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ACTIVE SOLAR RADIO REGIONS AT METRIC FREQUENCIES AND THE INTERPLANETARY SECTOR STRUCTURES

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ABSTRACT

The possible relation between type I noise active regions and the polarity distribution of the interplanetary magnetic field is examined for the period from 13 March to 21 August, 1968 (Solar Rotation Numbers 1842-1847) by using data from ground-based and satellite observations. In general four type I radio regions appeared during each solar rotation period except for Rotation No. 1842. The number of type I regions is the same as the number of sector boundaries. This result suggests that the configuration of the photospheric magnetic field extending into the interplanetary space may be related to the origin of the type I radio regions. Statistically the passage of the sector boundaries is delayed by approximately 5 days after the central

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meridian passage of the type I noise regions on the solar disk.

The position of the source of the sector boundaries and its relation to the type I radio regions are investigated by taking into account the mean bulk velocity of solar winds as observed by space probes. A model of the large-scale structure of type I radio regions and their relation to the sector structure of the magnetic field as observed in the interplanetary space is briefly discussed.

1. INTRODUCTION

At present it is widely believed that the interplanetary magnetic field near the earth is produced by the outward streaming of the plasma carrying with it the photospheric magnetic fields at low heliographic latitudes (less than 40^{o}) in association with the solar wind. This idea, based on the observations of the large scale photospheric magnetic fields and magnetic polarity distributions in the interplanetary space has been developed by many authors, (e.g., see the review paper by Wilcox (1968), which also contains references to work before 1968; and Schatten, Wilcox and Ness, 1969; Bumba and Howard 1969; Wilcox and Colburn, 1969; Wilcox, Severny, and Colburn, 1969; Wilcox, 1970).

On the other hand, Rosenberg and Coleman (Rosenberg and Coleman, 1969; Rosenberg, 1970) have proposed a different theory for the origin of the interplanetary magnetic field. Their analysis suggests that over most of a solar cycle, the dominant polarity of the interplanetary magnetic field in either the northern or southern hemisphere of interplanetary space is just that of the dipolar component of the sun's field in the same hemisphere. However recently, Wilcox, (1970) has critically reviewed the statistical significance of the heliographic latitude dependence of the dominant polarity of the interplanetary magnetic field proposed by Rosenberg and Coleman (1969). It has been proposed (Wilcox, Severny, and Colburn, 1969) that the interplanetary field is not generated by the magnetic fields associated with solar active regions, but rather by the large scale magnetic field of the sun. Schatten (1970) has shown quantitatively that these observations are in agreement with the potential field models of Altschuler and Newkirk (1969) and Schatten, Wilcox and Ness (1969)

Sakurai (1966a, 1966b) in considering the relationships between solar active longitudes and the polarity distribution of the interplanetary magnetic fields, found that the roots of the sector boundaries are located just east of the associated active longitudes. Furthermore, it was shown that these active longitudes, from which the sunspot groups effective for the production of solar proton flares are generated, persist for long periods of time, of the order of a few years.

It has recently been suggested that the solar active regions observed at metric frequencies are formed in the extended outer solar corona and are responsible for the formation of the coronal streamers extending into the interplanetary space (e.g., Fokker, 1963; Clavelier et al., 1968; Kai, 1970). It is known that the active source of type III burst storms at hectometric wave frequencies extends into the 10 - 30 solar radii from the solar surface (Fainberg and Stone, 1970a). Such a source may be connected with the coronal streamer and the sector structure of the interplanetary magnetic field.

2. SOLAR ACTIVITY DURING THE PERIOD FROM SOLAR ROTATION NUMBERS 1842 to 1847, 1968.

In this study, we have selected the period from Solar Rotation Numbers 1842 to 1847 (13 March - 21 August, 1968) because of the available observational data on the interplanetary magnetic field as described in Wilcox, Severny and Colburn,(1969). The data on the interplanetary magnetic field have been supplied by Ness and Fairfield (1970, private communication). The period mentioned above covers six solar rotations. We have made use of the radio data at 169 and 408 MHz obtained by the Nancay interferometric observations and solar flare data available from Solar Geophysical Data.

The radio regions observed at 169 and 408 MHz move westward on the solar disk due to solar rotation. This movement is seen in Fig. 1, where the high activity of the radio emission at 169 MHz is indicated by hatched areas. The radio sources at 408 MHz are shown with the plus and cross signs (+ and X) in the same figure. The cross sign gives an alternative position of radio source expressed by the plus sign. The abscissa and ordinate of this figure indicate time in days and the heliographic longitude, respectively. Three or four intense radio regions at metric frequencies appear during a solar rotation. The arrows in the figure indicate CMP of these active regions. The polarities of the interplanetary magnetic field as observed at the earth's orbit by satellites are shown above in Fig. 1.

The sector boundaries observed during the period under consideration are connected with the type I noise active regions by taking into account a plausible range of time delays. It is difficult in a few cases to associate the central meridian passage of such radio regions with the passage of the sector boundaries as is seen during the periods as April 15-19, May 14-19 and June 12-13.

The solid and open circles in Fig. 1 indicate the position of solar flares (Importance ≥ SF) which occurred in the northern and southern hemisphere of the solar disk, respectively. The day-to-day change of the positions of the active radio regions at metric frequencies is indicated with oblique lines in Fig. 1.

3. TYPE I ACTIVE REGIONS AND THE SECTOR STRUCTURE

The number of such radio regions is usually four or five per Solar Rotation as shown in Fig. 2, where intense radio regions are indicated with solid areas, and weaker regions by shaded areas. During the period covering Solar Rotation Numbers 1843 to 1847, four radio regions appeared in the northern hemisphere for each Solar Rotation. Apparently there is a one to one correspondence between these active regions and the sector boundaries as illustrated in Fig. 2. Therefore, it seems plausible that the source of the interplanetary sector structure is closely related to the configuration responsible for radio regions observed at metric frequencies.

As is shown in Fig. 1, the sector boundaries generally cross the vicinity of the earth several days after the central meridian passage of the radio regions. If we examine this time delay the histogram shown in Fig. 3 is obtained which shows that the passage of the sector boundaries occurs about five days after the central meridian passage of the metric radio regions. We estimate the speed of the solar winds which are recognized as responsible for the transport of the photospheric magnetic fields into the interplanetary space (e.g., Parker, 1958, 1963) as 350 km sec^{-1} for a 5 day time delay. ~ ·s value seems to be consistent with the most reliable one as observed by many space probes (e.g., Wilcox and Ness, 1965; Axford, 1968; Wilcox, 1968).

Although the solar wind properties reported by Hundhausen et al, (Hundhausen et al, 1970) applies to an earlier period to time, it is based on some 14,000 measurements obtained with the VELA 3 satellite from July 1965 to Nov. 1967. They obtain an average flow speed of 400 km/sec and a median speed of 380 km/sec. This average speed corresponds to a time 0.5 days shorter than the ~ 5 day delay deduced from a comparison of the central meridian passage of type I noise active regions and that of the sector boundaries.

This difference can be explained if on the average, type I noise regions are located ~ 8 degrees eastward from the position of the sources of the sector boundaries as shown schematically in Fig. 4a. Since the four radio regions shown in Figure 2 are separated by about 90 degrees. we can construct a model connecting the radio regions associated with type I noise storms and the sector structure of the interplanetary magnetic field, as shown in Fig. 4b. Figure 5 shows a model of the magnetic field lines from the sunspot groups extending into the outer corona. The field is inclined eastward to form the sector boundaries located on the east side of the active regions. Hatched areas show the two main parts of the type I noise active regions which are connected with the preceding and following sunspot polarities, respectively (Clavelier et al., 1968; Kai, 1970).

Type I noise active regions are estimated to be located in the regions 0.2 - 0.3 solar radii above the photospheric surface (e.g., Fokker, 1965; Kundu, 1965). During the period considered in this paper, all the active radio regions associated the sector boundaries in the interplanetary space are located in the northern hemisphere of the sun. We can thus conclude that this viewpoint is not consistent with the conclusion deduced from the suggestion of Rosenberg and Coleman (1969).

As is shown in Fig. 2, the number of the active radio regions during a solar rotation is generally four, one of which is, however, less intense than the other active regions.

It is clear that these four radio regions are related to the sector structure of the interplanetary magnetic field. During the increasing and maximum phases of the last solar cycle, No. 19, there also appeared four stable active regions which were mainly responsible for the generation of solar proton flares (Sakurai, 1967) and the enhancement of the coronal green line emission (Gnevyshev, 1963)). In our case, however, we could not detect a trend similar to that obtained by Gnevyshev (1963).

4. CONCLUSION

In this paper, we have examined the radio noise regions at metric frequencies (169 and 408 MHz) and their relationship to sector structure in the interplanetary medium for the Solar Rotation Numbers 1842 - 1847 (13 March - 21 August, 1968) by considering the polarity distribution of the interplanetary magnetic field observed by space probes. These radio emissions at metric frequencies seem to consist mainly of type I noise storms (Sakurai, 1970) and seem to be related to decametric and hectometric radio emissions as suggested by Fainberg and Stone (1970a).

The number of these type I noise active regions is, in general, four as is shown in Fig. 2, and corresponds to the sectors in the interplanetary space. The photospheric magnetic fields connected to the origin of the sector boundaries in the interplanetary magnetic field apparently play an essential role in the formation of type I noise active regions. These active regions seem to be inclined eastward on the solar surface as is indicated in Fig. 4 and 5. This latter result is consistent with the suggestion by Fokker (1963), Sakurai (1964, 1965) and Clavelier et al (1968).

In view of the correlation between type I radio noise regions and the sector boundaries, we suggest that superthermal electrons released from such regions may stream outward along the associated sector boundary and give rise to the hectometric solar radio emission in the interplanetary medium. The anticipated characteristics of type III solar radio emission from a packet of electrons injected into or near a neutral sheet has been considered by Weiss and Wild (1964).

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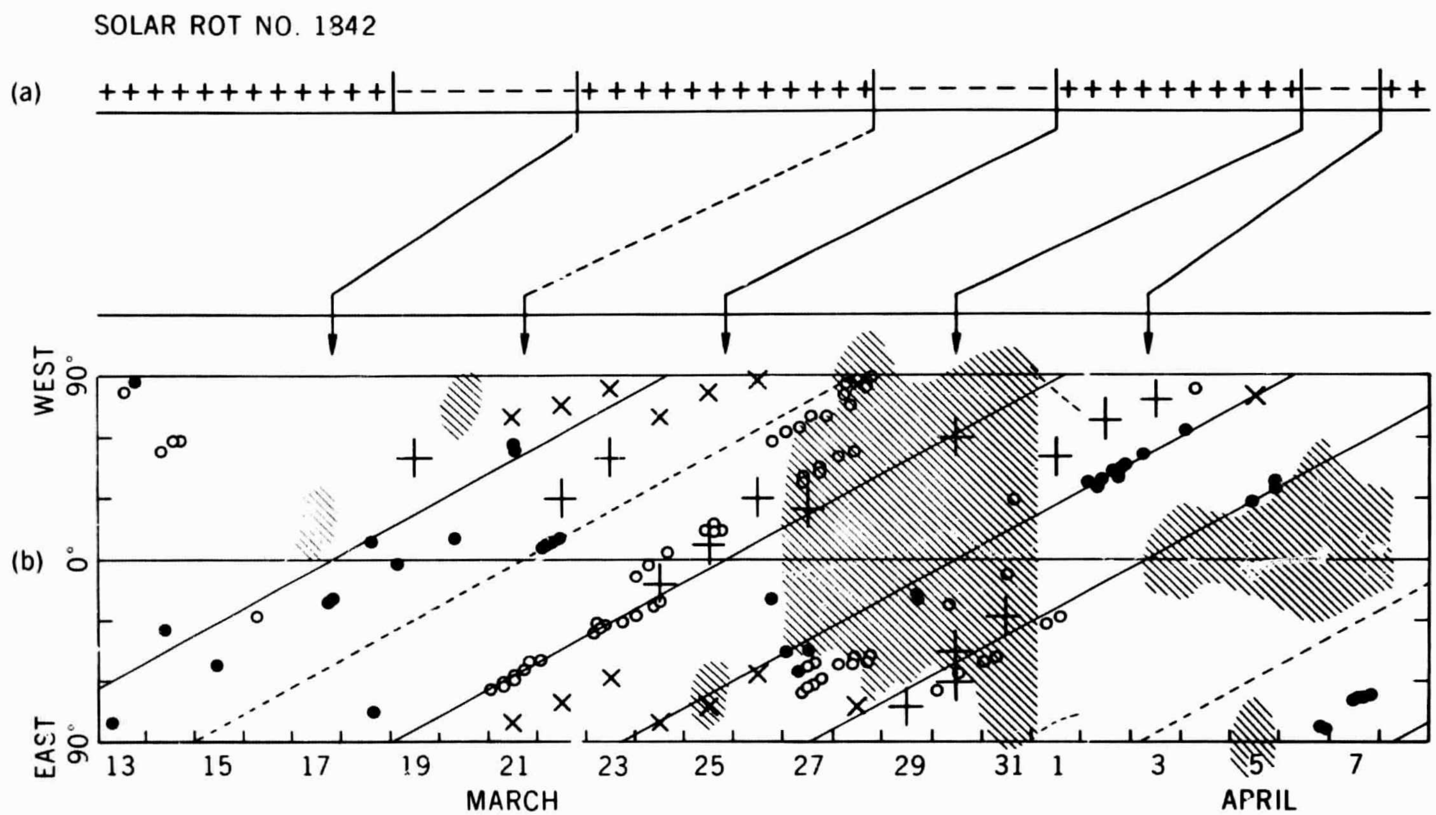

Fig. 1a- Solar activities as radio emissions at 169 and 408 MHz and solar flares and their movement on the solar disk. The hatched areas indicate the enhancement of noise storms identified with type I activity at 169 MHz. whereas the activity at 408 MHz is shown by plus and cross signs. Solid and open circles indicate the position of solar flares of importance $\geq$ SF in the northern and southern hemisphere, respectively. (a) the polarity distribution of the interplanetary magnetic field at the earth's orbit and (b) the day-to-day variation of type I noise sources with respect to the heliographic longitude.

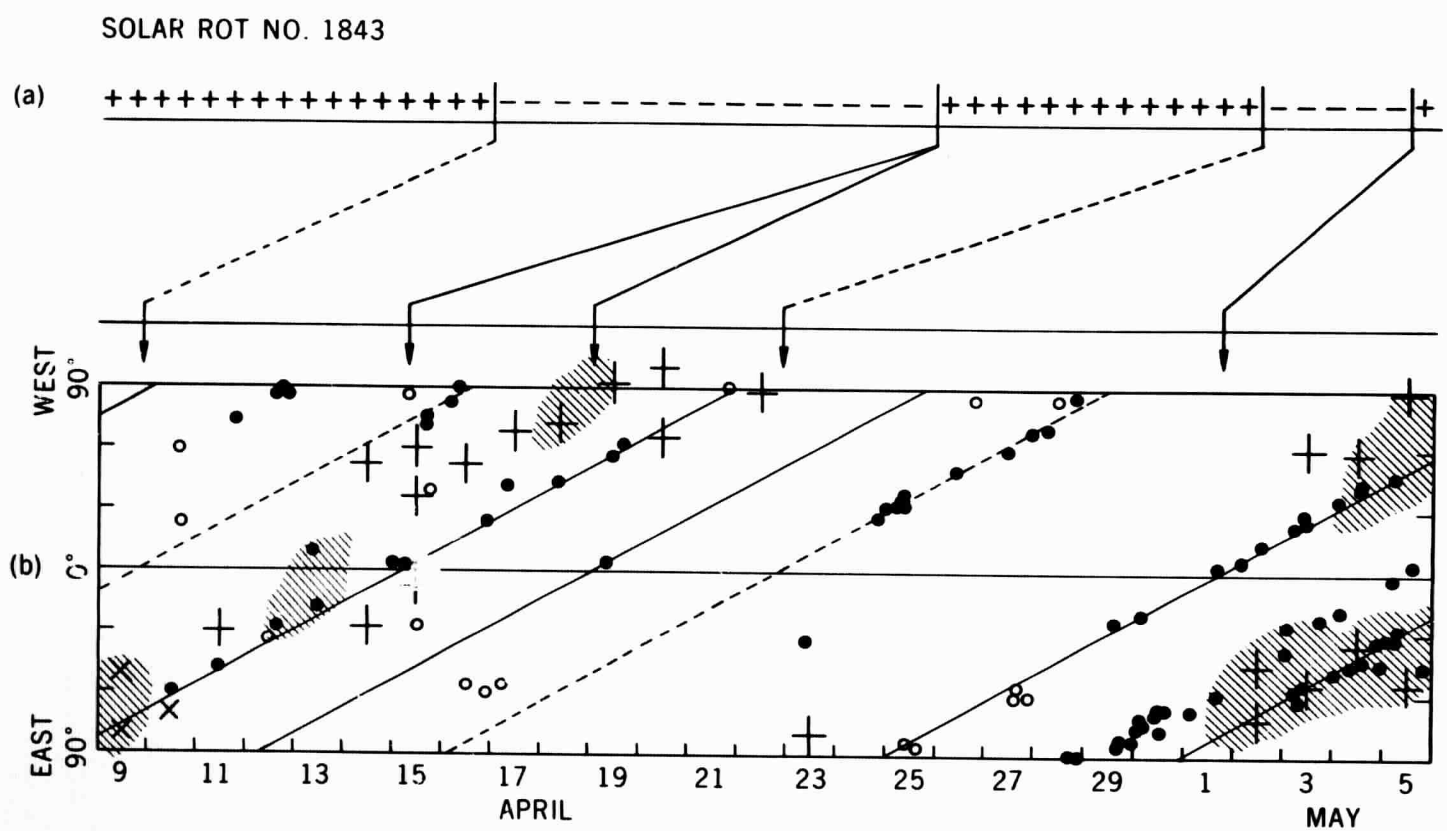

Fig. 1b - See Figure 1a for explanation.

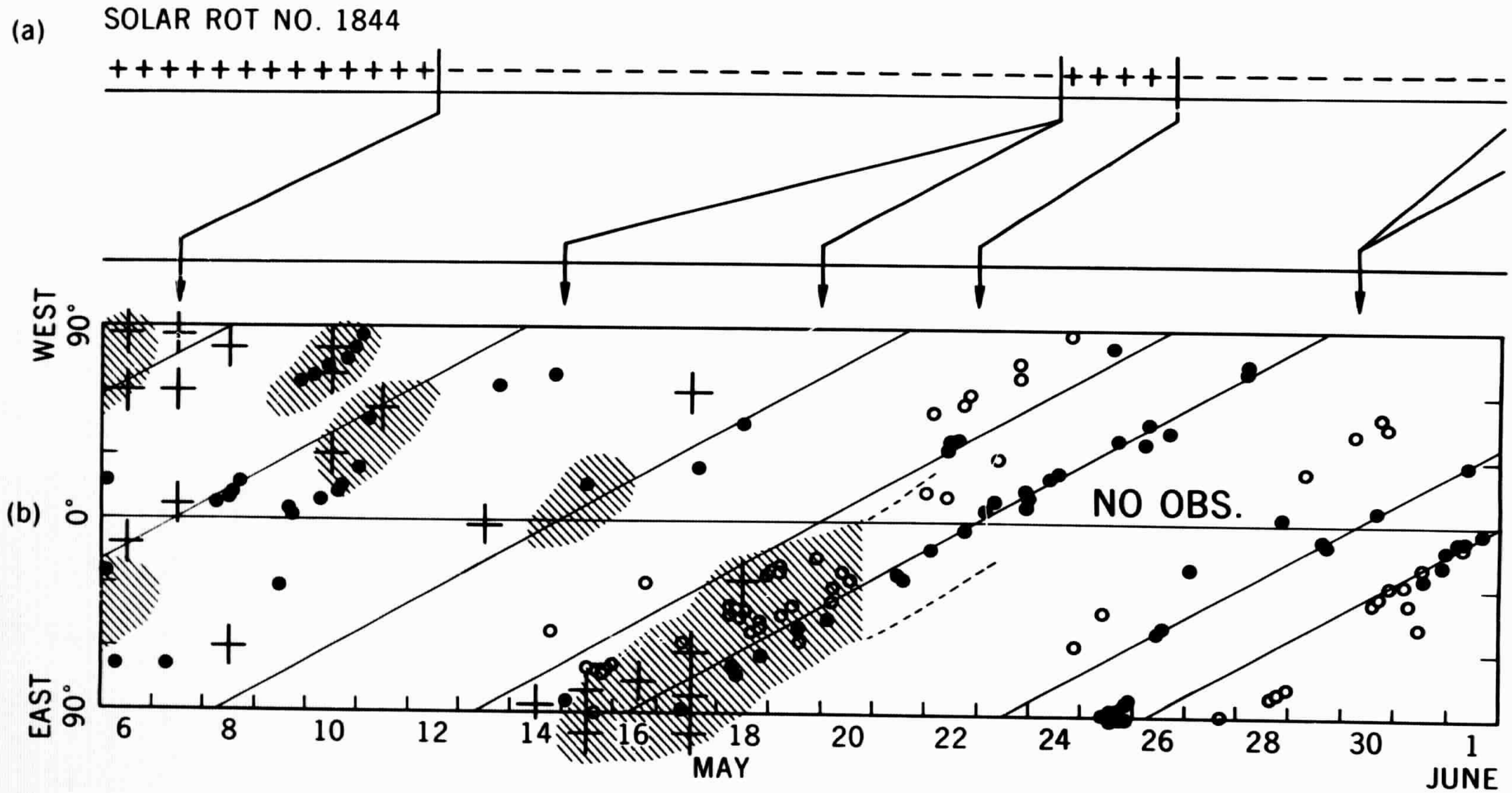

Fig. 1c - See Figure 1a for explanation.

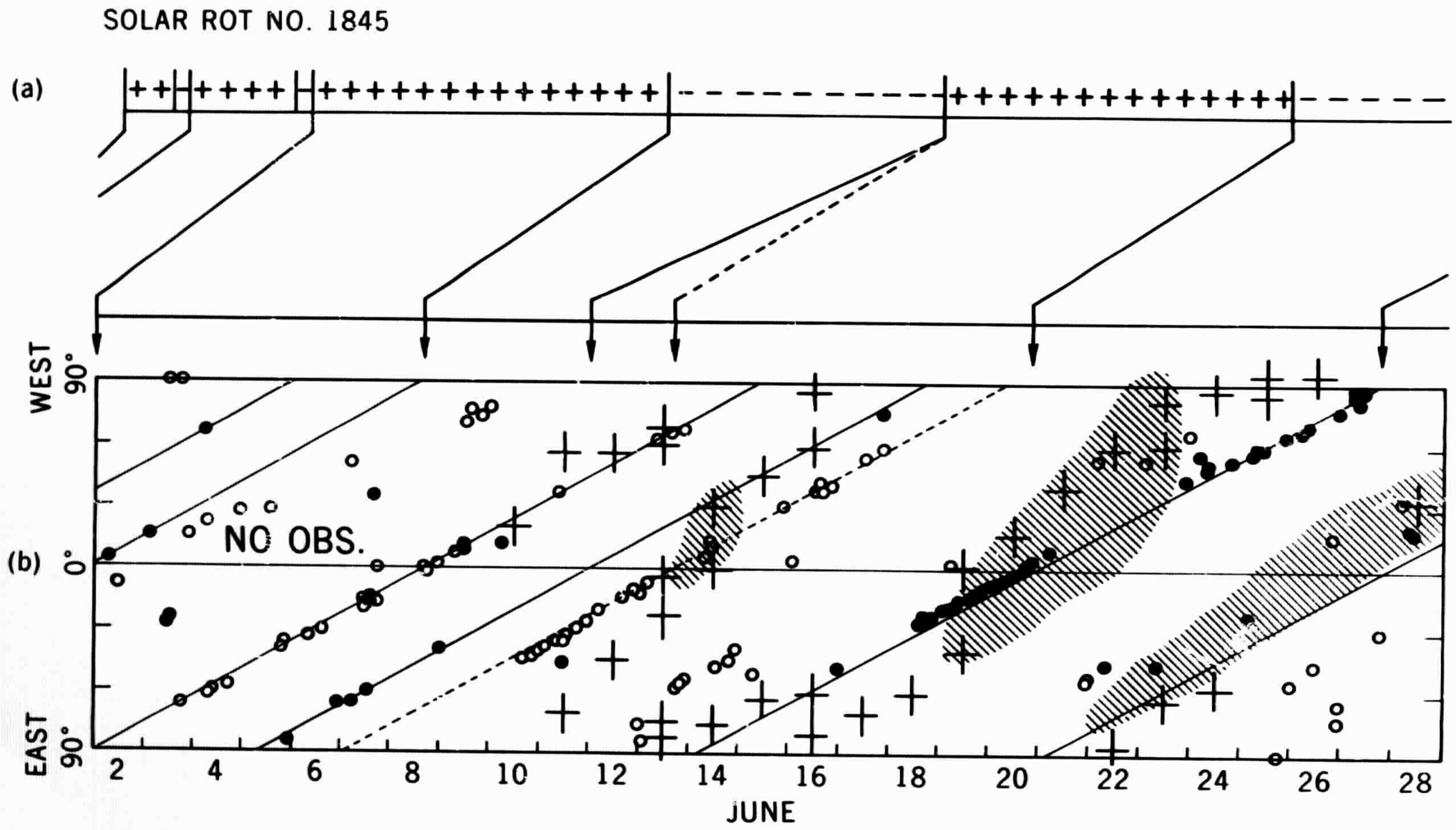

Fig. 1d - See Figure 1a for explanation

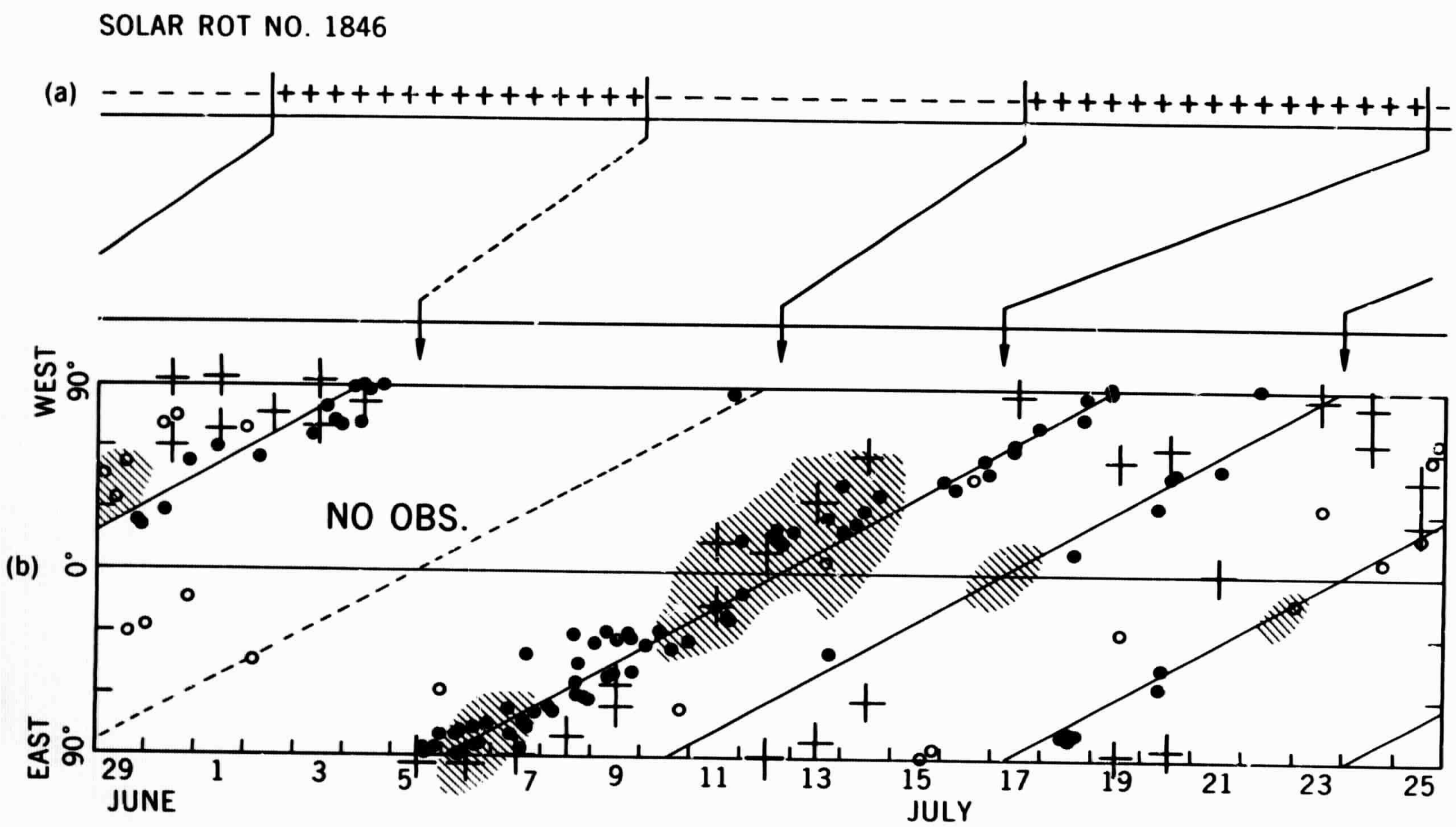

Fig. 1e - See Figure 1a for explanation.

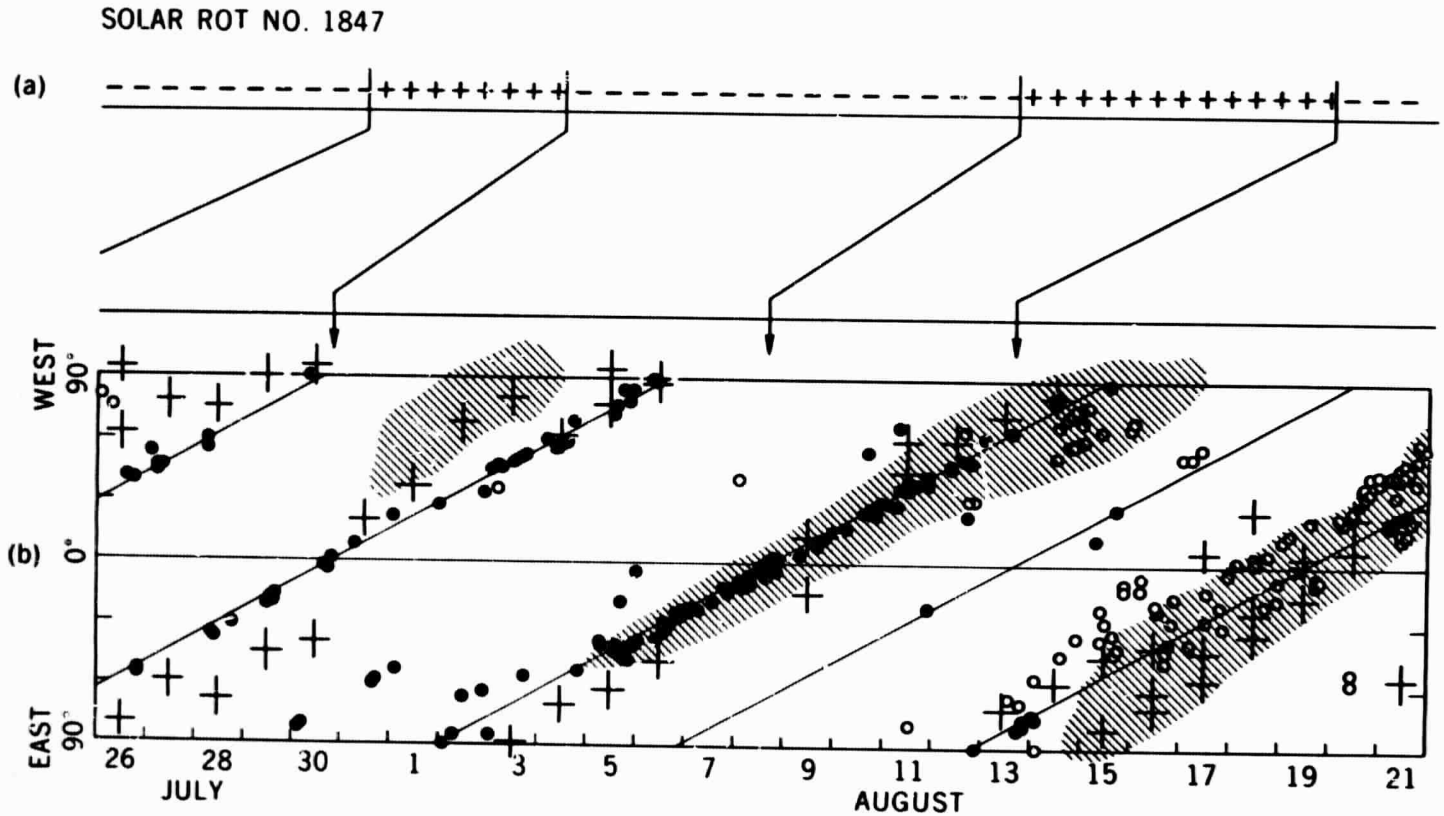

Fig. 1f - See Figure 1a for explanation.

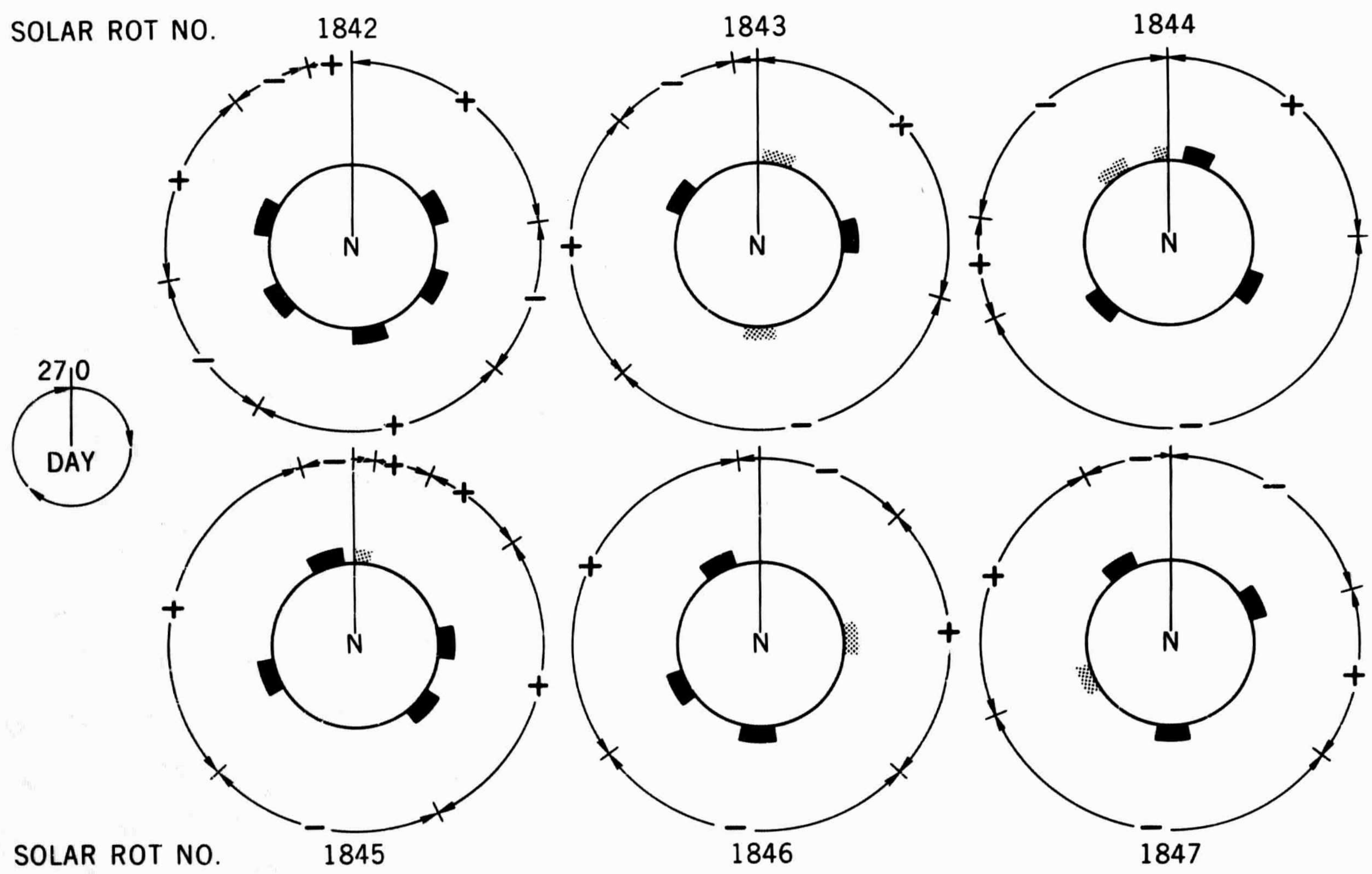

Fig. 2 - The heliographic longitude distribution of the radio active regions at metric frequencies and the polarity of the interplanetary magnetic field observed at the earth's orbit. The latter is not corrected with respect to the time delay accompanied by the transport of the photospheric magnetic field to the earth's neighborhood by considering the velocity of solar winds.

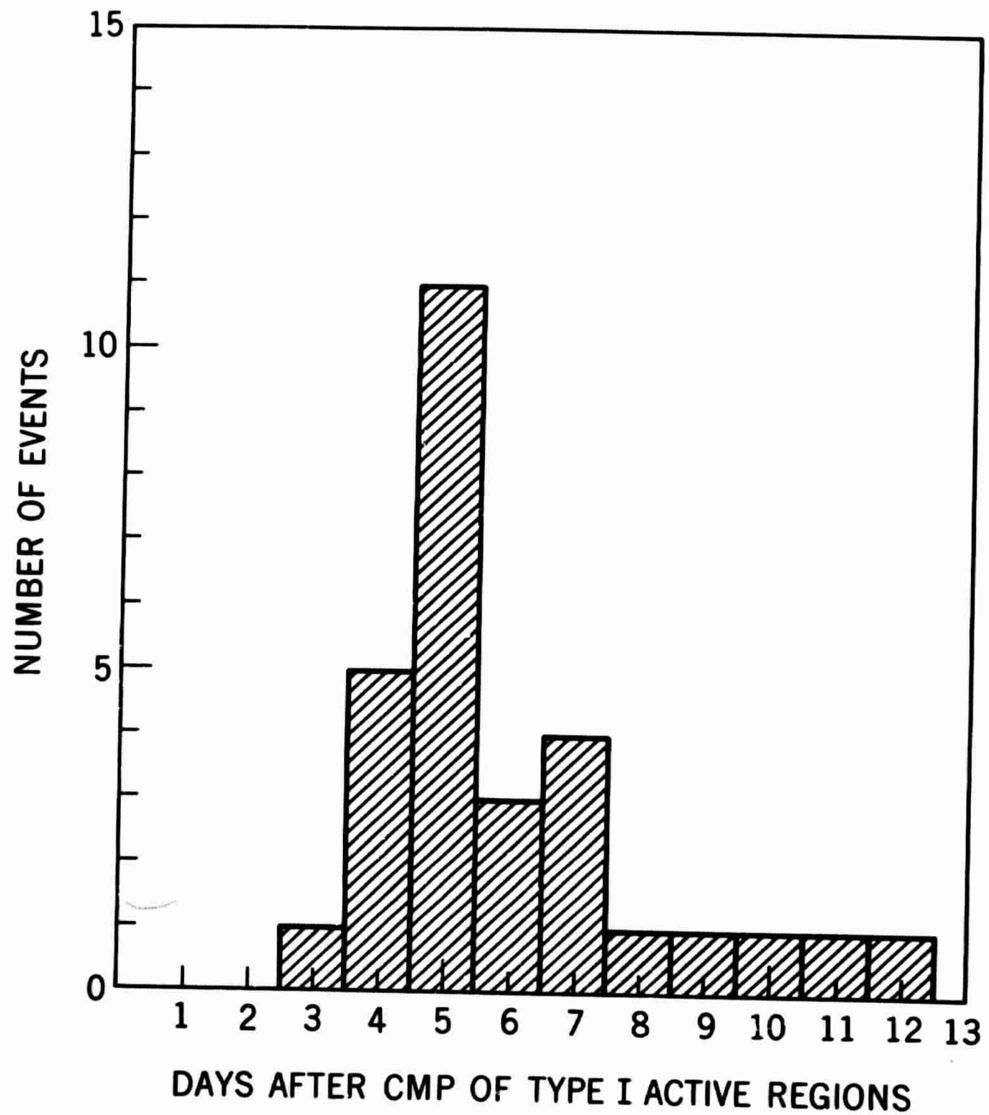

Fig. 3 - Histogram of the time interval between the central meridian passage of radio active regions at metric frequencies and the passage of the sector boundaries in the vicinity of the earth.

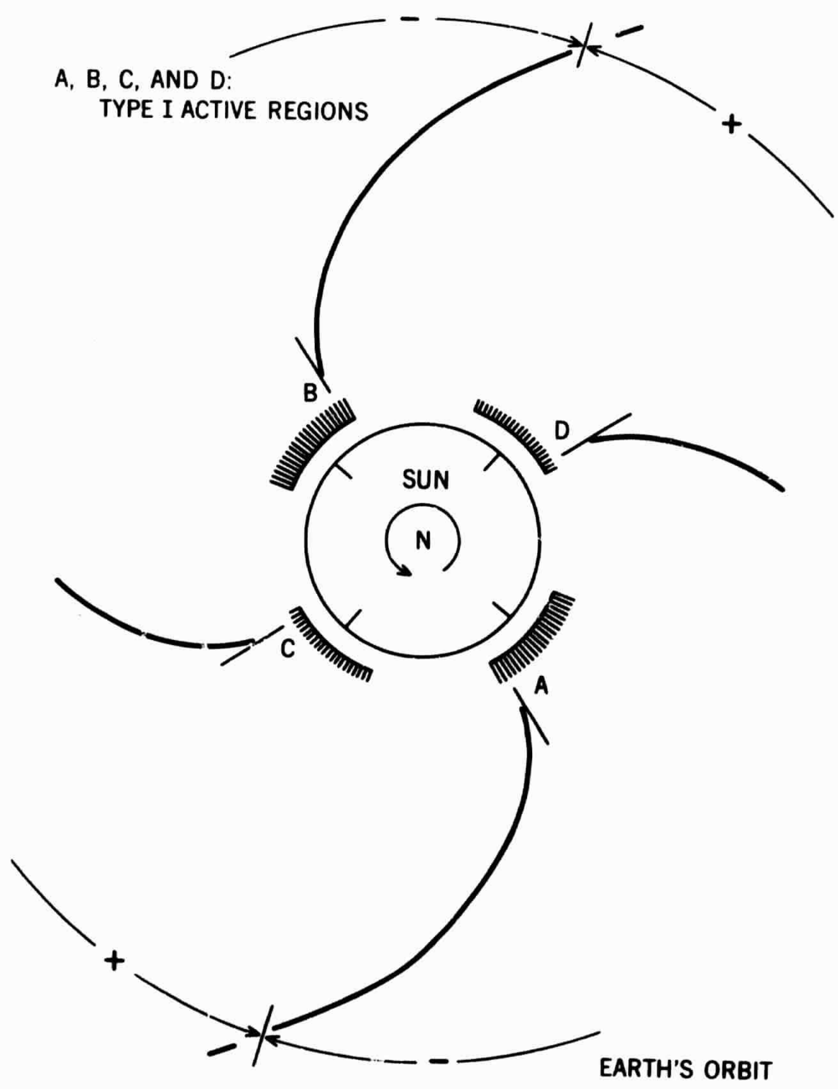

Fig. 4a- The schematic diagram of the sector boundaries extra polated from the observations of solar wind velocity by Pioneer VI and their relation to the position of type I noise active regions.

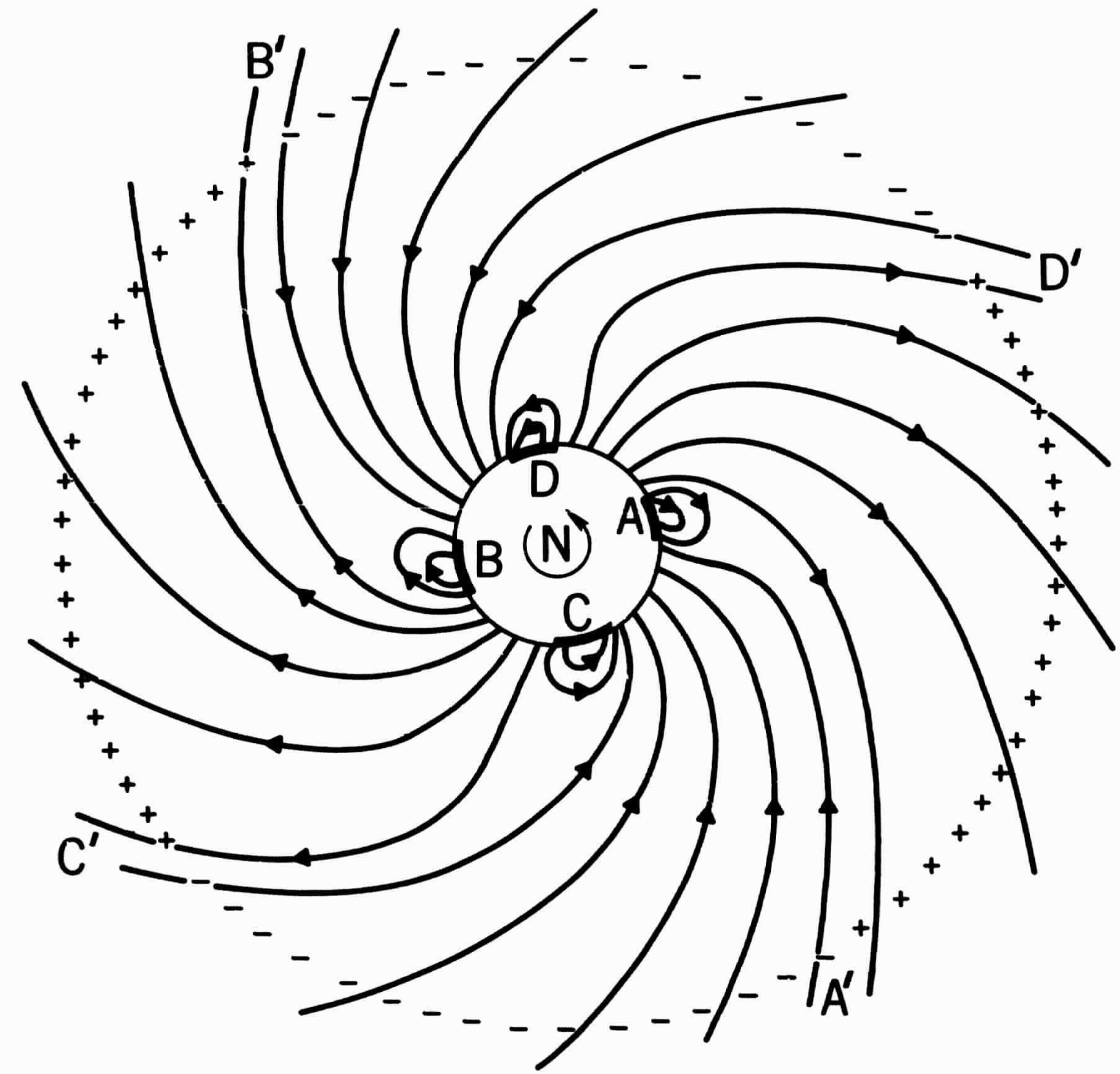

Fig. 4b- A model on the relationship between the type I noise active regions and the sector structure of the interplanetary magnetic field. A, B, C and D indicate the type I noise active regions and A', B', C' and D' give the sector boundaries.

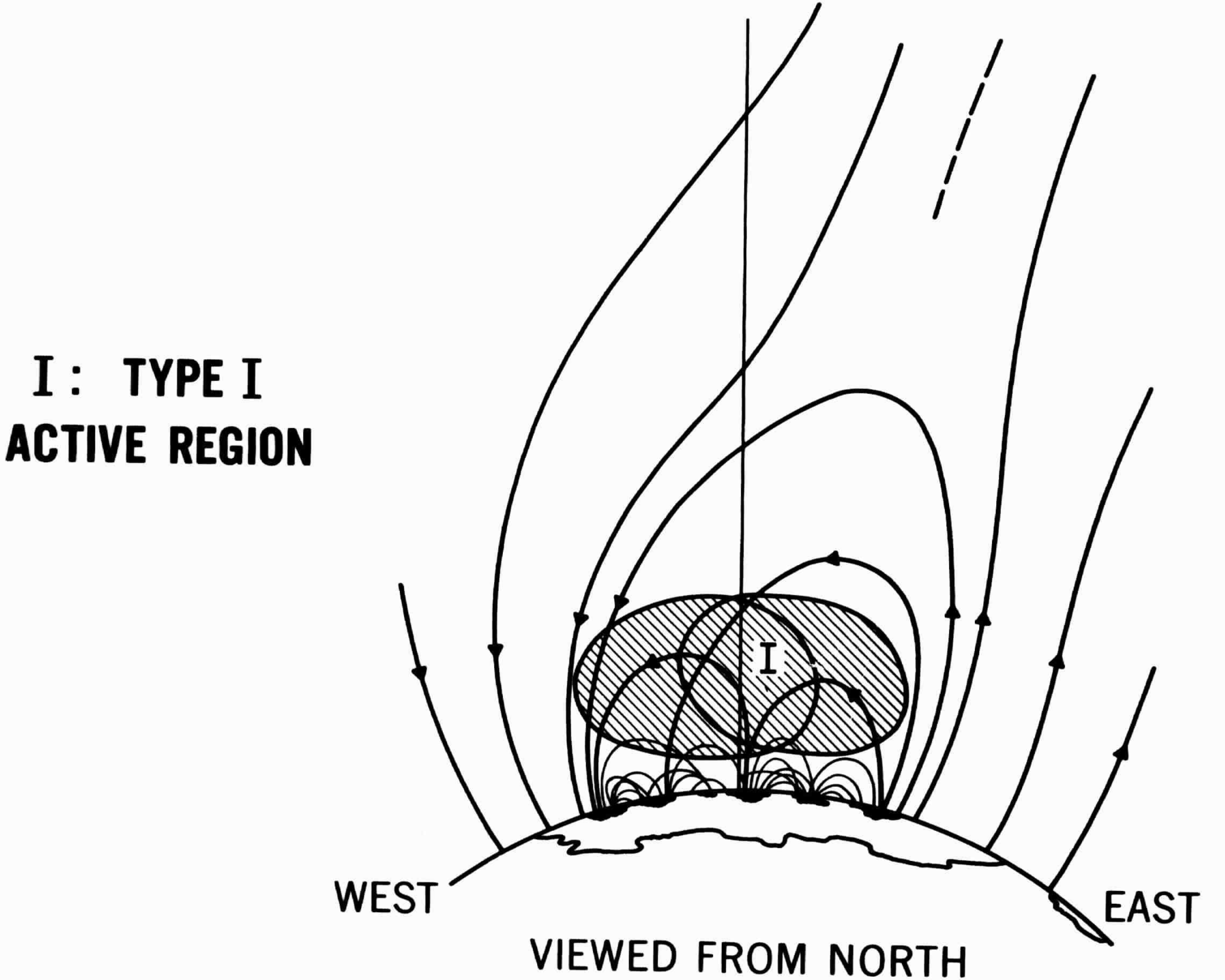

Fig. 5 - The structure of a type I noise active region and its relation to the sector structure of the interplanetary magnetic field. The dotted line shows the sector boundary.