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ON THE MAGNETIC CONFIGURATION OF SUNSPOT GROUPS WHICH PRODUCE SOLAR PROTON FLARES

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ABSTRACT

The configuration of sunspot magnetic fields is deduced by using the observational data on the development of type IV radio bursts and Hα-brightening areas over the umbrae of sunspot groups. Since both polarity areas are existent together within the same umbrae, the magnetically neutral regions are usually produced along the areas separating the one polarity area from the other. In the eastern portion of the preceeding sunspots, the gradient of sunspot magnetic fields is much steeper compared to all other portions and thus solar proton flares are triggered within or very near this portion. Hα-brightening areas develop mainly above the preceeding sunspots and their eastern portion of sunspot groups. This tendency seems to be closely related to the configuration of sunspot magnetic fields and the mechanism of solar proton flares.

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1. Introduction

The magnetic configuration of sunspot groups which are favorable for the occurrence of solar proton flares has been recently examined by Warwick (1966). She has shown that the magnetic configuration is very important for the occurrence of solar proton flares and is identified with the δ-type which has been recently proposed by Künzel (1960). The sunspot groups of this type are characterized by the co-existence of both polarities, north and south, within the same umbral regions (Künzel, 1960; Bray and Loughhead, 1962, 1965).

In general, solar proton flares, which are observable by Hα-emission brightness, develop over the areas separating from north to south polarity regions within the same sunspot groups. Thus, the coverage of sunspot umbral regions by Hα-brightening areas is always observed in association with solar proton flares, as has been shown by Dodson and Hedeman (1959), Ellison, McKenna and Reid (1961) and Malville and Smith (1963).

The sunspot groups which produce solar proton flares have some kind of rotational motion associated with their growth with respect to the heliographic latitude (Sakurai, 1967, 1969) This rotational motion seems to be deeply connected with the cause of solar proton flares, since, as is well known (for example, Kiepenheuer, 1953), most sunspot groups which are not related to the occurrence of proton flares do not show such motion.

In this paper, the magnetic configuration of sunspot groups where solar proton flares take place is examined by using the data on the center-to-limb change of characteristics of type IV radio bursts and Hα-brightening areas on the solar disk.

2. Magnetic Structure of Solar-Proton Flare Regions

Warwick (1966) has shown that the structure of sunspot groups which produced solar proton flares is identified with δ-type. Anderson (1961) further shows that solar proton flares develop within sunspot groups of types E and F, being surrounded by the one big penumbral regions.

It is further known (Dodson and Hedeman, 1959, 1960; Ellison, McKenna and Reid, 1961) that Hα-brightening areas always cover a part of the umbral regions of sunspot groups when solar proton flares develop. These phenomena are now called "the umbral coverage" of Hα-brightening areas, and well correlated with the generation of type IV radio bursts (Malville and Smith, 1963).

Sakurai (1964, 1965a) has shown that the time sequence of the development of type IV radio bursts from microwave to both decimetric and metric wave ranges shows a strong east-west asymmetry with respect to the solar longitude, referred to the central meridian plane of the solar disk as is reproduced in Fig. 1. It is certain in this figure that the start of metric wave emission (IVmA) is always delayed from that of microwave emission (IVμ) of type IV radio bursts and that this time delay becomes significantly longer as it moves eastward from the western limb.

Most of the Hα-brightening regions which are generated in association with solar proton flares cover some part of the umbral regions of sunspot groups (Sakurai, 1965b). On the basis of the data obtained by Dodson and Hedeman (1959, 1960), Malville and Smith (1963) and others, the magnitude of the umbral coverage by Hα-brightening regions is now arranged as a function of the solar longitude referred to the limb of solar disk as is shown in Fig. 2. This result also shows a strong tendency of east-west asymmetry similar to that for the time sequence of the development of type IV radio bursts which is shown in Fig. 1. Thus, it seems that this east-west asymmetric property is very useful for deriving a model of the magnetic configuration of sunspot groups.

These data on type IV radio bursts and Hα-brightness are arranged in a polar coordinate system with respect to some point over the photospheric surface, and are shown in Fig. 3. As is evident from this figure, the time difference between the occurrences of IVμ and IVmA components is strongly dependent on the direction of observation from the earth. The umbral coverage of Hα-brightening regions also shows the similar dependence in accordance with the direction of observation as shown in Fig. 3(b).

The emission mechanism of microwave (IVμ) and metric (IVmA) components is presently believed to be due mainly to synchrotron emission produced by energetic electrons moving within the sunspot magnetic fields where solar proton flares occur. Consequently, the magnitude of the most efficient radio frequency f_c emitted from those electrons is strongly controlled by the strength of sunspot magnetic fields and is given by

$$f_c \simeq 1.4 \, B_o \left(\frac{E_K}{m_o C^2} + 1 \right)^2 \text{ MHz},$$

along the same intensity su

and the pitch angle of the emitting electrons are the same everywhere, it is easy to draw the equi-frequency surface, i.e., the equi-intensity surface of magnetic fields with an assumption of the spherical expansion of radio sources of referring to the result as shown in Fig. 3(a). The surface thus obtained is shown in Fig. 4, which shows that the gradient of magnetic field intensity is much steeper in the eastern part than in the western part of the preceeding main sunspots, since the radio sources are thought of as expanding from some small areas located in the eastern portion of these spots.

The distribution of Hα-brightening areas over the sunspot groups is also deduced by using the result as shown in Fig. 3(b). The result is shown in Fig. 5, which shows that the Hα-brightening areas are mounded high up over the western portion of sunspot groups in the solar atmosphere and the preceeding part of sunspot groups is largely covered by the Hα-brightening areas. This result suggests that the triggering of solar proton flares is usually produced somewhere over the photosphere in the western portion of preceeding sunspots. This is very similar to the conclusion obtained for the development of type IV radio bursts (Fig. 4). Taking the result shown in Figs. 4 and 5 into consideration the configuration with solar longitude of sunspot magnetic fields which produce solar proton flares can be deduced.

It has been furthermore found (Sakurai, 1967) that these sunspot groups show a tendency to rotate counterclockwise (clockwise) in the northern (southern) hemisphere throughout their growth phase. Thus, the configuration of sunspot magnetic fields is deduced by referring to those results mentioned above. The configuration obtained is schematically shown in Fig. 6.

3. Development of Solar Proton Flares

The magnetic configuration of sunspot groups is related to the structure of Hα-brightening areas as is shown in Fig. 6. These areas are usually located between the preceeding and the following sunspots with opposite polarity, but often near the eastern portion of the preceeding sunspots (Fig. 5). This observational result suggests (Kiepenheuer, 1964) that some triggering action for the development of solar flares may originate within or near some magnetically neutral regions, over the umbrae of sunspot groups, which are necessarily produced near the eastern portion of preceeding sunspot groups, as many authors have discussed (for example, Dungey, 1958, 1959; Sweet, 1958, 1964; Petschek, 196 ; Severny, 1964, 1965). This triggering action seems to be closely related to the twisting motion of sunspot magnetic field lines (Sakurai, 1967). Since the magnetic configuration of sunspot groups mentioned before is in quasi-equilibrium state, the shearing stress due to the twisting motion would play an important role in generating some instability and further development of solar flares.

4. Discussion

In association with solar proton flares, energetic electrons responsible for the emission of type IV radio bursts are usually generated (for example, Smith and Smith, 1963; Webber, 1964; Kundu, 1965). It is certain that, as being deformed, the sources of type IV radio bursts start to expand from the small area located in the eastern portion of the preceeding sunspots to the coronal regions. Hα-brightening areas are generated around and extend from this area.

The magnitude of the gradient of magnetic field intensity at the eastern portion of the preceeding sunspots seems, further, to take an important part in generating solar flares, as has been inferred by Severny (1964, 1965).

The energetic electrons seem to be accelerated at the same time within or very near the regions where solar proton flares are triggered, being identified with somewhere at the eastern portion of preceeding sunspots. After acceleration, the clouds of these electrons expand nearly spherically through the sunspot magnetic fields. With this expansion, the cut-off frequency of type IV radio bursts becomes lower and lower, as has been shown in Fig. 1.

The explosive phase is identified with the initial stage of flare development immediately after this expansion starts. Energetic solar protons and heavier nuclei are accelerated during this phase through their interaction with violent and rapid magnetic field change.

5. Concluding Remarks

The three-dimensional configuration of sunspot magnetic fields where solar proton flares were produced has been deduced by using the observational data on the development of type IV radio bursts and Hα-brightening areas over the umbra of sunspot groups. The characteristics of the configuration of those sunspot magnetic fields are here summarized in Table 1.

As has been considered (Sakurai, 1967), the twisting motion of sunspot groups appears to play an important role in the triggering of solar proton flares, but any direct causal relation between this motion and the configuration has not been established yet. It is hence very important for the understanding of solar flare mechanism to establish the detailed configuration of sunspot magnetic fields. The twisting motion just mentioned further seems to produce some sort of shear stress along the magnetically neutral regions which are produced between the preceeding and following sunspots. These stresses may be related to the formation of the steep gradient of magnetic field intensity in the eastern portion of preceeding sunspots.

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Table 1 - Characteristics of Sunspot Magnetic Field Configuration which is Associated with Solar Proton Flares.

1) Type of Sunspot groups	δ-type (Warwick, 1966) Both polarity regions are usually surrounded by the same umbral regions. These umbrae are within the one big penumbrae (Anderson, 1961)
2) Relation between Hα-flare areas and the sunspot groups	a) Hα-brightening areas cover part of the umbral regions b) Hα-brightening areas are usually located over the regions bordering the opposite polarity regions, but somewhat nearer to the preceeding main sunspots than to the following ones, as shown in Fig. 4.
3) Distribution of magnetic fields.	a) The intensity of magnetic fields for the preceeding sunspots is much greater than that for the following ones. b) The gradient of magnetic field intensity is steepest at the eastern portion of the preceeding sunspots.

4) Proper motion of sunspot groups (viewed from the earth)

in northern hemisphere counterclockwise rotation

southern hemisphere clockwise rotation

5) Global structure of sunspot groups Fig. 6

a) Sunspot magnetic lines of force are strongly twisted anticlockwise (clockwise) in the northern (southern) hemisphere.

b) Preceeding spots are located northward compared to the following ones in the northern hemisphere and vice versa.

c) Magnetically neutral regions are generated in the areas bordering the opposite polarity regions within the same umbrae, but are located nearer to the preceeding spot groups.

CAPTION OF FIGURES

Fig. 1 - The time delay between the occurrences of microwaves to (a) decimetric and (b) metric waves of type IV radio bursts with respect to the solar longitude (Sakurai, 1964).

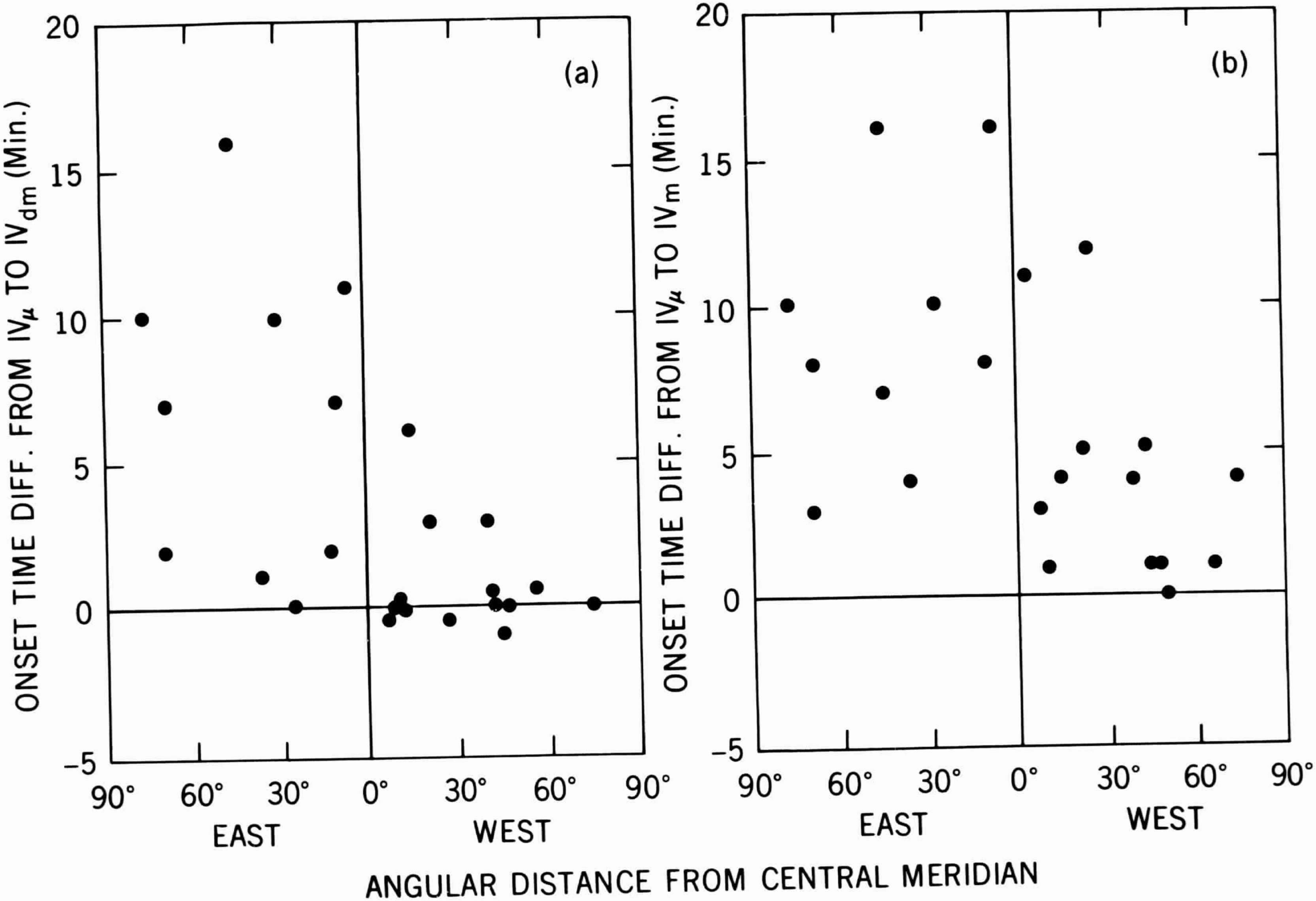
Fig. 2 - The umbral coverage of Hα-brightening regions with respect to the solar longitude. The amount of this coverage is given by the ratio of the areas covered by Hα-brightening areas to the whole areas of the umbrae of sunspot groups.

Fig. 3 - The polar diagrams of (a) the time delay as shown in Fig. 1 and of (b) the umbral coverage of Hα-brightening areas.

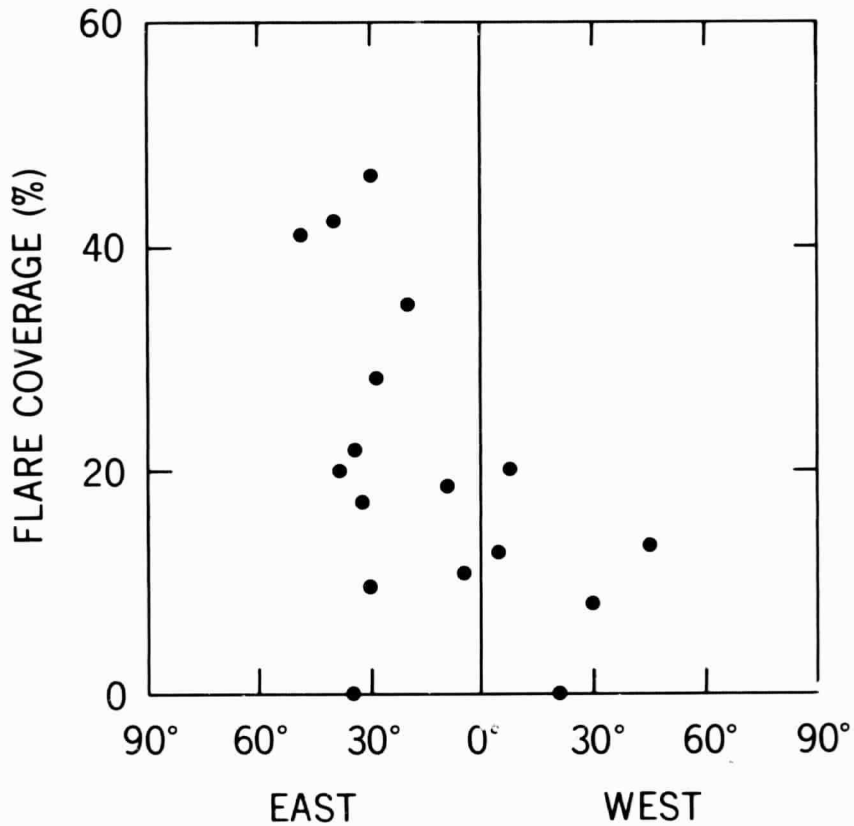
Fig. 4 - Several equi-intensity curves of sunspot magnetic fields deduced from the polar diagram of development of type IV radio bursts as shown in Fig. 3(a). From those curves, the magnetic configuration of sunspot groups is obtained with respect to the solar longitude.

Fig. 5 - The distribution of Hα-brightness areas deduced from the data on the umbral coverage of Hα-brightness as shown in Fig. 3(b)

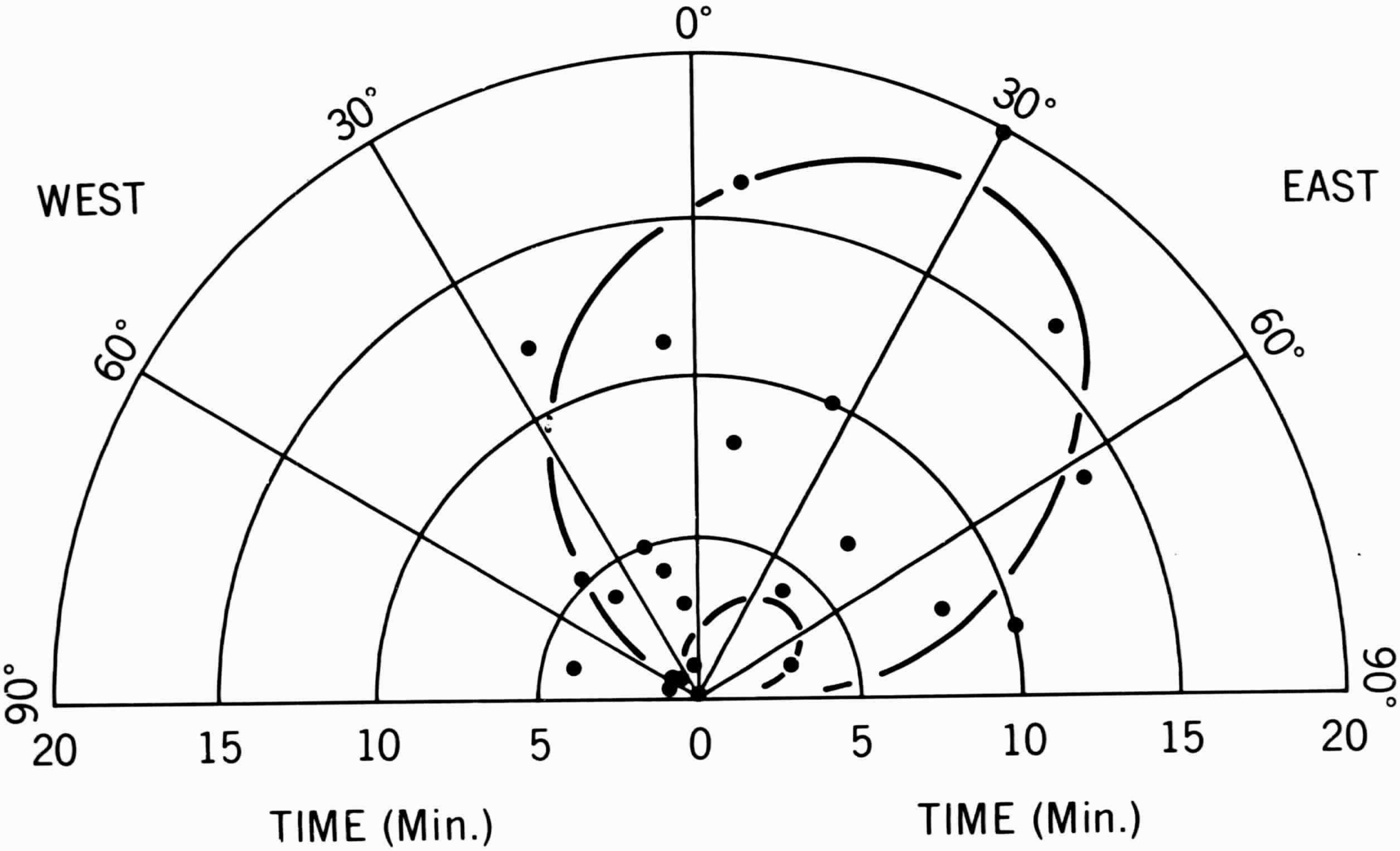
Fig. 6 - Gobal configuration of sunspot magnetic fields and the location of Hα-brightening areas in the northern hemisphere. Shaded area shows the Hα-brightening. P and F indicate the preceeding and following spots, respectively.



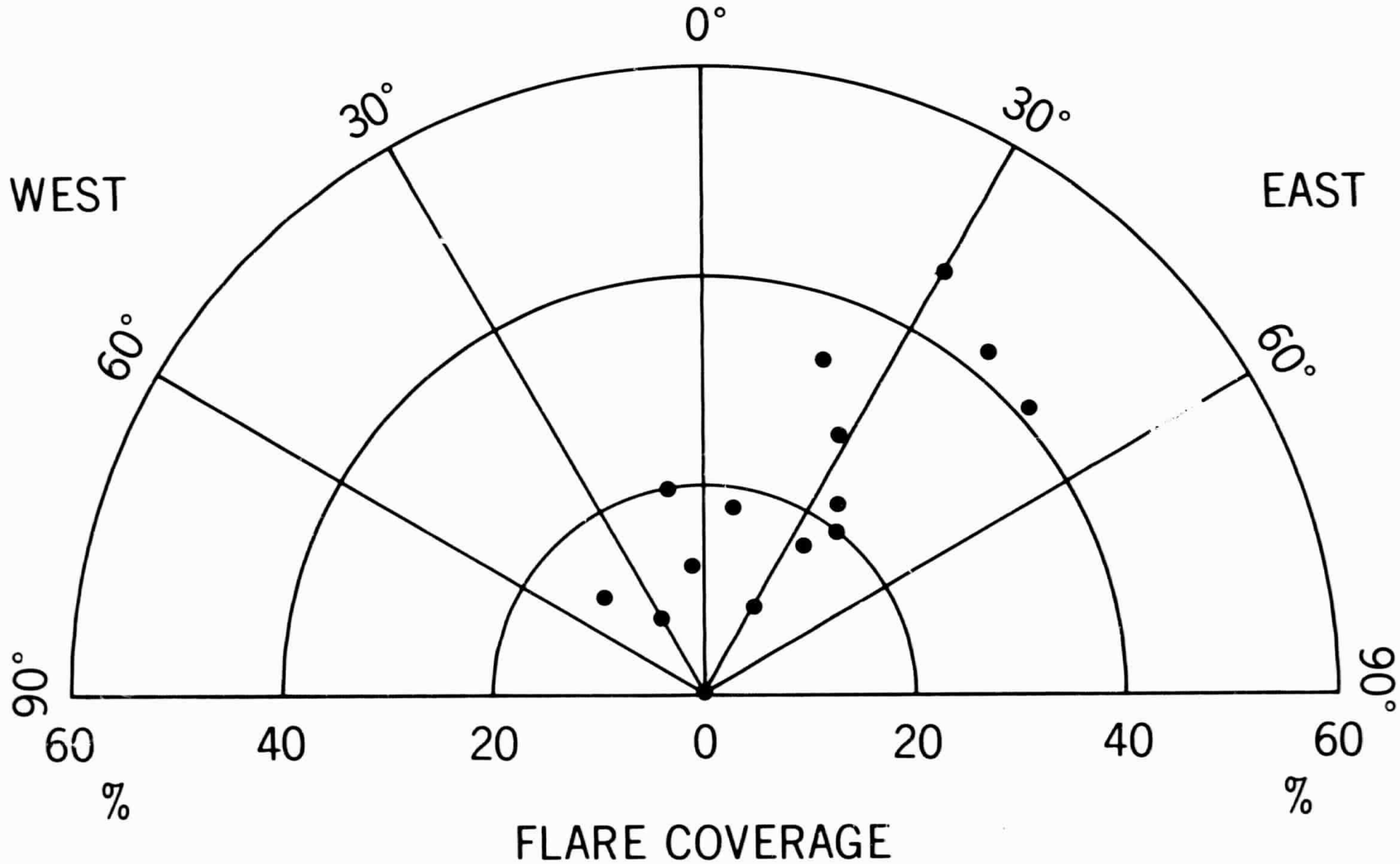
(a)
(b)
ONSET TIME DIFF. FROM IV$_\mu$ TO IV$_{dm}$ (Min.)
ONSET TIME DIFF. FROM IV$_\mu$ TO IV$_m$ (Min.)
20
15
10
5
0
−5
90°
60°
30°
0°
30°
60°
90°
EAST
WEST
ANGULAR DISTANCE FROM CENTRAL MERIDIAN

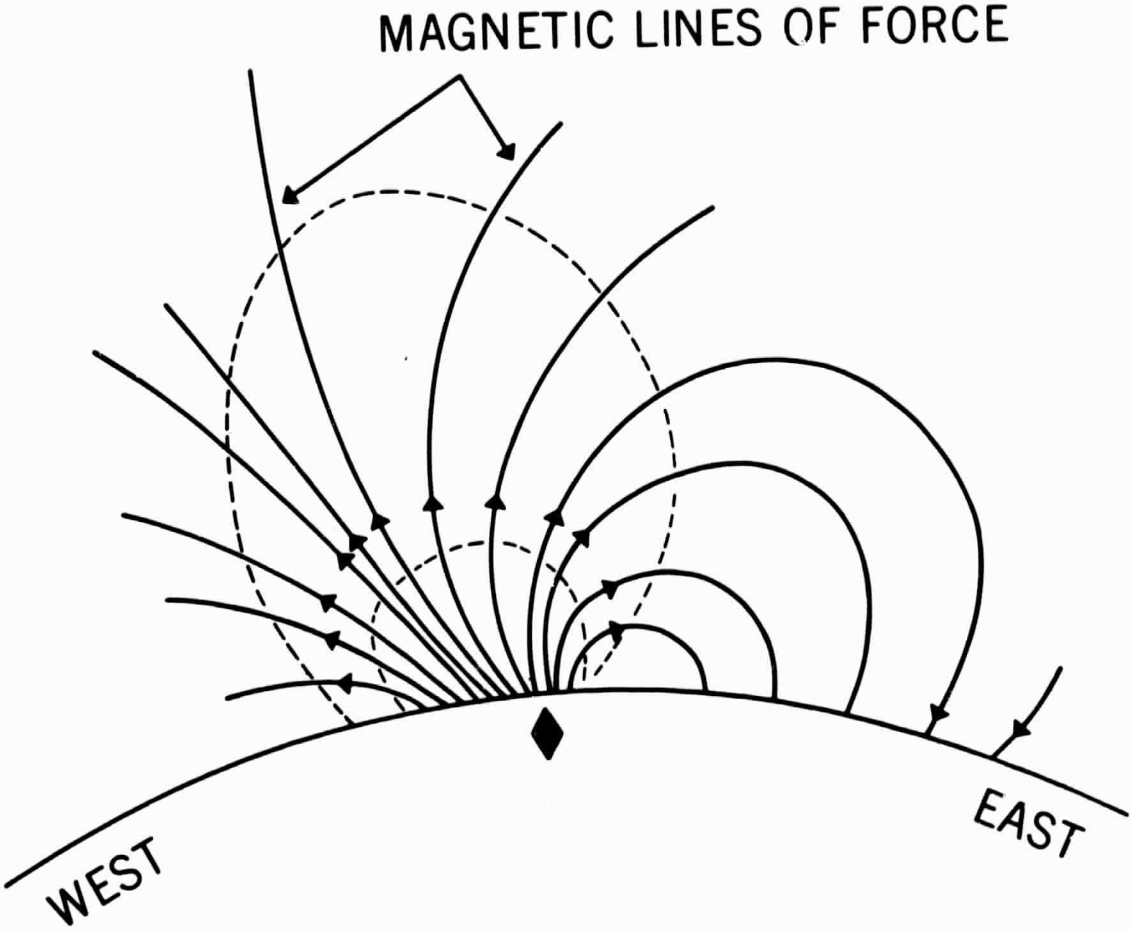


FLARE COVERAGE (%)
60
40
20
0
90°
60°
30°
0°
30°
60°
90°
EAST
WEST

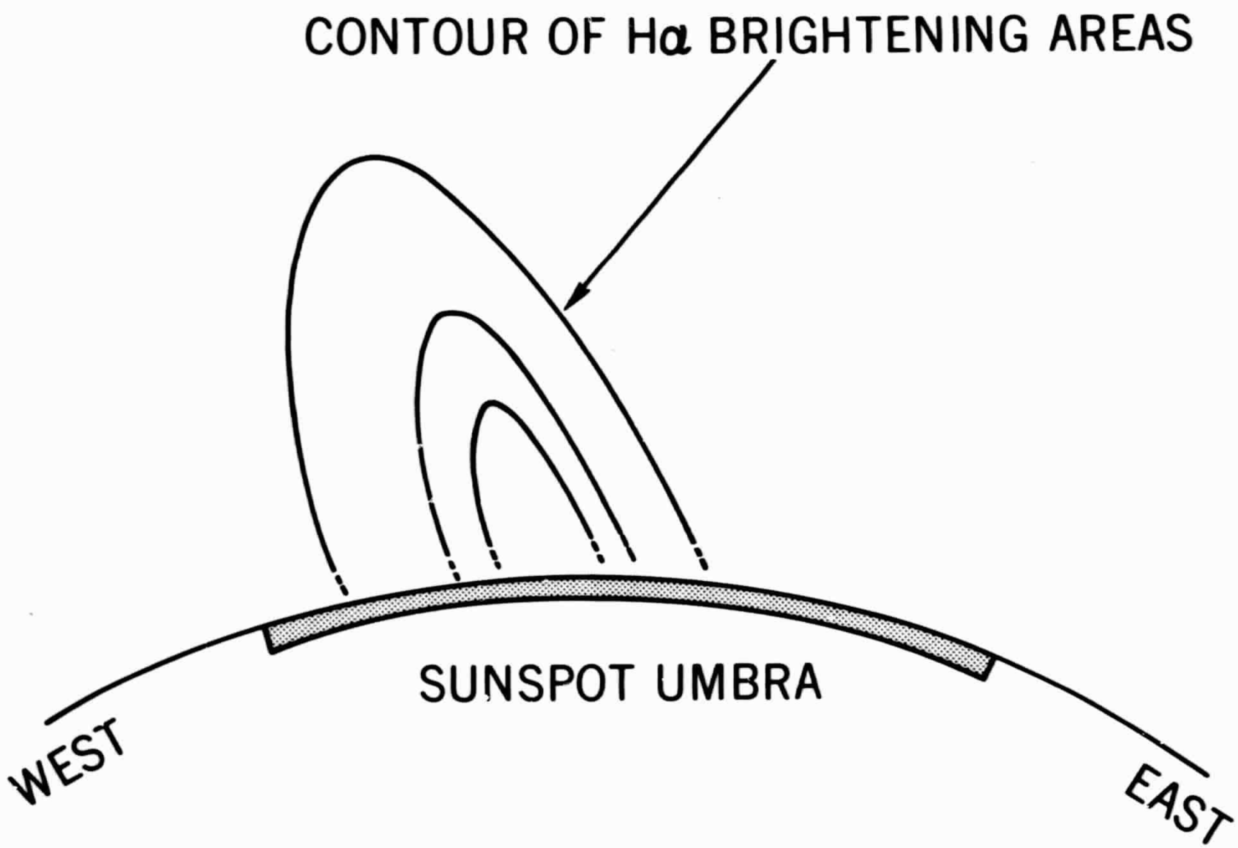


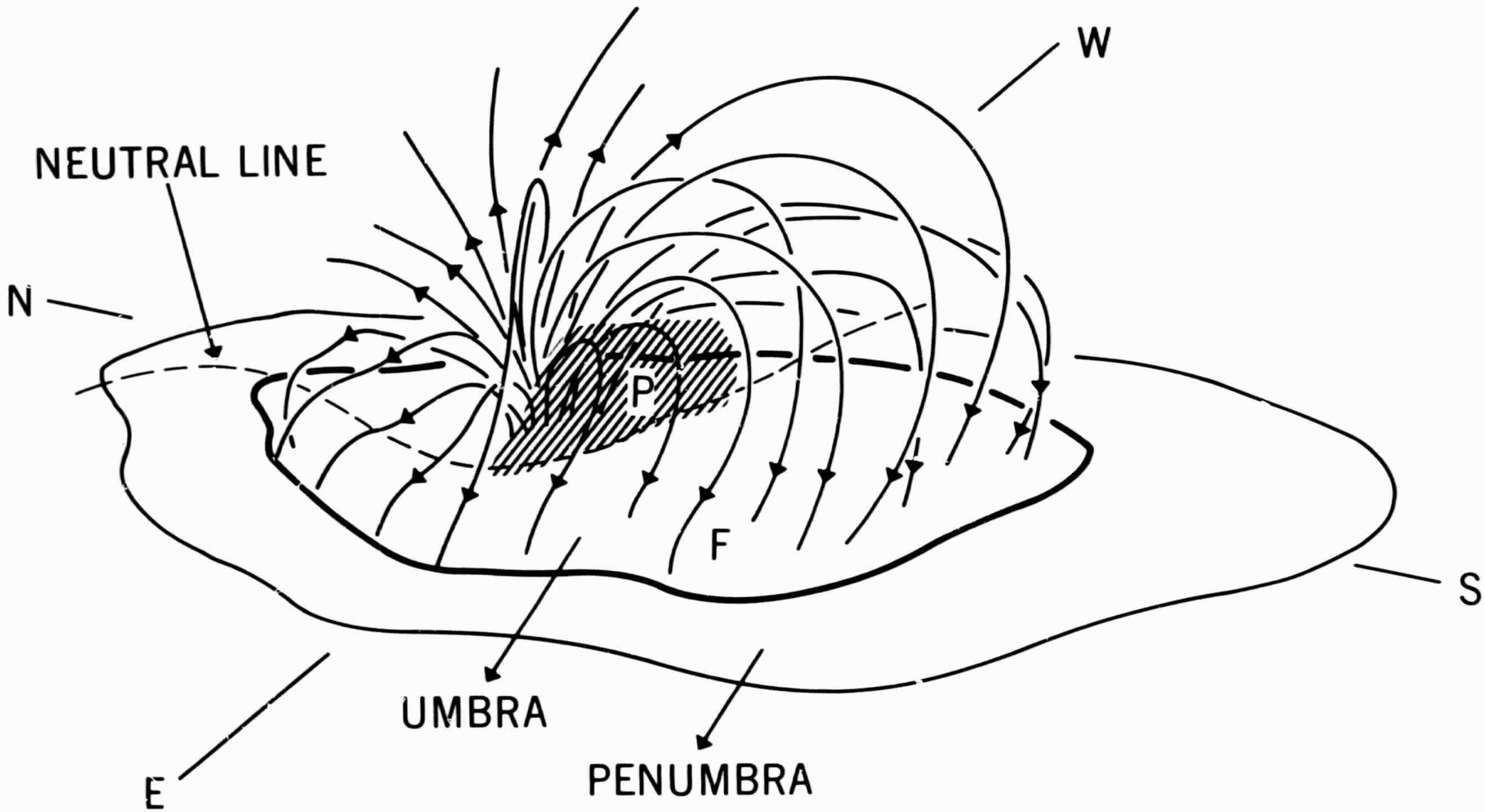
0°
30°
30°
WEST
EAST
60°
60°
90°
90°
20
15
10
5
0
5
10
15
20
TIME (Min.)
TIME (Min.)


0°
30°
30°
WEST
EAST
60°
60°
90°
90°
60
40
20
0
20
40
60
%
%
FLARE COVERAGE



◆ : POSITION OF FLARE TRIGGERING


CONTOUR OF Hα BRIGHTENING AREAS
SUNSPOT UMBRA
WEST
EAST


W
NEUTRAL LINE
N
P
F
S
UMBRA
PENUMBRA
E