of magnitude. Further analysis on the high degree of thermal anisotropy of the plasma ions and the non-radial nature of the plasma may lead to an understanding of the interaction of plasma with the magnetic field

MEASUREMENT OF INTERPLANETARY MAGNETIC FIELD USING SPACE PROBES

The early measurements of magnetic field using space probes were not very reliable due to the contamination of measurements by the magnetic field of the magnetic materials in the space-crafts. Our best information on the interplanetary magnetic field comes from the work of Ness[24] using a rubidium vapour magnetometer on IMP-1 satellite. The results showed that the interplanetary magnetic field varied between 4 and 7 gammas with occasional decreases to 1 gamma and occasional increases to 10 gammas. The direction of the field on an average was about 45° to the earth-sun line, thus showing good agreement with the spiral structure of the interplanetary magnetic field predicted by Parker and experimentally deduced by McCracken.

Even though the field vector lies predominantly in the plane of ecliptic often it is observed to make an angle of 20° with the plane of ecliptic. Wilcox and Ness[25] further showed that interplanetary magnetic field is divided into sectors, the field direction in adjacent sectors being opposite, one away from the sun and the other towards the sun. The large-scale sectorial structure shows a 27-day recurrence period equal to the synodic rotation period of the equatorial region of the sun implying that the interplanetary field corotates with the sun (Fig. 5). From a
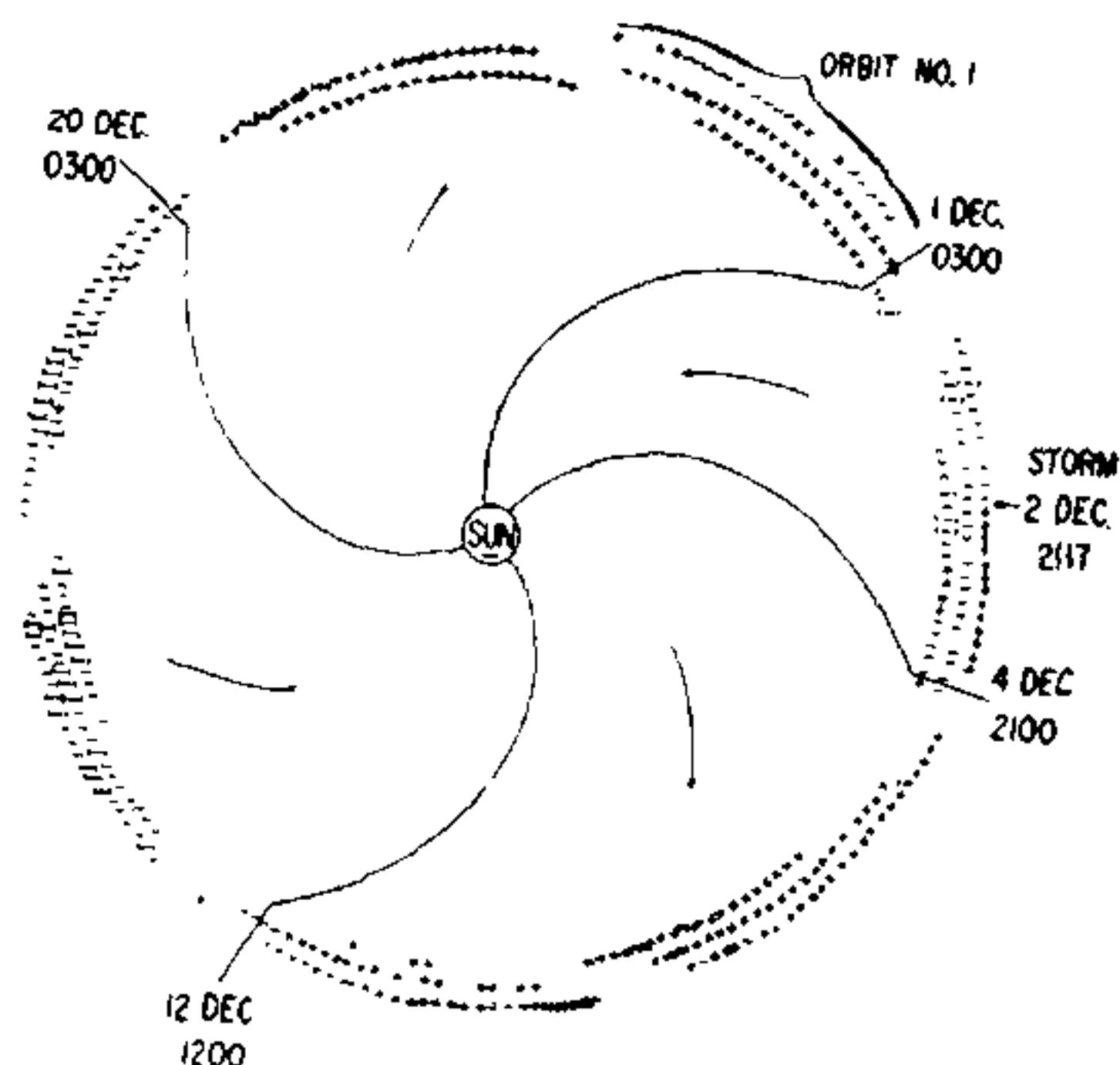
FIG. 5. Structure of the interplanetary magnetic field direction for solar rotations 1784 to 1786 as observed by IMP-1 satellite. The interplanetary field is shown to have a corotating sector structure with a strong 27-day recurrence tendency. + sign indicates the field direction away from the sun and — sign indicates the field direction towards the sun.

cross-correlation of the observed field direction with the direction of photospheric field of the sun, they conclusively proved that the field lines passing through the photosphere near the

center of visible disk of the sun, are dragged out by the solar wind to become a part of the nearby interplanetary field.

The study of low energy cosmic ray increases by Bryant et al.[26] and by the Iowa group shows the existence of a strong recurrence tendency of such increases associated with M-region storms. These isotropic increases which are generally not associated with either type, IV type radio emission or optical flares, found to occur immediately after the sector boundary of the magnetic field. The recent cosmic-ray observations on Pioneer 6 by McCracken, Rao and Bukata[27] have revealed the existence of Forbush type decreases of cosmic-ray intensity which are intimately correlated with the M-region magnetic storms. These recurrent decreases have been interpreted as due to the exclusion of galactic particles by enhanced magnetic field strength within the standing shock wave created at the interface where the fast plasma from a 'hot spot' overtakes the slow plasma from the remainder of the corona.[28] As shown in Fig. 6, which applies to the
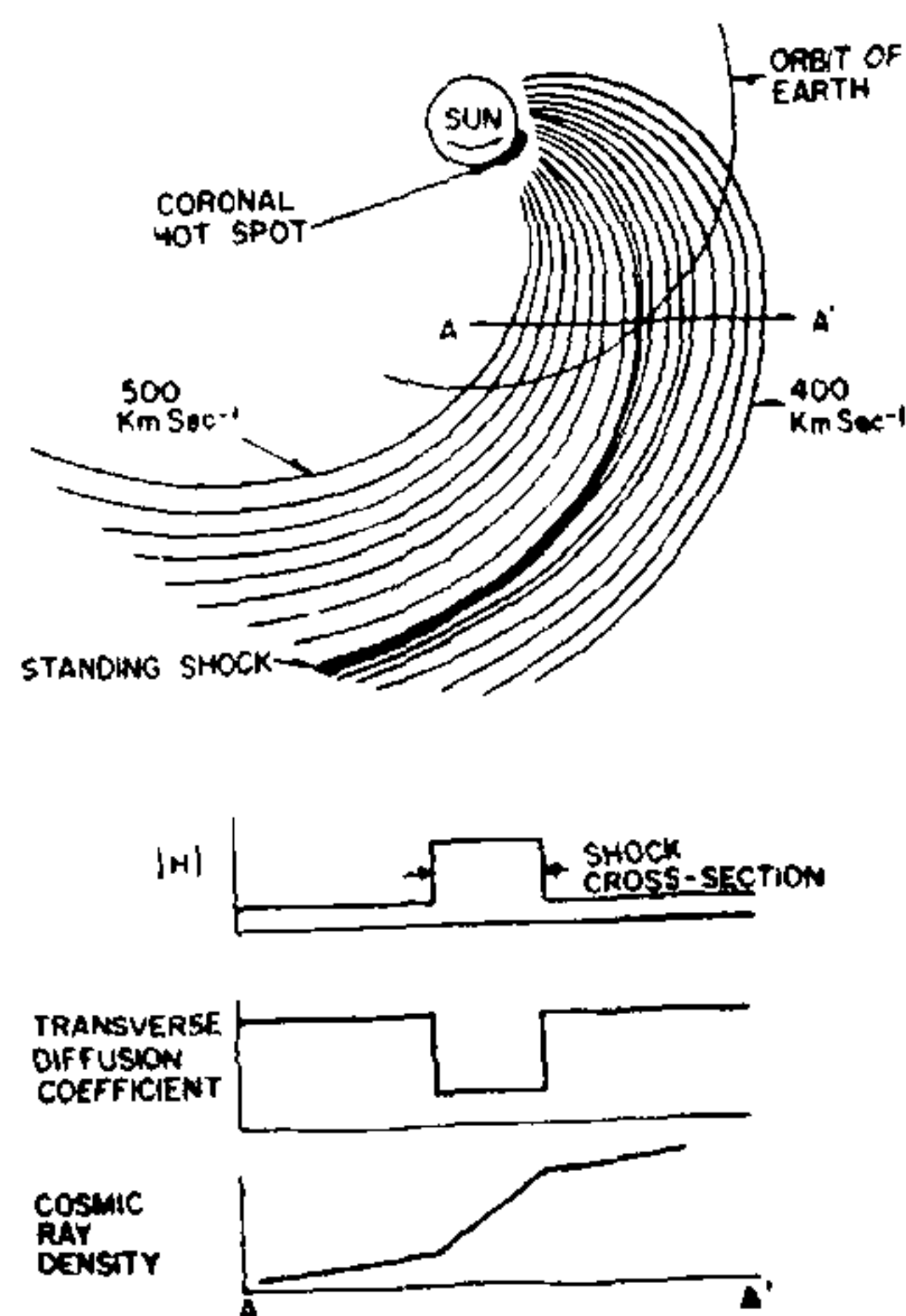
FIG. 6. The model of the standing shock wave generated by a single coronal hot spot. The intense interplanetary magnetic field at the shock prevents galactic particles from entering the region inside the shock.

instantaneous situation, an observer crossing from outside to inside the shock will see a steadily decreasing cosmic-ray intensity with the passage of time. The intensity inside the shock will recover to its normal value due to the longitudinal diffusion. Comparing the onset of recurrent Forbush decreases with the sectorial boundaries of interplanetary field

observed earlier by IMP-1 and Mariner IV space-crafts, McCracken, Rao and Bukata concluded that the onset of Forbush decreases correlated well with the sectorial boundaries suggesting that the standing shock waves involved to explain the recurrent Forbush decreases define the edges of these sectors.

The initial results from Pioneer 6 by McCracken, Rao and others[29] have already provided a great insight into the large-scale structure of interplanetary magnetic field. During the period of its operation from December 1965 to May 1966, more than 16 solar flare increases have been observed by the cosmic-ray detector designed by the above authors. They have shown that the cosmic radiation flux of mean energy 13 Mev/nucleon exhibited extreme anisotropies practically throughout each flare effect, anisotropies persisting in excess of 48 hours (Fig. 7). The
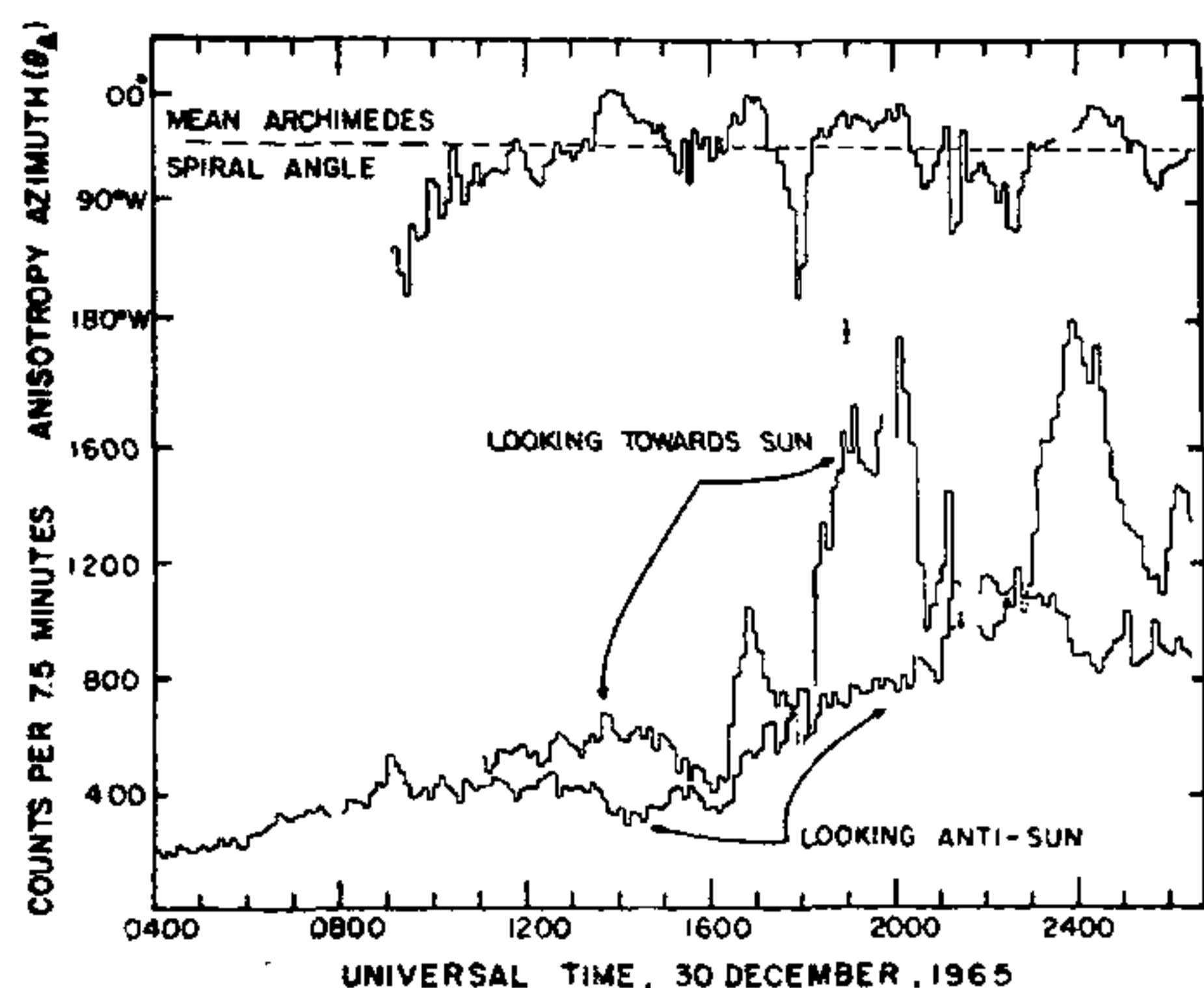

FIG. 7. The cosmic-ray anisotropy during the initial stages of the flare effect that commenced on December 30, 1965 as observed by Pioneer VI. The figure shows the 7·5 minute samples from two directions one looking towards the sun and another looking in the anti-sun direction. The mean directions of anisotropy during the same period are also shown in the figure.

direction of anisotropy has been observed to exhibit marked and abrupt changes the maximum flux coming sometimes from even the anti-sun direction. The direction of anisotropy shows one to one correlation with the direction of the interplanetary magnetic field measured by Ness[30] on the same space-craft. These results indicate that the cosmic radiation was flowing away from the sun along well-defined and intertwined filamentary magnetic field structure embedded in the solar wind. The great persistence of extreme anisotropies indicate that the fields within each filament are very well ordered in so far as 13 Mev particles

are concerned. The abrupt changes in the directions of anisotropy and of the interplanetary magnetic field occur as different corotating filaments pass by the space-craft, the magnetic field in adjacent filaments being non-parallel to each other. The filaments have a typical scale size of 3×10^6 km. which is about 21 gyroradii for 13 Mev particles. The cyclotron radius of 1 Mev proton being about 2×10^6 km. would sample the field in more than one filament in each cyclotron revolution experiencing scattering as it passes from one filament to the other. Thus the anisotropies of high energy particles will be comparatively short-lived.

In summary, the interplanetary field seems to be populated with filaments containing well-ordered magnetic fields, which are rooted to the sun, and which are intertwined and twisted with immediate neighbours *en route* to the orbit of earth. The whole population retains the general Archimedes spiral field configuration, even though on any given tube, local deviations from this pattern do occur. These results have changed our picture of the interplanetary field completely. The presence of small-scale scattering centres with interplanetary magnetic field to explain the short-lived anisotropy in flares is not needed any more. The same function is achieved by the filamentary magnetic field structure of small dimensions. Further analysis of Pioneer 6 and 7 deep space probe cosmic ray and magnetic field measurements are bound to add a wealth of information to our existing knowledge.

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KHAT AND CONGENITAL ABNORMALITIES

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KHAT addiction is still a problem in Yemen and other Arab countries. The problem was brought to the attention of the W.H.O. Commission on narcotic drugs in 1956, since then it had been discussed at successive sessions.[1,2] The question to be answered was whether Khat had the ill-effects comparable to those drugs under international control, or whether it is completely harmless and does not warrant any international action. The Commission came to the conclusion that nothing could be done until the medical aspects of the problem are studied. That study had not yet been undertaken because the chemical and the pharmacological identification of the active ingredients of Khat had not been encountered.

It is due to this point that the idea arose to investigate the effects of the crystalline Khat alkaloids on the developing chick embryo hoping to start a series of research work that would justify appraising Khat as a harmful drug.

To 25 gm. finely ground Khat leaves, 70 ml. ether and 35 ml. chloroform were added. The dried leaves were shaken and then allowed to stand for 10 minutes. 5 ml. of diluted ammonium hydroxide were added and shaking was continued for 6 hours followed by extraction for further 6 hours with the same solvent. The filtrate was extracted thrice with 10 ml. portions of Normal sulphuric acid. The acid extract was left to evaporate at room temperature. White needle-like crystals were then obtained, these were recrystallised from ethanol, dried, weighed and used as such for the purpose of the present experiments.

White Leghorn fertilized eggs were injected with $\frac{1}{2}$ c.c. distilled water containing 10 mgm. of crystalline Khat extract after 24 hours incubation. The eggs were then re-incubated for further 24, 48 and 72 hours before sacrificing the embryos.

Figure 1 shows a Khat extract-treated embryo aging 96 hours with monstroud phenotype. It is clear that nearly half the blastoderm had been degenerated. In this respect, Khat resembled colchicine which was found to cause the degeneration of a part of the blastodisk.[3] The process of cranial flexture was stopped at a level of a more early stage of 43 hours. The cervical region of the embryo was prevented from further flexion, and persisted at the long axis of the embryo. The caudal flexion failed completely to start, thus the characteristic C-shape of similarly aged normal embryos was lost ; an abnormal S-figure was acquired instead. This may be attributed to the complete paralysis of the posterior half of the embryo from performing any process of the positional orientation. The process of torsion could, however, take place in the anterior half of the body.

The prosencephalon (PROS.) could not differentiate into the diencephalon and telencephalon. Similarly, the mesencephalon (MES.) was not able to add to its wall the characteristic thickening. The rhombocephalon, however, could differentiate into the meten-MET. and myelencephalon (MY.) though it was reduced in size. The neural tube (NT.) took a zig-zag S-shaped pathway subsequent to the abnormal figure of the embryo. Of the special