METER-WAVELENGTH OBSERVATIONS OF THE SOLAR RADIO BURST STORM OF AUGUST 17–22, 1968

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Abstract. Meter-wavelength observations are presented for the solar radio storm of August 17–22, 1968. The data comprise dynamic spectra and high-resolution brightness distributions from the 80 MHz radioheliograph.

It is found that the storm consisted essentially of type III bursts at the lower frequencies and type I at the higher frequencies; the transition, usually near 60 MHz, was fairly sharp. The type I source was located over an active region associated with a large sunspot group. The type III position was displaced about 0.5 $R_{\odot}$ transversely from the type I, in a region of low magnetic field.

The evident close association between the two types of emission can best be explained by disturbances originating in the type I region, propagating outwards through a region of weak magnetic field, and triggering an electron acceleration process, probably at the cusp of a 'helmet' structure. The observed frequency and spatial relationship between the type I and type III components in events of this kind follow as a natural consequence of this model.

A comparison of these results with the hectometer-wavelength satellite observations of the 1968 August event makes possible a qualitative estimate of the outward path of the type III exciters through the corona, and it is apparent that below the solar wind region of the corona this path departs considerably from the radial direction.

1. Introduction

During 1968 August a great storm of solar radio bursts occurred, characterized by intense type I radiation at frequencies above about 60 MHz, and by a continuous succession of type III bursts at lower frequencies. This event is of particular interest as the first of its kind for which extensive long-wavelength observations were made with satellite-borne receivers. Fainberg and Stone (1970a,b; 1971) and Sakurai (1971) have published data from the RAE satellite, which carried a swept-frequency receiver covering the range 0.2–5.4 MHz and six fixed-frequency radiometers between 0.54 and 2.80 MHz. By a statistical analysis of the records of many thousands of type III bursts, these authors were able, with certain assumptions, to derive values for the average speed of the type III exciters and to deduce their path.

In this paper we present observations made in the period August 17–22, 1968, of the solar spectrum at meter wavelengths and of the positions of the sources of bursts at 80 MHz. These results in themselves provide an unusually clear example of the relationship between type I and type III storm radiation. Taken in conjunction with the satellite data they provide an opportunity to examine the path of the type III exciters through the corona between the 80 and 0.7 MHz plasma levels – i.e. over a range of heights from about 0.6–30 $R_{\odot}$ above the photosphere.

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2. Observations

The meter-wavelength observations were made at the solar radio observatory at Culgoora. They comprise dynamic spectra covering the range 7–220 MHz with 0.25 s time resolution, and 80 MHz radioheliograph 'pictures' of the Sun at the rate of one pair of pictures per second, showing right- and left-handed circular polarization, with a pencil beam of about 4′ in width. In addition, we have made use of Hα photographs from the CSIRO Culgoora optical observatory and from the University of Hawaii's observatory at Mount Haleakala, together with published sunspot and magnetic data.

A. DYNAMIC SPECTRA

Typical sections of the spectrum record in the range 25–150 MHz are reproduced in Figure 1 for the four days* August 18, 19, 20 and 21, the period of intense and continuous activity. On August 17 and 22 there was very much weaker, intermittent activity. Throughout August 18–21 the most prominent spectral feature was a strong type I storm, mainly at frequencies above 75 MHz but extending as low as 50 MHz at times on August 18 and 19. On August 20 the spectrum shows a continuous succession of type III bursts, starting at frequencies in the 25–80 MHz range but usually below 60 MHz. There is some indication on our records that similar type III storms also occurred on August 18 and 19, the bursts on these days starting below 25 MHz. (Another spectral feature on our records, which will not be discussed any further in this paper, is a storm of reverse-drift pairs in the 25–50 MHz frequency range.)

Apart from the storm activity, a number of 'flash phase' type III bursts were recorded. These were quite different in character from the type III bursts of the storm, being generally more intense and starting at much higher frequencies (above 100 MHz). These are typical of isolated type III bursts which often accompany the flash phase of a flare, and comparisons with optical data for this period show that in most cases bursts of this type were correlated with small flares from McMath plages 9598 and 9593 (see Section 2(c)). As these bursts are not directly associated with the storm activity we shall not discuss them further.

B. 80 MHz RADIOHELIOGRAMS

The 80 MHz radioheliograms are dominated by the type I storm component, which shows almost complete right-handed circular polarization (RH) during the period of intense activity. On August 17, when the storm was very much weaker, it was about 50% RH polarized. The structure of the noise storm underwent considerable changes with time, and on one day (August 20) the source appeared double with two intensity maxima. It remained, however, completely unipolar (RH) throughout. A second continuum source, apparently not connected with the main noise storm, was present

* The dates in the text refer in each case to the UT day which *began* during the Culgoora observing period. The observing period was from about 20^h30^m to 06^h30^m UT for the spectrograph, and 23^h00^m to 04^h30^m for the radioheliograph.

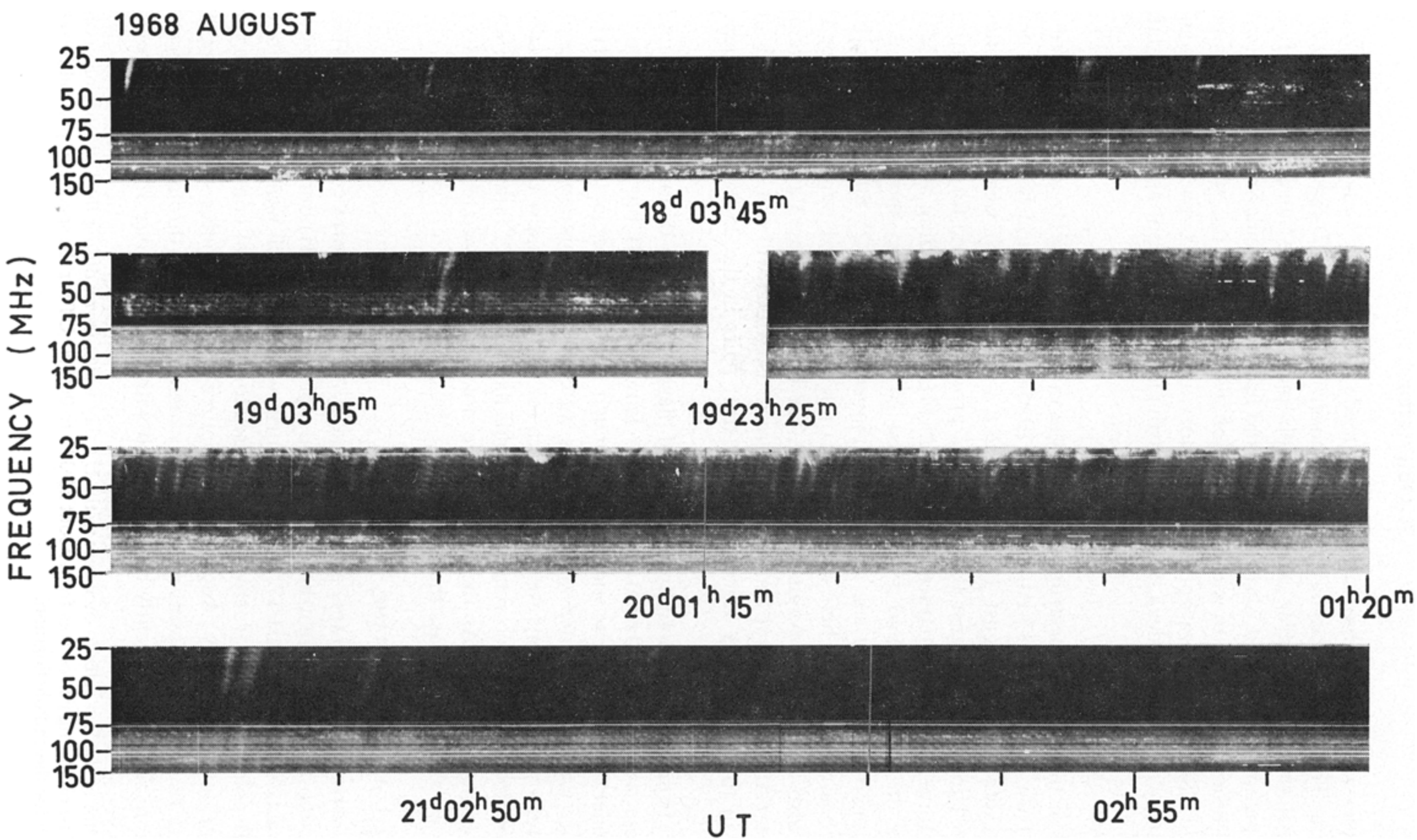

Fig. 1. Dynamic spectra in the frequency range 25 to 150 MHz during selected periods of the type I–III storm of August 17–21, 1968 (UT).

near the center of the solar disk for about one hour on August 18. This was also unipolar (RH).

Although most of the storm type III bursts had starting frequencies below 60 MHz the bursts began on a few occasions, particularly on August 19 and 20, above 80 MHz and were recorded on the radioheliograph. These bursts were in all other respects similar to the rest of the storm. The type III bursts on the radioheliograms can be distinguished from the type I storm by the fact that they show little or no circular polarization, and by their consistent displacement in position from the type I source. A similar displacement between type III and type I sources was observed also on August 17 and 22. Kai's (1970) 80 MHz observations of isolated type III bursts associated with type I storms showed a similar pattern to the present results, although with somewhat smaller displacements between the type I and type III sources.

Radioheliograms and spectra of representative type III storm bursts observed on 1968 August 19 and 20 are shown in Figure 2, while Figure 3 summarizes the observations of the relative 80 MHz positions of type III and type I sources for these two days.

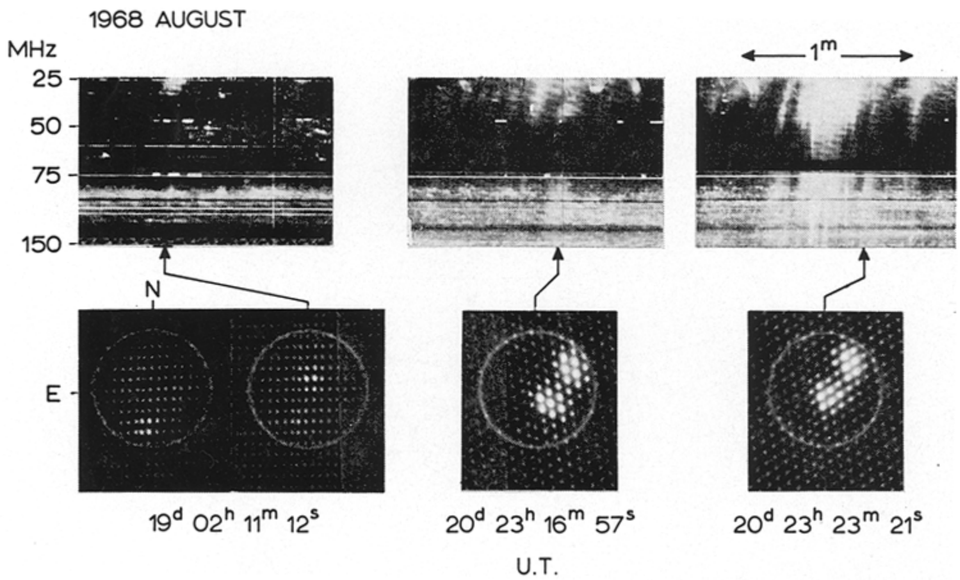

Fig. 2. Examples of radioheliograms (RH circular polarization) and dynamic spectra for type I storm and type III bursts. The eastern and western bright regions are the type I and type III sources respectively (cf. Figure 3). In the first example the heliogram on the left was taken a few seconds earlier than that on the right, and shows the type I source only.

C. OPTICAL OBSERVATIONS

The optical observations for this period show a complex distribution of chromospheric plages dominated by two main centers – McMath regions 9593 and 9597. These plages were both extended bipolar regions (see Mount Wilson map for August

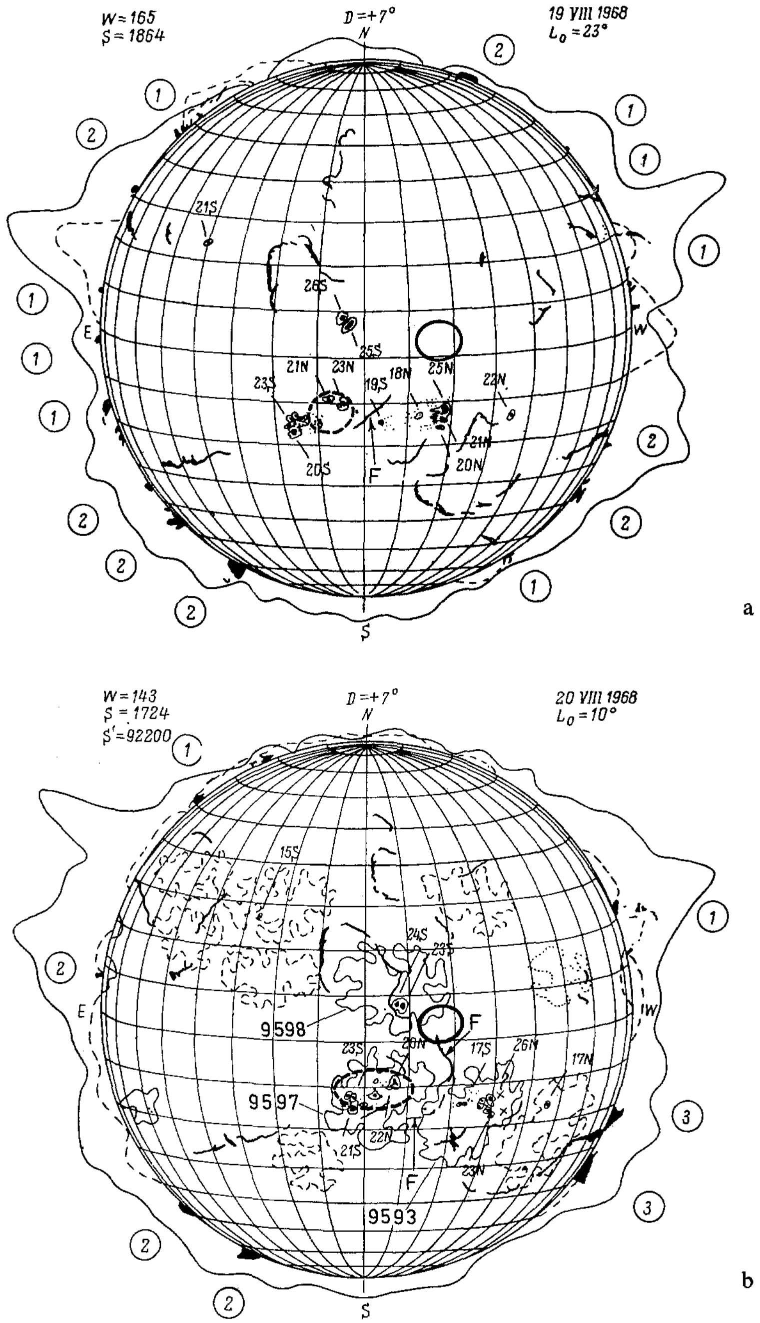

Fig. 3. Composite optical and radio maps for (a) 1968, August 19 and (b) August 20, 1968. The optical data are adapted from *Solnechnye Dannye* (Pulkovo, 1968 August), and refer to observations at ~ 05^h UT. The McMath plage numbers have been added in (b), and *F* denotes the filament to which reference is made in the text. The ellipses represent 80 MHz halfpower contours of the type I (dashed lines) and type III (full lines) sources. The scale of the 80 MHz radioheliograms has been reduced in the ratio 1.6:1, corresponding to the nominal height of the 80 MHz plasma level (0.6 $R_\odot$ above the photosphere); in this way, the radio and optical positions can be directly compared for radial displacements.

21 in Figure 4). The strength and polarity of the sunspot magnetic fields are given in Figure 3 and will be mentioned later. Sakurai (1971) has estimated that the flare activity from 9593 was about twice that from 9597 during this period. Most of the flares were small – of importance 1 for 9593 and 1- or subflares for 9597. A feature of importance in the following discussion is a stable dark filament aligned along the zero field region between 9593 and 9597 and indicated by F in Figures 3 and 4.

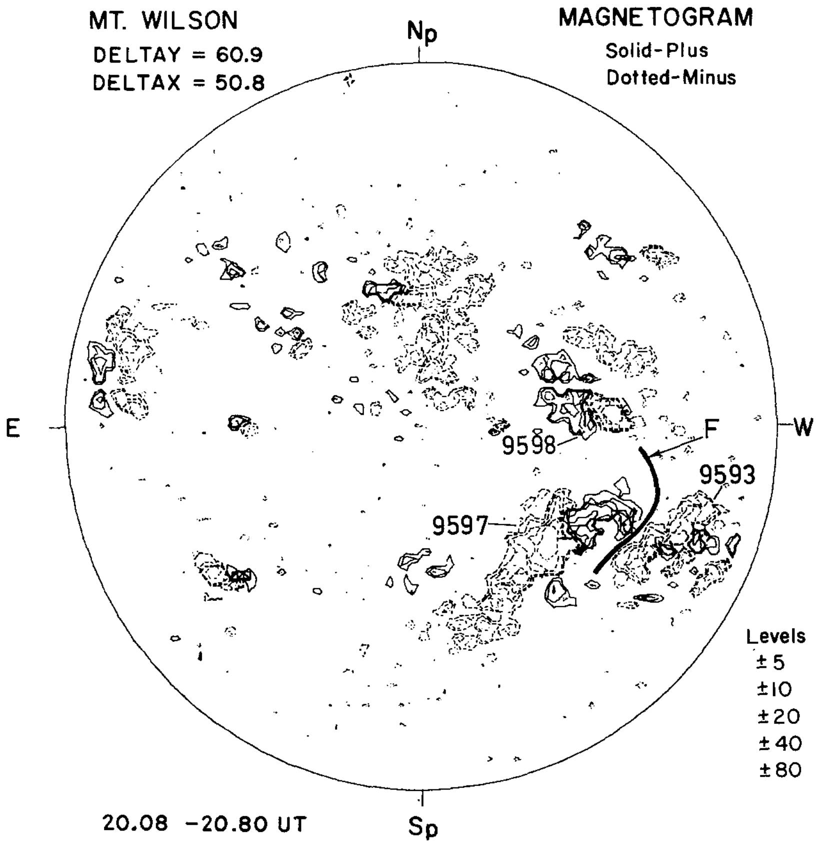

Fig. 4. The Mount Wilson solar magnetogram for 20^h UT on August 21, 1968. The plage regions associated with radio emission are indicated by their McMath numbers. The filament F between regions 9597 and 9593 is sketched.

3. Discussion of the Meter Wavelength Observations

A. THE SOURCE POSITION AND POLARIZATION OF THE TYPE I RADIATION

The radioheliograms indicate that the type I storm was located above the large active region 9597 (see dashed ellipses of Figure 3). These positions were determined from observations taken near transit each day to minimize any errors due to refraction.

Similar source positions were observed at 169 MHz at Nançay (M. F. Lantos, private communication).

As we have already mentioned, the type I storm showed almost complete RH circular polarization. It is generally accepted (Takakura, 1963) that the circular polarization of type I emission results from plasma radiation propagating in the ordinary mode in a strong magnetic field. On this hypothesis the observed sense of polarization corresponds with the magnetic polarity of the trailing and growing sunspots in the active region 9597. A second type I event, observed on August 18, was located over region 9598 and was also strongly right-hand polarized.

B. RELATIONSHIP BETWEEN TYPE I AND TYPE III STORM ACTIVITY

We shall assume that both the type I and type III emission observed at 80 MHz comes from near the corresponding plasma level. On this basis, the heliograph observations indicate that the type I storm source is in the strong magnetic field region above plage 9597 while the type III storm source at 80 MHz is at a considerable tangential distance from this point ($\approx 0.5\ R_{\odot}$ to the west) (see full ellipses of Figure 3). Since the starting frequency of these type III bursts was near 80 MHz it would appear that the observed position is close to the point at which the type III electrons are accelerated. This position is located approximately above one end of the dark chromospheric filament between plage regions 9597 and 9593 (see Figure 3). From Figure 4 it can be seen that the filament lies in a region of weak or zero longitudinal magnetic field; such filaments, in fact, often indicate the presence of a neutral magnetic plane higher in the corona (McIntosh, 1971). If this is so in the present case, the neutral plane provides a path along which the type III electrons can travel outwards through the corona (Weiss and Wild, 1964). Another possible example of type III bursts excitation along a neutral plane has been reported by McLean (1970).

Previous studies of type I–type III storms (Malville, 1962; Hanasz, 1966; and Boischot *et al.*, 1971) show that the spectral pattern of the August 1968 event is almost invariably observed, with the type III bursts starting near the low-frequency limit of the type I activity. This consistent behaviour over many events strongly suggests a direct connection between the two types of emission. Gordon (1971) has proposed a mechanism in which the low phase-velocity plasma waves (excited by the weakly suprathermal electrons that produce type I bursts (Takakura, 1963)) are scattered to high phase velocities (0.1–0.6 c); these waves then cause the rapid acceleration of electrons to type III velocities. Gordon suggests that this can explain why type III bursts often start near the lower frequency limit of the type I bursts. However, any such process would always produce type I and type III bursts from sources located close together. Our 80 MHz observations show that this is not the case, so that some alternative explanation must be sought.

C. MODEL OF THE SOURCE REGION

We suggest that the association of type I and type III activity in the 1968 August storm can best be explained by postulating that the energetic electrons which excite the type III bursts are accelerated near the observed position of the 80 MHz source, and that the requisite energy is released by the triggering of a magnetic instability at this point by a disturbance propagating from the type I source region. A possible model is shown in Figure 5. We assume that magnetohydrodynamic waves propagate along

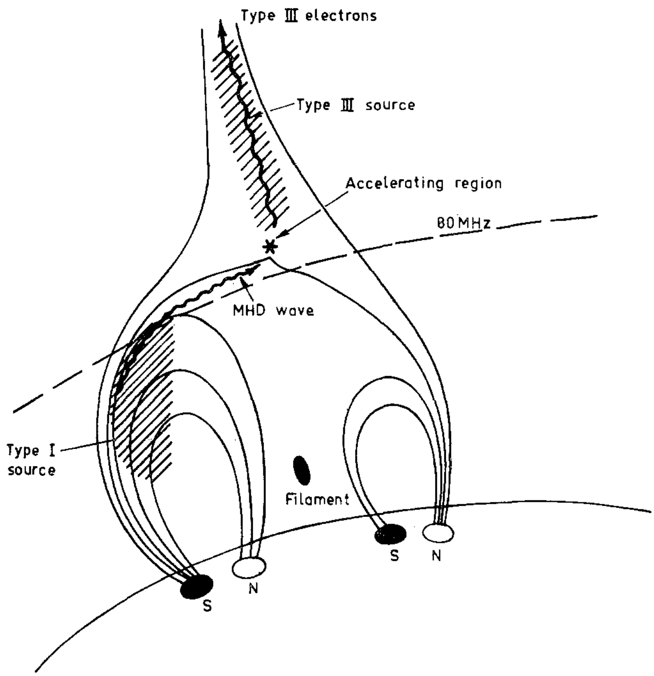

Fig. 5. The proposed model for the type I and type III sources, based on meter-wavelength observations (see text).

the closed strong fields of a bipolar spot group; waves of this kind have previously been invoked to explain the acceleration of the type I radiating electrons (Takakura, 1963; Trakhtengerts, 1966) and the 'drifting chains' of type I bursts (Wild and Tlamicha, 1966). Sufficiently energetic mhd waves may reach the top of the closed loop structure and trigger a pinch instability (Sturrock, 1966) at the cusp of a helmet magnetic structure of the type discussed by Pneuman (1968). The height of the cusp will determine the starting frequency of the type III bursts. Eclipse photographs show that such closed field structures often extend out to about 1 $R_{\odot}$. On a standard density model such as 2 × Newkirk (Newkirk, 1961) this height would correspond to the 45 MHz plasma level, which is comparable with the observed starting frequency of most of the 1968 August storm bursts.

The model of Figure 5 at once suggests a simple geometrical explanation of the observed frequency and spatial relationship between associated type I and type III storm activity. This model is based on the assumptions that the type III emission originates at the plasma level in a region of weak magnetic field with open field lines (i.e. above the cusp of a helmet structure), whilst the type I source is located at the plasma level in the strong closed magnetic field over an active region. (Boischot *et al.* (1971) also have suggested that the type I–type III boundary corresponds to the transition from closed to open magnetic-field lines.) It follows from the geometry (Figure 5) that the type III electrons are accelerated at a level near, or somewhat above, the maximum height in the corona from which type I emission takes place; hence, the starting frequency of the type III bursts will be at or below the low-frequency cut-off of the type I. The 80 MHz positions of the type III storm bursts will therefore be displaced tangentially from the type I source, as was observed.

4. Comparison of the Meter and Hectometer Wavelength Observations

Whatever the explanation of the position of the type III bursts, the observations unambiguously determine the position of the type III source at the radioheliograph frequency of 80 MHz. As we have already emphasized, the spectra of the bursts shown in Figure 2 indicate that they are typical of the type III storm bursts, and differ from the rest of the storm only in having slightly higher starting frequencies.

The RAE satellite data show that at heights in the corona where the plasma frequency is 0.7–2.8 MHz, i.e. about 10–40 $R_\odot$ above the photosphere, the path of the type III exciters was parallel to the outward radial direction from region 9597 (Fainberg and Stone, 1970b; Sakurai, 1971). On the other hand, the type III source position in the 80 MHz radioheliograms is some 20° of solar longitude west of this active region. We now examine the significance of this apparent discrepancy between the two sets of observations.

It may be assumed that beyond a few solar radii from the photosphere the magnetic field lines are drawn out by the solar wind and therefore follow the 'garden-hose' spiral form of the latter (Figure 6a). The consequent deflection from the radial direction is, however, much too small to account for the results. Fainberg and Stone (1971), using the same set of satellite observations, find that the solar wind velocity was 380 km s^{-1} at heights between 14 and 36 $R_\odot$; this value leads to a deflection of only about 6°.

Another possibility is that the electron stream associated with the hectometer-wavelength bursts did not produce the type III bursts observed at 80 MHz, but was accelerated at a point directly above region 9597, at a greater height than the 80 MHz plasma level. Against this it must be argued that the simultaneous occurrence of two such intense and persistent streams of electrons is highly unlikely. In addition, since electrons from the meter wavelength source region must presumably continue into the outer corona we should expect to find evidence of a second exciting stream in the hectometer-wave observations; this is apparently not the case.

The most satisfactory explanation of the observations seems to be simply that the magnetic fields, and so the electron stream, are non-radial between the 80 MHz plasma level (about 0.6 $R_\odot$ above the photosphere) and the height (a few solar radii) at which the influence of the solar wind becomes dominant. This requires no assumption of

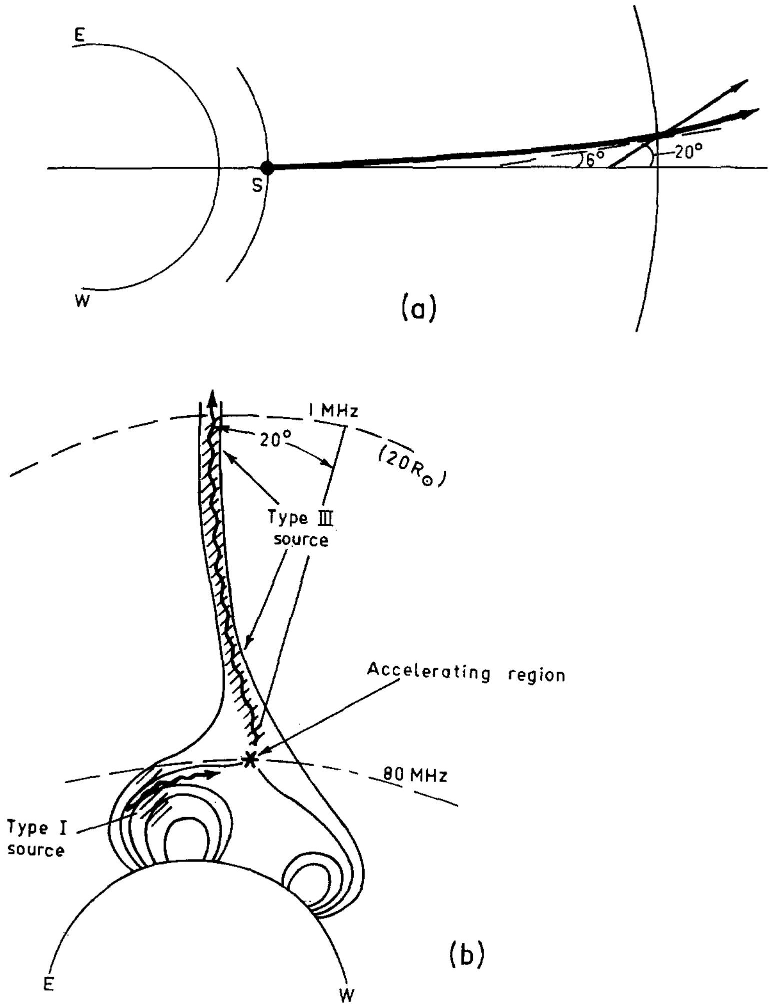

Fig. 6. Possible models of the type III region: (a) type III electrons accelerated at point S are deflected from the radial direction by the solar wind alone (heavy line). This gives a deflection of only 6° at 20 $R_\odot$, whereas Fainberg and Stone's (1971) results show that at this height the stream was inclined at about 20° to the radial direction from the 80 MHz source near S. (b) The streamer guiding the type III electrons is tilted away from the radial direction before it is drawn out by the solar wind.

unusual structures in the corona; non-radial streamers are common features in eclipse photographs, and Palmer and Lin (1972) recently found that a similar configuration was required to explain the relationship between observations of type III bursts and of an associated electron event. Figure 6b explains in this way the relation between the meter- and hectometer-wavelength results, and is at the same time consistent with the model for the lower corona (Figure 5) derived from the meter-wavelength observations alone.

5. Conclusions

In the storm of August 17–22, 1968, the positions of the sources of the meter-wavelength bursts indicated that the type I emission was generated in a region of strong magnetic field, whilst the type III bursts occurred in a weak field region. The two sources were separated by about 0.5 $R_{\odot}$.

The low starting frequency of the type III bursts (only occasionally above 80 MHz) leads us to conclude that the site of the acceleration of the exciting electrons was close to the observed 80 MHz type III source position. The presence of a dark filament in optical Hα records suggests that this source was in or near a magnetically neutral plane, and we propose a model in which the electron acceleration was produced by the release of energy in the unstable region at the cusp of the helmet magnetic-field structure.

Since there is evidence of a direct connection between the two types of emission in this type I–type III storm and in similar storms we conclude that the type III acceleration process is triggered by small disturbances originating in the type I source region and propagating out through the region of weak magnetic field. It appears that these results preclude, at least in the present case, the possibility of mechanisms such as that proposed by Gordon (1971), in which the acceleration of the type III electrons takes place *within* the type I source region.

From a comparison of our meter-wave observations with the hectometer-wave data from the RAE satellite we conclude that the type III electrons follow a non-radial path between the 80 MHz plasma level (height 0.6 $R_{\odot}$) and the solar wind region of the corona. This appears to be the only satisfactory way in which to explain both the observed position of the 80 MHz bursts and the observed path of the exciters between the 0.7 and 2.8 MHz plasma levels.

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