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ON THE CHARACTERISTICS OF THE SOLAR ACTIVE REGIONS RESPONSIBLE FOR THE GENERATION OF TYPE III RADIO BURSTS AT HECTOMETRIC FREQUENCIES IN AUGUST 1968

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ON THE CHARACTERISTICS OF THE SOLAR ACTIVE REGIONS RESPONSIBLE FOR THE GENERATION OF TYPE III RADIO BURSTS AT HECTOMETRIC FREQUENCIES IN AUGUST 1968

by

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ABSTRACT

The RAE (Radio Astronomy Explorer) satellite observed enormous numbers of type III radio bursts at hectometric wavelengths from 13 to 25, August in 1968. The drift rate of these bursts reached a maximum around the middle of 20 August. This means that the source responsible for these bursts gradually moved on the solar disk in association with the rotation of the sun. During this period, there were two large active sunspot groups, MacMath Nos. 9593 and 9597, which were located in the southern hemisphere and adjacent to each other. By examining the observational data on solar flares, type I noise storm activity and energetic electron flux increases, it is shown that the active region, MacMath No. 9597 is

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responsible for the generation of these type III radio bursts. The relation between type III bursts producing electron beams and type I noise activity is briefly discussed and a model of this active region is qualitatively described.

INTRODUCTION

In August, 1968, the RAE satellite observed enormous numbers of type III radio bursts at hectometric wave lengths. The drift rate of these radio bursts reached a maximum around the middle of 20th of August (Fainberg and Stone, 1970 a,b). This result suggests that, on this date, the energetic electron beams responsible for the excitation of these bursts were ejected almost radially along the sun-earth direction from some active regions located on the solar disk. These active regions seem to have passed by the central meridian of the solar disk around the 20th of August.

During the period from 10 to 25, August, there were two distinct large active sunspot groups, MacMath Nos. 9593 and 9597, in the southern hemisphere of the sun. Roughly speaking, these two active regions passed by the central meridian between 17-18 and 19-20, August, respectively, although we cannot define the exact dates of their central meridian passage, because of the large expanse of these active regions in the east-west direction. Since both active regions were located adjacent to each other in the southern hemisphere, both regions could be responsible for the production of many type III radio bursts at hectometric waves (Sakurai and Stone, 1970).

In this paper, by comparing the observational data for both active regions, we can study the characteristics of these active regions and the relation between the cause of these type III radio bursts and the nature of the active sunspot regions. The model of active regions which produce the energetic electron beams responsible for the emission of these radio bursts is considered in relation to the radio noise activity at metric wave frequencies.

2. The Solar Activity Associated with the Active Regions MacMath Nos. 9593 and 9597

In association with the movement of both active regions MacMath Nos. 9593 and 9597 on the solar disk, many small solar flares were generated in these active regions as is shown in Figure 1. In this figure, the ordinate represents the days from 13 to 27 August and the abscissa indicates the heliographic longitude measured from the central meridian of the sun. As time increased both active regions moved westward and passed the central meridian between 17-18 and 19-20 August, respectively. The drift rate of the type III radio bursts at hectometric wave frequencies observed by the RAE satellite reached the maximum at about the middle of 20th August (Fainberg and Stone, 1970 a), and this time is plotted in Figure 1 with the filled circle. The uncertainty of CMP time is indicated by the error bars.

As is estimated from Figure 1, the flare activity for the active region MacMath No. 9593 was about twice that of region MacMath No. 9597 during their passage over the solar disk. The longitude distribution of solar flares is also shown in the lower half of the figure with respect to each of the active regions MacMath Nos. 9593 and 9597. It is clear that the position of solar flares is highly concentrated in the longitude regions between 30° and 60° West on the solar disk.

As is well known, the position of the solar flares which produce distinct energetic electron events at the earth's orbit is almost always located in the longitude regions 60° ± 16° West on the solar disk (Lin and Anderson, 1967; Lin, 1970). It is, therefore, likely that the position of many solar flares which occurred within the active region MacMath No. 9593 was located in the longitude region favored to generate such discrete electron events on the earth. However, such an event has not been observed by satellites during that period (Lin, 1970: Private communication to R.G. Stone). This result shows that, in spite of the highly active generation of solar flares at the region MacMath No. 9593, these flare apparently did not generate any distinct electron events.

In order to study the cause of this difference, we must investigate the characteristics of the solar flares associated with the region MacMath No. 9593. First, we examine the importance of these solar flares. The distribution of solar flare importance is shown in Figure 2. In this figure, this distribution is shown for both active regions. For MacMath No. 9593, the importance of most solar flares (24) is SN and the importance of about 20 other flares are SF and SB. It follows, therefore, that the solar flares of importance SF - SB occurred many times in the region MacMath No. 9593 during its passage on the solar disk. The active region MacMath No. 9597 shows the distribution of flare importance similar to that associated with the active region MacMath No. 9593 as is seen in Figure 2b.

At present, we have much observational data on the solar flares which produced distinct energetic electron events (Van Allen and Krimigis, 1965; Lin and Anderson, 1967; Lin, 1970). If we analyze statistically the importance of these flares, we obtain the result shown in Figure 3. The mean importance of the solar flares associated with distinct electron events is 1N, and most of such solar flares are between 1F and 1B in importance. Consequently, it is clear that the mean importance of the solar flares generated in the regions MacMath Nos. 9593 and 9597 is to some extent smaller than that of the solar flares associated with distinct electron events. It seems, therefore, that most solar flares associated with both active regions were too small to accelerate energetic electrons which could produce distinct electron events. This seems to be a reason why these active regions did not produce any distinct electron event despite the fact that the position of many solar flares was located in the longitude 30° - 60° West favorable for the observation of distinct electron events. However, though not as efficient, these small solar flares could accelerate electrons which were observed as the background flux increase of energetic electrons during 21 and 24, August as indicated in Figure 1 (Lin, 1970: Private communication to R.G. Stone). Thus, we can conclude that such small solar flares of importance $\leq$ SB do not seem to generate energetic electron streams which would produce distinct electron events such as observed by Van Allen and Krimigis (1965) and Lin and Anderson (1967).

Secondly, we must examine the radio noise activity associated with both active regions which is also useful in examining the generation of energetic electrons from solar flares. Lin and Anderson (1967) have found that, near the central meridian of the solar disk, the solar flares which produced distinct electron events were usually associated with the active regions in which type I noise storm activity was high. Sakurai (1970) shows that most solar flares which produced distinct electron events were produced within the active sunspot groups which were highly active in the emission of type I noise storms. He discusses the acceleration of such energetic electrons in solar flares and their relation to the origin of type I noise storms. Hence the generation of energetic electrons in solar flares may be connected to the ambient suprathermal electrons which are responsible for the emission of type I radio noise storms by means of some plasma processes. The daily variation of type I noise storm activity during 13 to 25, August can be examined by using the interferometric observational data at Nancay for 408 and 169 MHz (Solar Geophysical Data). As shown in Figure 4, type I noise storm activity was only associated with the active region MacMath No. 9597. It is deduced that the source of energetic electrons responsible for type III radio bursts at hectometric wave frequencies observed by the RAE satellite is attributed to the active region MacMath No. 9597. It seems that small solar flares of importance SN or less are also able to generate energetic electron beams which can excite the plasma waves necessary for generating type III radio bursts at hectometric wave frequencies. Such energetic electrons were certainly observed as the increase of background flux of energetic electrons during 21 to 24, August. Thus the region responsible for the excitation of type III radio bursts at hectometric wave frequencies seems to be connected with the active regions MacMath No. 9597.

3. Energetic Electrons and Type I Noise Storms

Type III radio bursts at hectometric wave frequencies as observed by the RAE satellite are causally associated with the electron beams passing through the outer corona (10 30 $R_{\odot}$; $R_{\odot}$ solar radius, 7×10^{10} cm) (Fainberg and Stone, 1970 b) after ejection from the type I noise active region, MacMath No. 9597 in association with small solar flares or chromospheric disturbances. These electron beams have not been observed as distinct electron events during the period from 13 to 25, August since the parent solar flares were too small to generate such events on the earth. These electrons were detected as an increase of the background flux of electrons in the interplanetary space as shown in Figure 1, and it is likely that these electrons were very effective in exciting type III radio bursts at hectometric wave frequencies since their estimated energy range 10 - 100 Kev is enough to excite the plasma waves responsible for type III radio bursts (Sakurai, 1967, 1970).

The energetic electrons which are necessary to generate type III radio bursts may be partly produced from the ambient suprathermal electrons in the type I noise active regions (Sakurai, 1970) since these active regions are located beneath the exciting regions of type III radio bursts as in the case of the active region MacMath No. 9597 (Kai, 1970). The speed of the ambient suprathermal electrons is usually several times higher than the mean thermal speed of ambient plasma electrons (e.g. Takakura, 1963). These electrons are continuously accelerated in the active region MacMath No. 9597. With the onset of solar flares, a part of these would be preferentially accelerated to speeds higher than a tenth that of light, which is necessary to excite the plasma waves responsible for the emission of type III radio bursts. It thus seems that the existence of the source of type I noise storms is a necessary condition for the generation of energetic electron beams which can excite type III radio bursts.

We can, therefore, conclude that, though much more active in flare production, the active region MacMath No. 9593 is not responsible for the generation of type III radio bursts and that the active region MacMath No. 9597 only is effective in producing energetic electron beams which can excite plasma waves.

4. Model of the Active Region MacMath No. 9597

Type I active regions are generally located around 0.2 - 0.3 $R_{\odot}$ above the sunspot groups (Morimoto and Kai, 1961; Fokker, 1968; Kundu, 1965). Recently, Kai (1970) shows that the position of type III radio burst sources is always different from and higher than that of type I noise storm sources, and the structure of the former and the latter is uni-polar and bi-polar, respectively.

In case of the active reigon MacMath No. 9597, the configuration of the sunspot groups is classified as a βP type which means that this configuration consists of bi-polar structure (Solar Geophysical Data). Since we have discussed the relation between type I and type III radio sources earlier, we can consider the vertical structure of the active region MacMath No. 9597. A schematic model of this active region thus deduced is shown in Figure 5. Two main sources of type I noise storms are lying above the preceding and following main sunspot groups. Whenever some disturbances such as small solar flares occur somewhere within this active region, part of the energetic electrons would be accelerated and then ejected to outer space as shown by arrows in the figure. These electrons would pass through the neutral sheet under the guidance of sun-spot magnetic field lines extending to outer space as shown in Figure 5. Furthermore, these electrons would excite some instability along the neutral sheet and then ambient electrons there would in addition be accelerated. These secondary accelerated electrons also seem to be responsible for the generation of type III radio bursts at hectometric wave frequencies as observed by the RAE satellite. These observed type III radio bursts, therefore, seem to be associated with the increase of background flux of energetic electrons. The source of type III radio bursts is located high up in the outer corona and is of uni-polar structure as discussed by Kai (1970). The neutral sheet mentioned above seems to extend upward to the outer coronal region from 10 to 30 $R_{\odot}$ or higher and to be very stable during the period of one solar rotation or more as judged by on the active region MacMath No. 9597 (Fainberg and Stone, 1970 b).

The solar winds transport this neutral sheet to the earth's orbit. When this sheet sweeps the earth's neighborhood, the polarity of the interplanetary magnetic field must change from positive to negative. Since we have not observed a polarity change, this neutral sheet seems to have been smoothed out near the earth's orbit as is seen in Figure 6. In this figure, by assuming the most plausible speed of solar winds (e.g. McCracken, 1962; Fainberg and Stone, 1970 b), the dates of such neutral sheets which sweep the earth are indicated in the diagram of the polarity distribution of the interplanetary magnetic fields (Fairfield, 1969: Private communication) and Kp-indices. Around these dates thus estimated, we could observe only the south polarity of the magnetic field in the interplanetary space. In this case, the neutral sheets mentioned above would have been merged and smoothed out with the ambient interplanetary magnetic fields and plasmas.

5. Summary

Throughout this study, we have obtained many results which are of value in the study of generation mechanisms of energetic electrons responsible for the emission of type III radio bursts and the influence of type I radio noise active regions on these energetic electron production. Here we summarize the results obtained in this paper: (1) Weak solar flares of importance $\leq$ SB cannot generate energetic electron beams which are observable as distinct electron events at the earth's orbit. In order to associate these distinct events, the importance of solar flares must usually be greater than 1F as shown in Figure 3; (2) The solar flares capable of generating energetic electrons usually occur somewhere within the sunspot groups which are highly active in emitting type I noise storms or bursts as in case of the active region MacMath No. 9597; (3) In association with solar disturbance such as solar flares, energetic electrons in the type I noise active region would be accelerated and then ejected into the neutral sheet in the outer corona. The ejected electrons excite the plasma waves which are transformed into electromagnetic waves in the neutral sheet. These waves are observed as type III radio bursts at hectometric wave frequencies by the RAE satellite; (4) The source of such type III radio bursts was connected with the active region MacMath No. 9597. This active region was associated with type I noise storm activity during its passage of the solar disk (Figure 4); (5) The source of type I noise storms consists of bi-polar structure, whereas that of type III source is of uni-polar type and located high up in the outer corona above type I noise active region (Figure 5); (6) The increase of background energetic electron flux during 21 to 24, August was produced by the frequent emission of energetic electrons from the active region MacMath No. 9597; (7) The neutral sheet appears to be smoothed out and merged in the interplanetary space near the earth's orbit. In this case, we cannot detect any evidence of such sheets near the earth by the satellite observation of the interplanetary magnetic fields.

In order to understand the acceleration processes of energetic electrons associated with type I noise active regions, we need more detailed information about physical properties of these active regions and the mechanism of type I noise storms.

Acknowledgement

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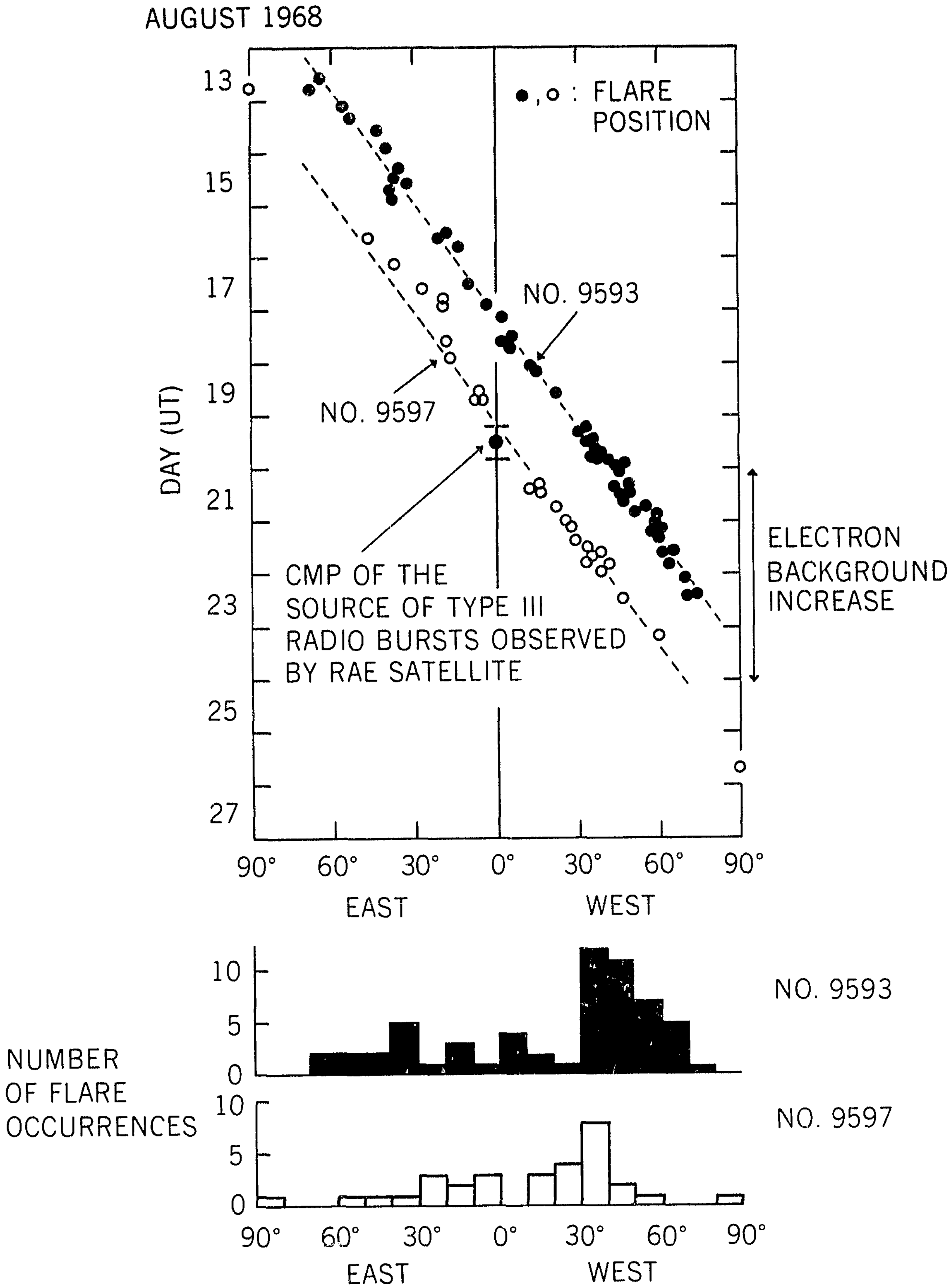

Figure 1. Solar flare activity associated with the active regions MacMath Nos. 9593 and 9597 during their passage of the solar disk. The filled and open circles indicate the position of solar flares associated with both active regions. The filled circle with error indication along the central meridian shows the time of the central meridian passage of the source of type III radio bursts at hectometric wave frequencies observed by the RAE satellite. The lower part of this figure presents the longitudinal distribution of solar flares associated with both active regions.

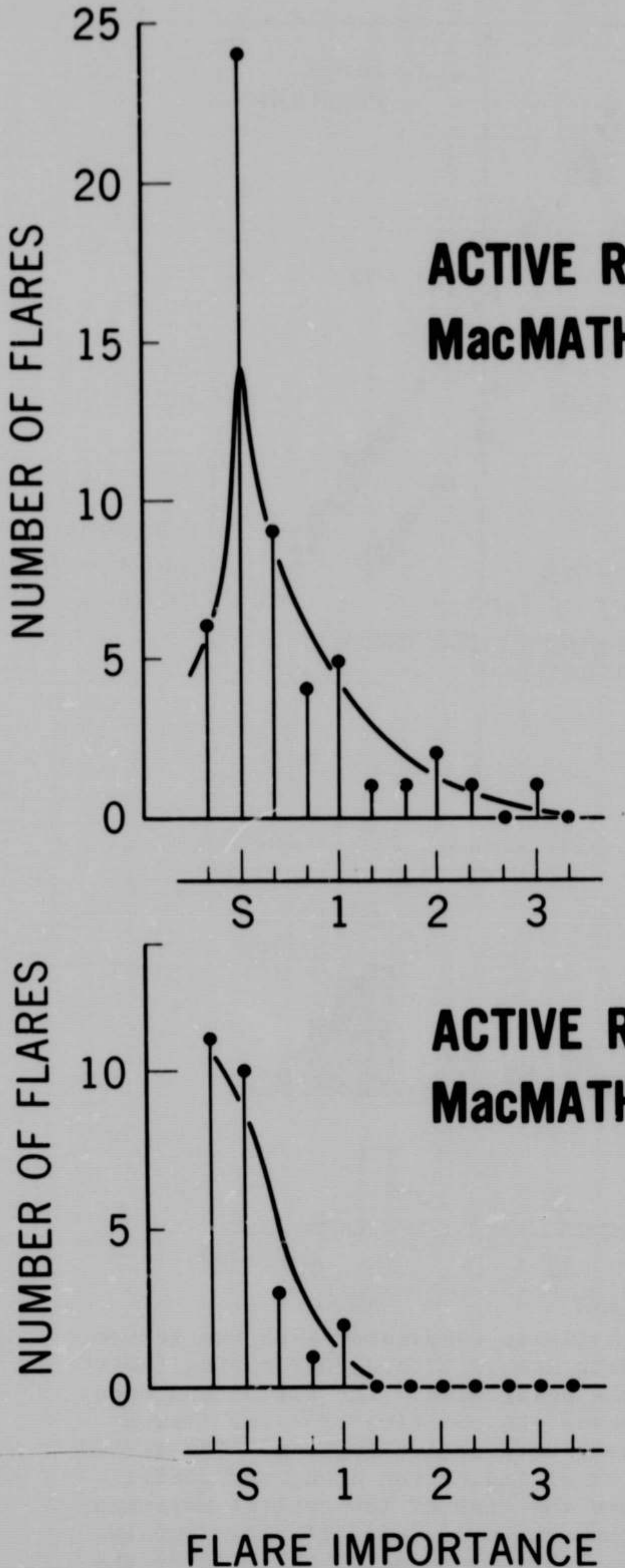

Figure 2. The distribution of the importance of solar flares associated with the active regions MacMath Nos. 9593 and 9597.

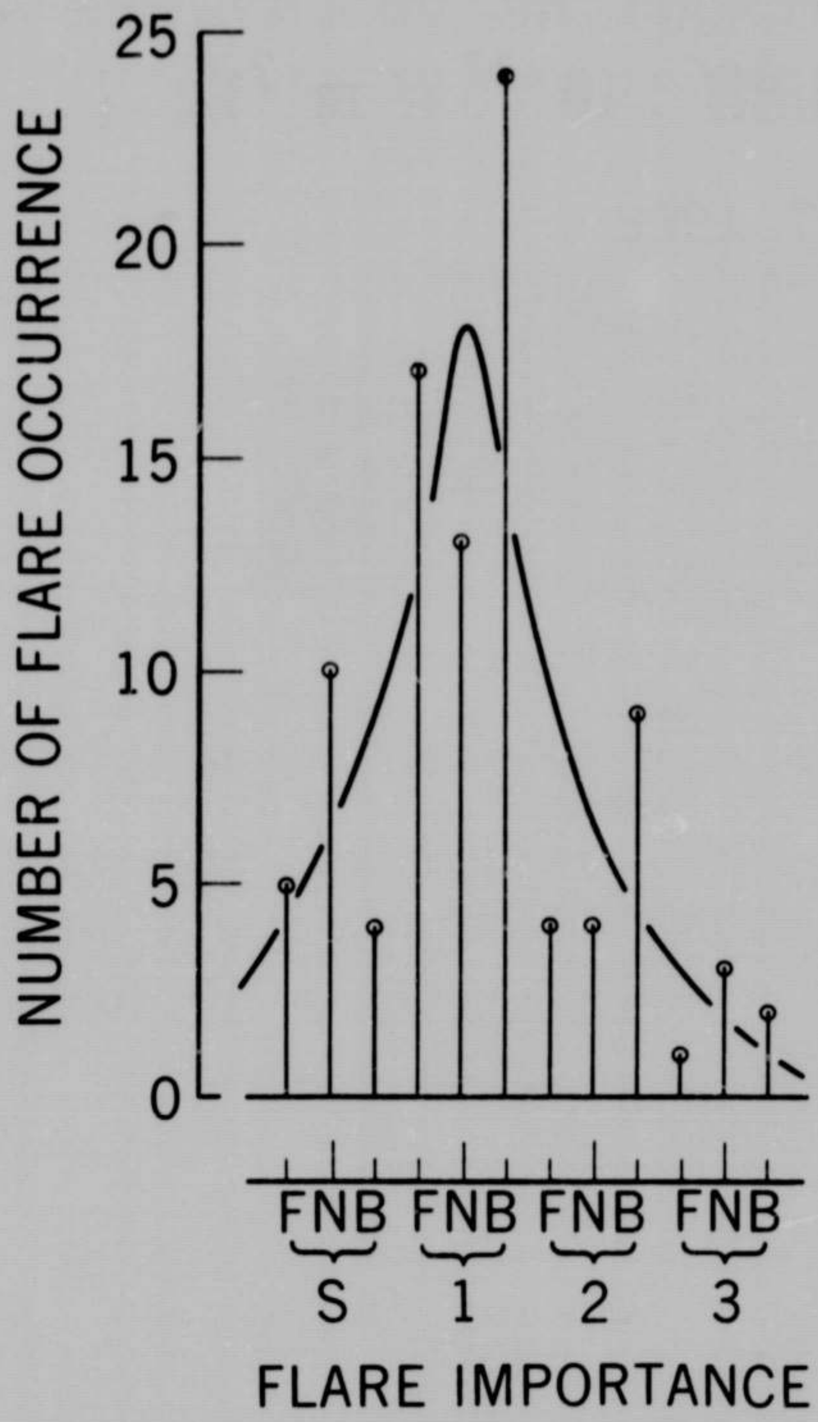

Figure 3. The distribution of the imporance of solar flares which produced distinct energetic electron events on the earth. This result is obtained from the data published in Lin and Anderson (1967) and Lin (1970).

NANCAY INTERFEROMETRIC OBSERVATION AT 169 MHz
(UNIT : 10^{-22} W m^{-2} Hz^{-1})

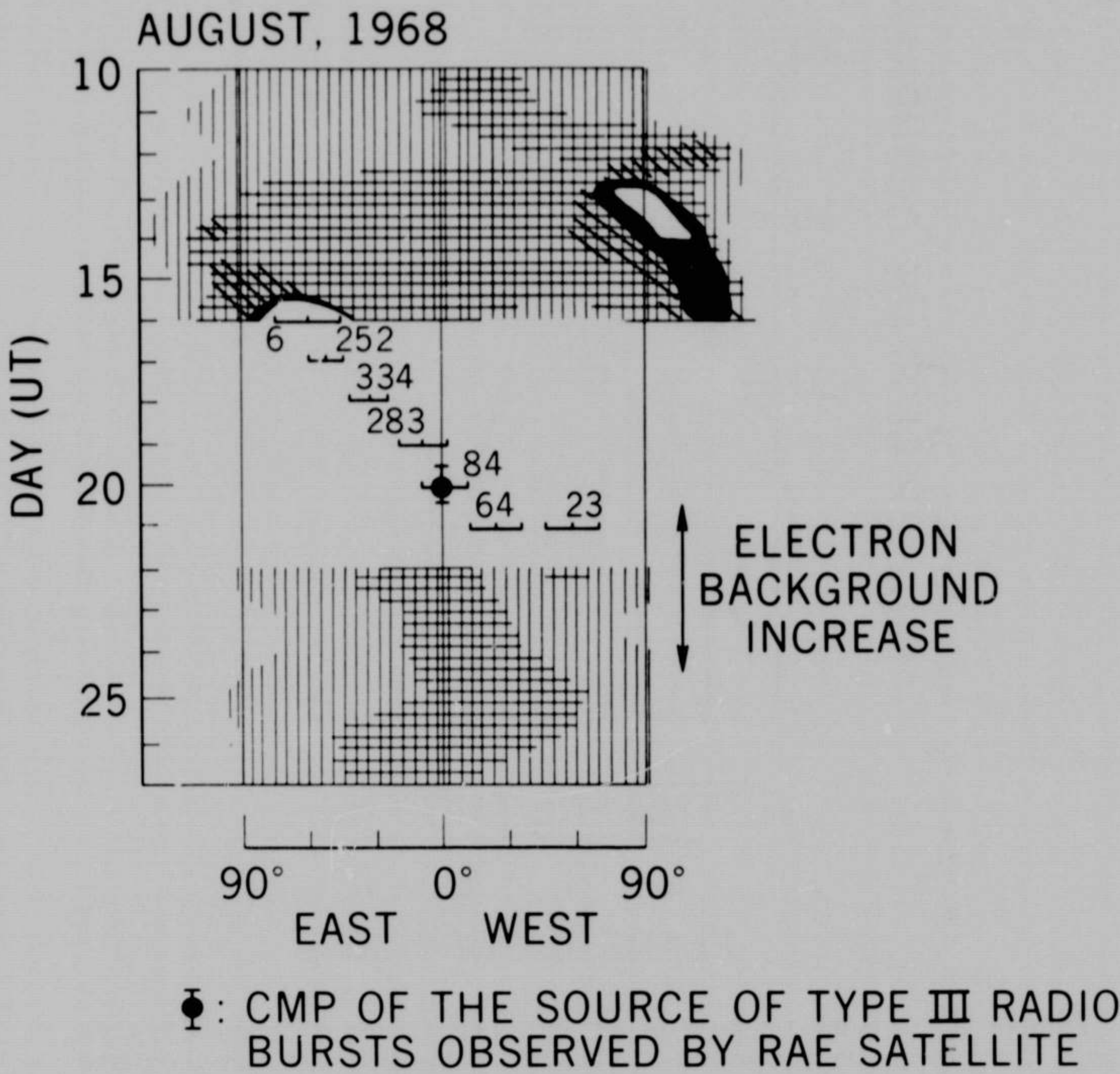

Figure 4. Nancay interferometric observation at 169 MHz of the active regions MacMath Nos. 9593 and 9597 during the period 13 to 25, August 1968.

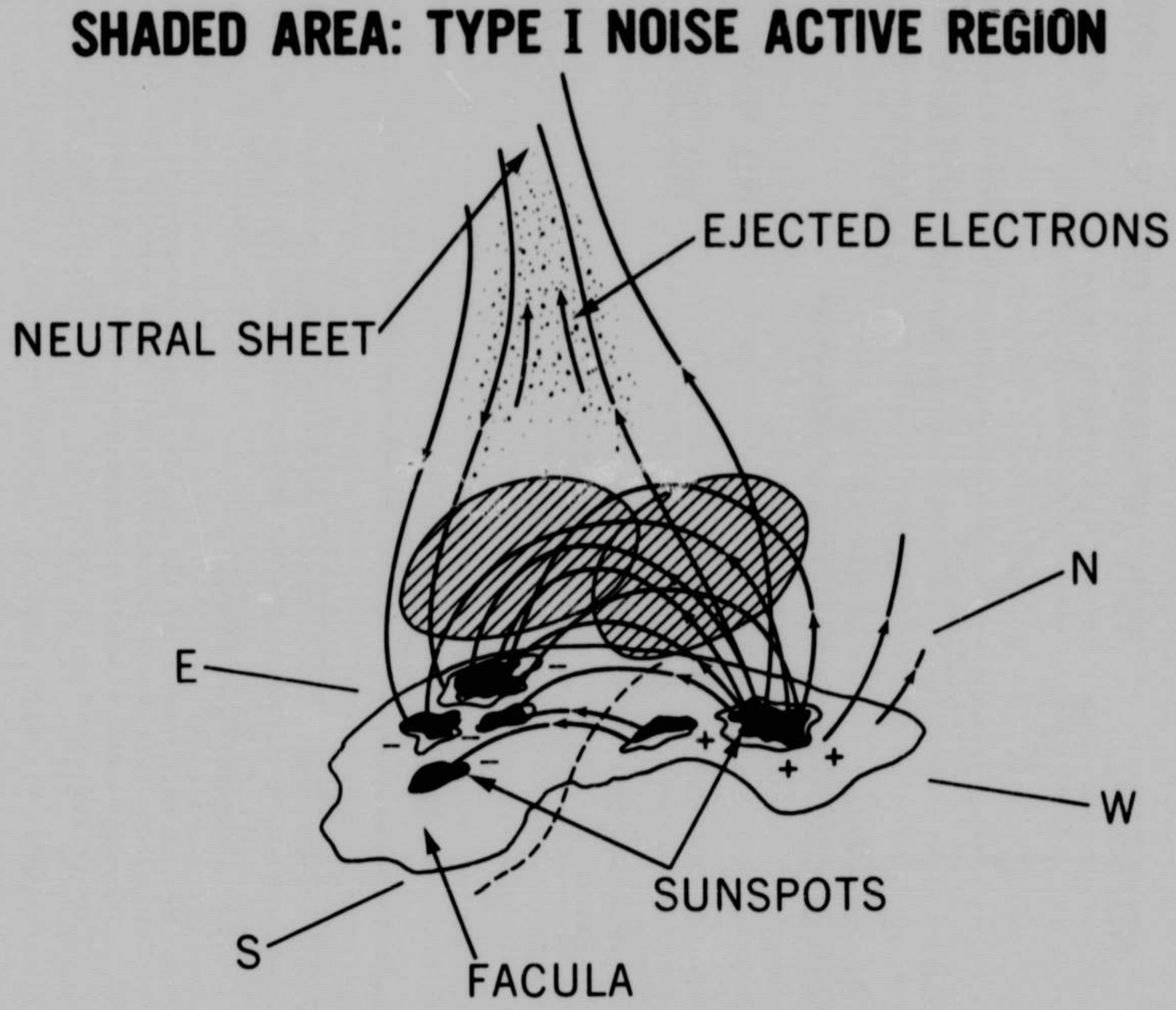

Figure 5. The model of the active region MacMath No. 9597

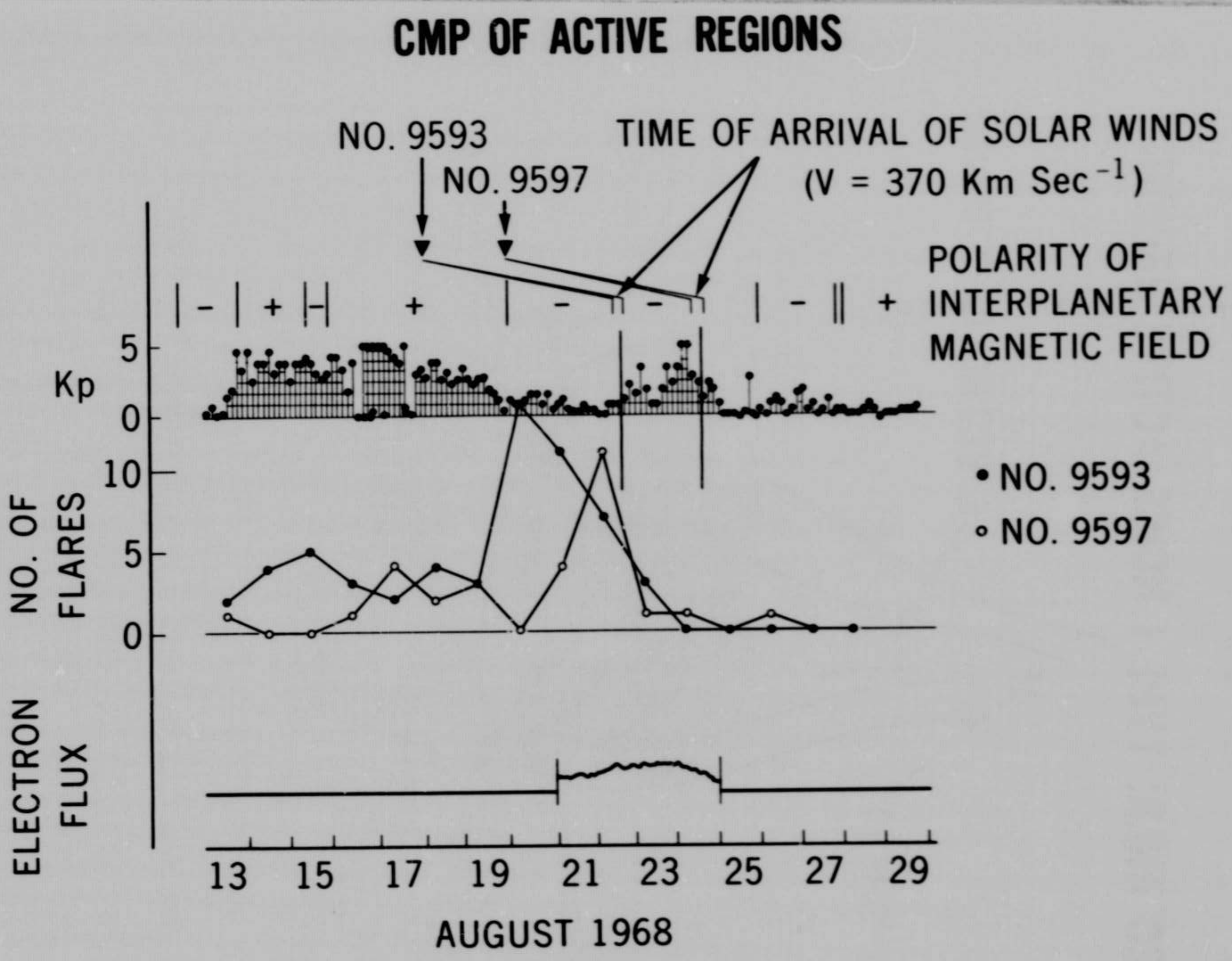

Figure 6. The sweeping dates of the neutral sheets associated with the active regions MacMath Nos. 9593 and 9597 near the earth's orbit in comparison with the polarity distribution of the interplanetary magnetic fields and Kp indices. The lower half indicates the daily number of flare occurrence and the variation of background electron flux.