THE TYPE IV SOLAR RADIO BURST AT METRE WAVELENGTHS

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Summary

Properties of 24 sources of type IV emission at metre wavelengths (including the long-lived continuum storms) have been observed by interferometry in the frequency range 40–70 Mc/s and by dynamic spectroscopy in the frequency range 15–210 Mc/s. The characteristics investigated are the positions, movements, and angular sizes of the sources, and the spectrum and polarization of the emission.

Two varieties of the metre-wave type IV burst with distinctive characteristics, notably in height and movement of the source and in polarization of the emission, have been recognized. These two varieties have been designated "moving" and "stationary" type IV bursts; they are probably separate phenomena related only through a common initiating disturbance. The stationary type IV emission appears to emanate from near the plasma level, but there is no appreciable dispersion of position with frequency over a narrow range of frequencies. No physical distinction is found between the shorter stationary events and the beginnings of the long-lived continuum storms, but notable changes in source properties develop towards the ends of continuum storms.

I. Introduction

The type IV solar radio burst is an event characterized by persistent broad-band continuum emission. It is almost always associated with a major solar flare. At metre wavelengths the type IV burst is usually, though not invariably, preceded by a type II (slow-drift) burst. The importance of, and interest in, the type IV burst are enhanced by its geophysical significance. There is a strong correlation between the occurrence of such a burst and the delayed incidence at the Earth of solar protons and geomagnetic disturbances.

The fully developed type IV event is very complex. The emission may extend in frequency from the decametre to the centimetre range. Wild (1962), in summarizing the views of various observers in the field, has suggested that three components should be recognized. These are distinguished by their characteristics in spectrum, time variation, polarization, position, and angular size. The components, whose radiations are located in the metre, decimetre, and microwave bands, will be referred to as types IVm, IVdm, and IVμ respectively. Pick-Gutmann (1961), Boischot and Pick (1962), and others have further suggested that the IVm component can be divided into two parts with distinctive characteristics. There is still considerable doubt as to whether the decimetre emission should be regarded as a distinct component or as merely an extension of the microwave component and perhaps also of the metre-wave component.

The lowest frequency at which systematic measurements of the characteristics of type IVm bursts, other than spectral features, have been reported is 169 Mc/s

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(Boischot 1958). Much data have also been accumulated by the Japanese workers at 201 Mc/s (e.g. Morimoto 1961). At frequencies lower than 169 Mc/s, only isolated measurements have been reported (97 Mc/s, Payne-Scott and Little 1952; 87 Mc/s, Kundu and Firor 1961; 40–70 Mc/s, Wild, Sheridan and Trent 1959).

This paper presents a systematic and detailed description of the properties of the type IV source in the frequency range 40–70 Mc/s. Inevitably, there is some repetition of material that has already appeared in the literature, but most of the data are new. It need scarcely be added that one of the objectives is to attempt a clarification of the nature of the type IVm event, by appeal to the new results that provide information on the type IV source at heights of one solar radius or more above the photosphere. The characteristics investigated are the positions, movements, and angular sizes of the sources, and the polarization of the emission. Supplementary spectral observations over the frequency range 15–210 Mc/s have been included, and indeed the spectral appearance has been adopted as the sole criterion for the recognition of type IV events.

II. Instrumentation

The equipment supporting the present investigation consists of three distinct instruments, namely, the Dapto dynamic spectrograph, the swept-frequency interferometer, and the swept-phase interferometer.

Several parts of the equipment, notably aerials and receivers, are common to more than one of the instruments. Time sharing between the different functions is achieved by a switching sequence. The swept-frequency interferometer is used for the measurement of the source position and of the phase of the polarization. Measurements of the degree of polarization and of the angular size of the source are made with the swept-phase interferometer. The operation of the interferometers and the reduction of the records have been described in detail by Wild and Sheridan (1958), Wild, Sheridan, and Neylan (1959), and Sheridan (1963).

III. Selection of Events and Nomenclature

As pointed out by Wild (1962) the type IV event is nowadays conveniently defined as a true spectral type that can in general be recognized from spectral records without appeal to subsidiary data. In accordance with this principle, the events in the present sample have been classified as type IV from their spectral appearance alone. We adopt the criteria which McLean (1959) has shown to be appropriate for our wavelengths, namely, that the spectrum be smooth (though not necessarily completely without bursts) and that the event be associated with a type II burst.*

The Dapto data were analysed by taking 17 events which satisfied the above selection criteria and dividing them into two classes, namely, bursts which lasted for a comparatively short time (a few hours or less), and the long-enduring events classified as continuum storms by Pick. This procedure was prompted by the French

* Two events, both flare-associated, have been classified as type IV, though they were not preceded by a type II burst. Instead, they were preceded by a fairly short-lived group (duration less than 10 min) of type III bursts superimposed on a patchy continuum, the whole showing traces of the slow frequency drift characteristic of the type II burst. These peculiar events may be degenerate type II bursts.

suggestion that the type IVm burst could be divided into two distinct parts, the first of which had a duration of less than 2 hr, whilst the second part, with a duration of a few hours or more, was exemplified by the continuum storms. Thus, 12 of the shorter events and the beginnings of 5 of the longer events were available for analysis; limitations on the operation of the interferometers meant that a continuum storm whose start was observed could not be followed for more than 4 hr. In addition, 7 continuum storms, whose start was not observed by us, have been identified from lists kindly supplied by Mme Pick-Gutmann and from the Harvard Catalog of Type II and Type IV bursts (Maxwell, Hughes, and Thompson 1962); for these storms our observations commenced from 4 to 17 hr after the start of the storm. Beginnings (age <4 hr) and ends (age >4 hr) of continuum storms were also differentiated in the analysis, following the French observation that continuum storms may sometimes develop into normal noise storms, with type I bursts.

The present analysis has clearly indicated that in the frequency range 40–70 Mc/s no physical distinction can be drawn between the shorter events and the beginnings of the longer events, including continuum storms. However, as will be described in later sections, the aging of a continuum storm may be accompanied by the development of burstiness in the spectrum, by an increase in the size of the source, and by the onset of random variations in position and polarization which do not appear to be characteristic of the beginnings of these storms. The term "continuum storm" will be retained as a convenient label to describe the more persistent type IVm bursts, but it must be emphasized that no physical distinction between continuum storms and type IVm bursts is thereby implied.

IV. Spectral Features

The main spectral features, as revealed by the Dapto records, have already been described by McLean (1959). Generally similar features have been observed by Thompson (1962) and Thompson and Maxwell (1962), in the frequency range 25–580 Mc/s, with the Harvard spectrograph. The main characteristics noted by McLean are (*a*) the event consists almost entirely of a smooth broad-band continuum, (*b*) slow intensity variations with period of the order of half an hour may be present, and (*c*) at the start the continuum may show detailed structure and frequently exhibits a low frequency cut-off which drifts from high to low frequencies at rates similar to those of type II bursts. It may be added that on those occasions when short-lived bursts (duration a few seconds or less) appear superimposed on the continuum, the bursts are broad band and have a wispy appearance quite unlike narrow-band type I bursts.

The temporal relations between the type IVm burst and the associated type II burst are illustrated in Figure 1. The onset of the continuum may be before, at, or after the end of the type II burst, but cases in which the continuum commences before the start of the type II burst are rare at our frequencies. The average delay between the start of the type II burst and the start of the type IV burst is about 10 min. The time required for the intensity of the continuum to reach its maximum value varies widely, from a few minutes to over an hour in one exceptional case. The average is 25 min. Hence the average time lapse between the explosion which initiates the composite II–IV event and the maximum intensity in the continuum radiation is about 30 min. It is apparent from Figure 1 that the continuum storms build up more rapidly than the shorter duration type IV bursts.

Only two of the events were associated with optical flares weaker than importance 2. In both cases the continuum radiation was, significantly, extremely weak.

Fine structure is rather common and pronounced in the spectra near the ends of continuum storms. It generally takes the form of broad-band bursts of very short duration, identical with the wispy structure already mentioned, but narrow-band bursts have also been observed. Fine structure, incidentally, also occurred, although to a lesser extent, in two of the five continuum storms whose beginning was observed.

An examination has been made for possible connections between spectral features and other characteristics, such as the position and movement of the source and the degree of polarization. No outstanding connections have been found. A few minor relations, as a rule no more than hints, will be described as they arise.

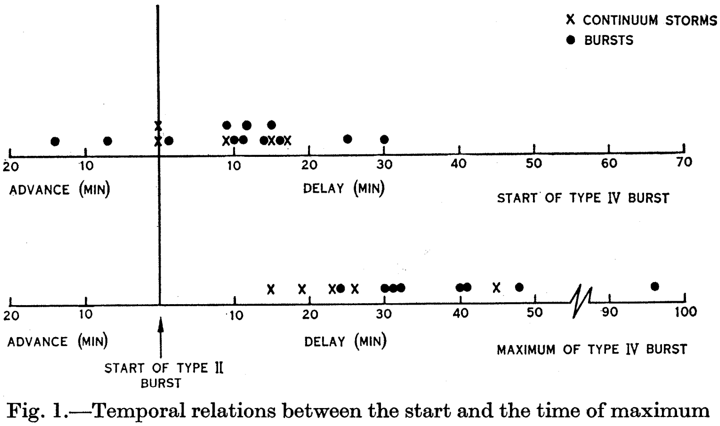


Fig. 1.—Temporal relations between the start and the time of maximum intensity of type IV bursts and the start of the associated type II bursts.

V. Position and Movement

The error in a single measurement of position* made with the long base-line interferometer is approximately 2′ arc. Some use is also made of position measurements with the short base-line; in these cases the error is about 4′ arc. The error in the mean position for a given burst, which may be estimated from over 100 individual measurements, is correspondingly less, except when the intensity of the burst is very low. Ionospheric wedge refraction effects, which are a potential threat to the accuracy of the position measurements (Wild, Sheridan, and Neylan 1959; Weiss 1963) are easily recognized. Nevertheless, it is not possible to be certain that the effects of ionospheric refraction, whether regular or irregular, have been completely removed.

* Positions are measured simultaneously at several frequencies in the range 40–70 Mc/s. The source position is specified by its *position coordinate*, defined as the projected distance between the centre of the disk and the source, measured in the terrestrial east-west direction. For a description of the method and accuracy of position measurements see Wild, Sheridan, and Neylan (1959) and Weiss (1963).

(a) *Position*

The sources of type IV bursts almost invariably exhibit movement at some stage during their lifetimes. The movement may be irregular, or consist of quasi-periodic oscillations about some stable position, or be systematic in time. Characteristically such systematic displacements occur at the start of bursts, when they are rapid and pronounced; if they occur later in the burst, the rate of movement of the source is comparatively slow. In most cases it is possible to specify a *stable position*, which the source settles down to or oscillates about.

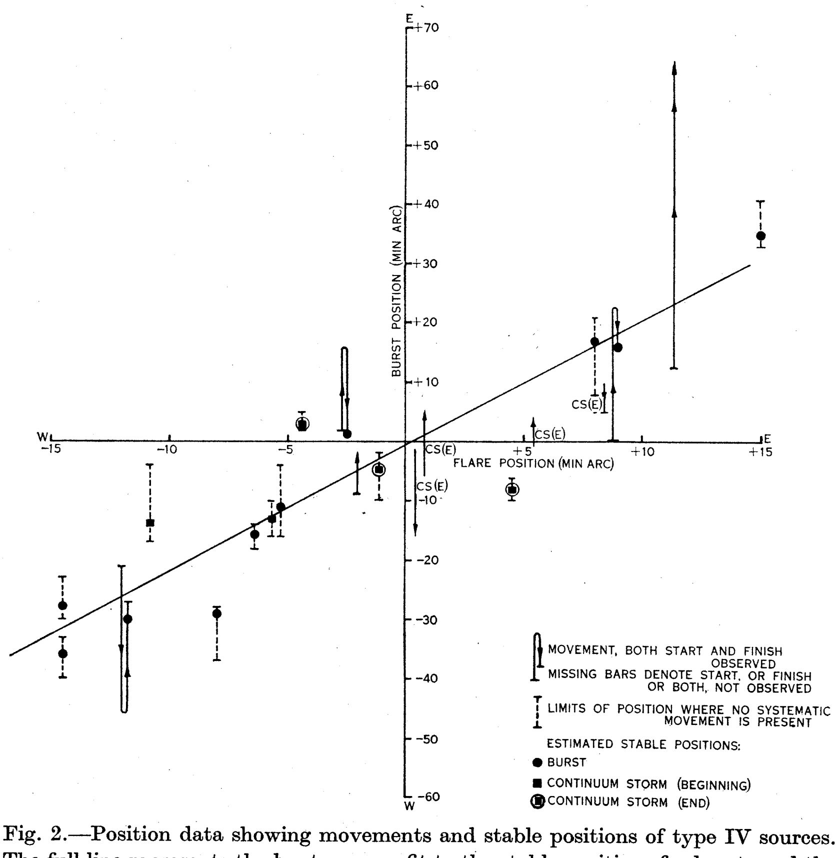


Fig. 2.—Position data showing movements and stable positions of type IV sources. The full line represents the least squares fit to the stable positions for bursts and the beginnings of continuum storms, CS(E) denotes ends of continuum storms without stable positions.

The position data are summarized in Figure 2. Stable positions, systematic movements, and the limits of irregular movement are indicated. The sources of type IV emission exhibit little or no angular dispersion with frequency (see Section V(b)) and the positions in Figure 2 are obtained by averaging over all frequencies in the range 45–65 Mc/s. If it is assumed that on the average the type IV source lies radially above the flare, the mean height of the stable positions is given directly, in terms of the photospheric radius R_0, by the slope of the relation between burst position and flare position. The mean height is estimated to be $2\cdot11\pm0\cdot26R_0$, which seems indistinguishable from the mean height, $1\cdot97\pm0\cdot28R_0$, derived from a similar analysis of the positions of the fundamental bands of type II bursts at the same frequencies (Weiss 1963). The latter are presumed to lie near the plasma levels and so it seems reasonable to conclude that, on the average, the stable positions of the sources of type IV bursts are located close to (possibly slightly above) the mean plasma level for the small range of frequencies involved (45–65 Mc/s). A similar proximity to the appropriate plasma level of the stable sources of type IVm bursts at higher frequencies is indicated by the results of Pick (1960) (169 Mc/s) and of Morimoto (1961) (201 Mc/s). (See also Section VIII(a).)

TABLE 1

POSITIONS OF TYPE IV SOURCES

Date of Observation	Type of Event*	Flare Position Coordinate†	Position Coordinate† (min of arc)				$P_{45}-P_{60}$	$\bar{P}$	Sample Size
			45	50	55	60			
29.vii.58	B	−11·8	−28·6	−28·5	−27·9	−28·2	−0·4	−28·3	22
22. x.58	B	−5·3	−11·9	−10·1	−9·6	−9·4	−2·5	−10·3	9
7. i.59	B	−2·1	−3·3	−3·6	−3·7	−2·6	−0·7	−3·3	6
3.xii.59	CS(E)	−4·4	—	+3·4	+3·0	+3·2	—	—	26
11. i.60	CS(E)	+0·8	−1·4	−0·9	−1·5	−1·8	+0·4	−1·4	15
29. iii.60	CS(E)	+5·4	+0·7	+0·9	+1·1	+1·6	−0·9	+1·1	29
30. iii.60	CS(E)	+4·5	−7·2	−7·8	−8·3	−8·4	+1·2	−7·9	31
31. iii.60	CS(E)	+0·4	−11·2	−12·8	−11·9	−13·2	+2·0	−12·4	11
5. iv.60	B	−14·5	−35·4	−35·5	−33·2	—	—	—	18
28. iv.60	B	+8·0	+18·6	+13·6	+14·5	+17·5	+1·1	+16·1	20
27. vi.60	B	+9·4	+19·3	+20·2	+20·9	+21·9	−2·6	+20·6	6
11. xi.60	CS(E)	+8·4	+4·7	+4·5	+4·8	+4·6	+0·1	+4·7	56
15. xi.60	CS(B)	−5·7	+13·4	+12·9	+12·6	+12·7	+0·7	+12·9	39
28.vii.61	B	−8·0	−31·7	−30·6	−29·2	−28·8	−2·9	−30·1	37

* B = burst, CS(B) = continuum storm (beginning), CS(E) = continuum storm (end).

† The position coordinate is defined as the projected distance between the centre of the disk and the source, measured in the terrestrial east-west direction.

(b) *Variation of Position with Frequency*

Mean source positions, averaged within frequency bands 5 Mc/s wide, are listed in Table 1. The variation of position $P_{45}-P_{60}$ is plotted against $\bar{P}$ in Figure 3. Clearly these data contain no suggestion that there is any systematic variation of position with frequency such as is typical of the sources of bursts of types II and III. The sample of events selected for analysis contains only one burst exhibiting rapid initial movement, but the absence of any systematic variation of position with frequency is characteristic also of the "moving" type IV bursts (see also Wild, Sheridan, and Trent 1959).

The observed lack of systematic variation of position with frequency in our frequency range appears to conflict with the above data on the heights of the type

IVm sources, which can reasonably be interpreted as indicating that the stable position of the source is located near the appropriate plasma level for all frequencies in the range 40–200 Mc/s. Further observations are needed to resolve this paradox. The present implication is that for stable type IV sources the radiation originates near the plasma level, but probably over a much greater depth of solar atmosphere than for the drifting bursts of spectral types II and III. Over small frequency ranges, the dispersion of position with frequency may be suppressed by smoothing over irregularities in the solar atmosphere.

(c) *Movement*

Systematic rapid movements are confined to the initial stages of type IV bursts. Of 12 bursts whose positions were recorded from the start of the emission, only 4 showed evidence of rapid movement. In all cases the initial direction of movement

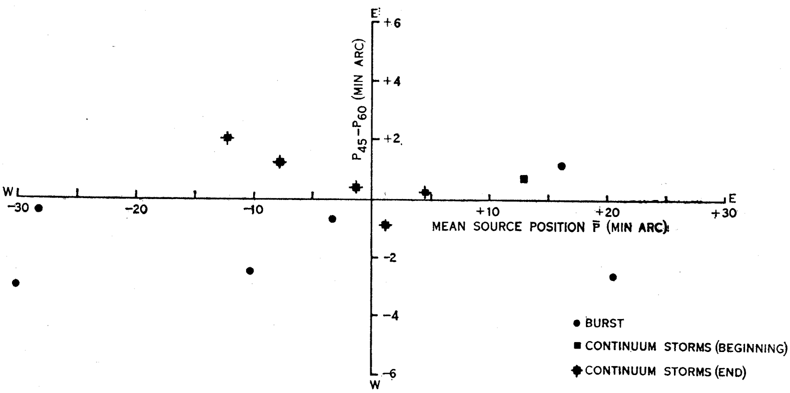


Fig. 3.—The variation of position $P_{45}-P_{60}$ as a function of stable position $\bar{P}$ (averaged over all observed frequencies) for type IV bursts.

was outwards, away from the centre of the disk; this stage occupied 5–20 min. In three of the four cases the outward movement was followed by a slower inwards movement to a final stable position. In the remaining case the position record ended shortly after the commencement of the burst and subsequent inwards movement, had it occurred, would not have been observed. In no case was rapid outward movement followed by stabilization of the source position without prior return towards the centre of the disk.

The position changes for these four events are reproduced in Figure 4. On the data available it is impossible to determine the true directions of motion of the sources in the solar corona. It is, however, evident that the motion is not always radial. Components of motion projected onto the solar disk are estimated very approximately in Table 2.* The speeds are lower limits to the true speeds of ejection; they are of the same order as the faster of the speeds given by Boischot (1958) in his original description of the type IV burst. Non-radial motion has also been reported at 169 Mc/s by

* To estimate the approximate speeds, it has been assumed that the motion is tangential to the Sun's surface if the source is initially located close to the centre of the disk, and radial if the initial position of the source is far removed from the centre of the disk.

Boischot and at 87 Mc/s by Kundu and Firor (1961). There is, however, surprisingly little scatter about the mean line drawn in Figure 2, which suggests that regardless

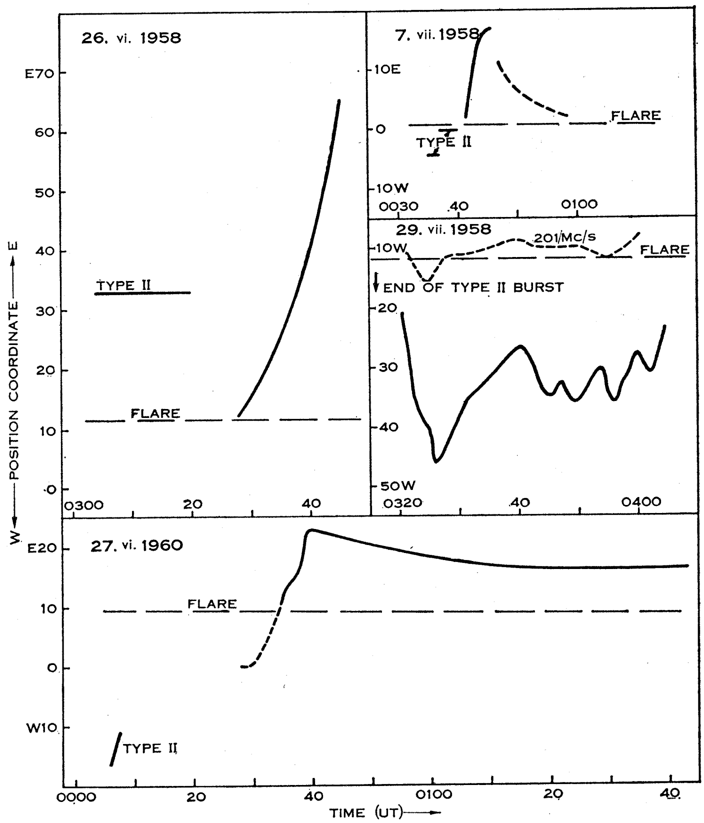


Fig. 4.—Type IV bursts which exhibit rapid initial movement. The movement at 201 Mc/s for the event of July 29, 1958 is partially suppressed by blending with an intense coexisting type I noise storm.

TABLE 2

PROJECTED SPEEDS OF TYPE IV SOURCES

Date	Predominant Component of Motion	Apparent Speeds (min arc/ min)		Projected Speeds* (10^3 km/s)	
		Out	In	Out	In
26. vi.58	Radial	3·06	—	2·2	—
7.vii.58	Tangential	6·00	0·68	4·4	0·5
29.vii.58	Radial	4·55	1·73	3·3	1·3
27. vi.60	Tangential	3·07	0·20	2·2	0·1

* Speeds of motion projected onto the solar disk; these are lower limits to the true speeds.

of any initial movement the stable position finally taken up by the source is to a good approximation radially above the flare. The ends of continuum storms appear to be exceptional in this respect, and it is probably significant that for four of these seven storms the sources exhibit slow systematic displacements, with drift rates of from 0·03 to 0·06′ arc/min. Such slow displacements are most plausibly interpreted as tangential source movements. Corresponding speeds are low, less than 50 km/s. Sustained slow wanderings of this type appear to occur only rarely in the initial stages of type IV bursts.

Examples of type IV bursts that do not show the characteristic systematic initial movement appear in Figure 5.* In the sample of events studied such absence of movement is actually more common than the movements already described.

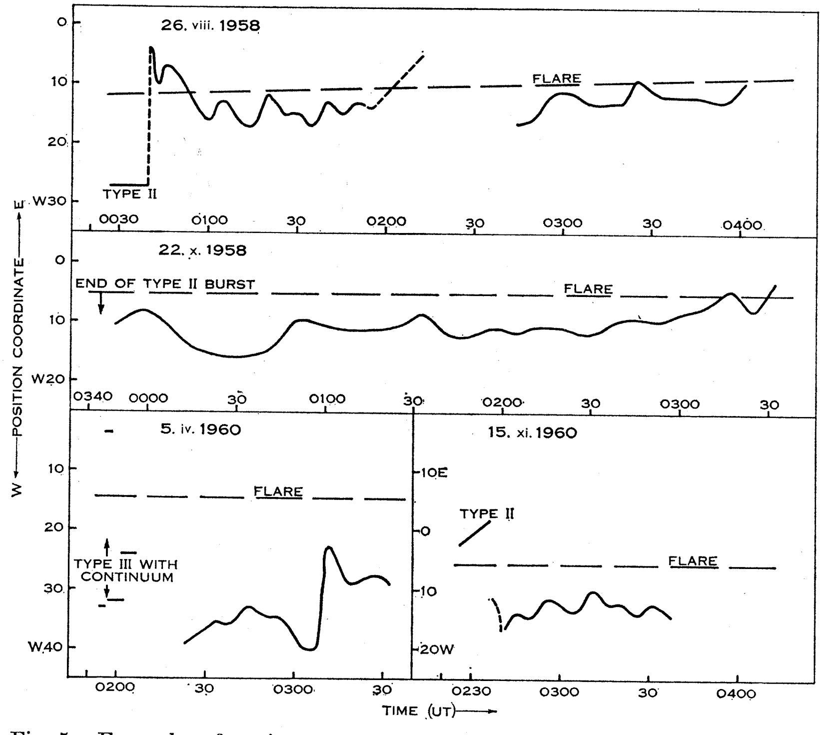


Fig. 5.—Examples of stationary type IV bursts. The events of August 26, 1958 and November 15, 1960 developed into continuum storms.

The event of April 5, 1960 (also in Fig. 5) is an interesting example, and the only one, of a type IV burst whose source position changes discontinuously during the lifetime of the burst. The event is unusual, although not unique, in that the type IV burst was preceded, not by a type II burst, but by a type III-continuum event of the kind described in the footnote on p. 527. The change in position of the source of the type IV emission was accompanied by a notable increase in the burstiness of the

* Similar slow outwards movements and irregular fluctuations about a stable source position occur in the later stages of four of the six outbursts studied by Payne-Scott and Little (1952). These four appear to be type IV bursts. The observations were made between September 1949 and August 1950, comparatively early in the decline from maximum solar activity in the previous cycle.

emission. The two type IV sources appear to be linked to two distinct sources responsible for the emission in the preceding type III-continuum event.

Some care is required in the interpretation of the apparent inwards source movements. The observations are consistent with the hypothesis that the moving and stationary sources are identical, in which case the outwards movement is followed by return and stabilization of the same source. But this is not the only possibility. If two sources are present simultaneously, the interferometer will record only their centre of gravity. Hence the inwards return to a stable position could be produced by a blend of two co-existing sources: the one an outwards-moving source

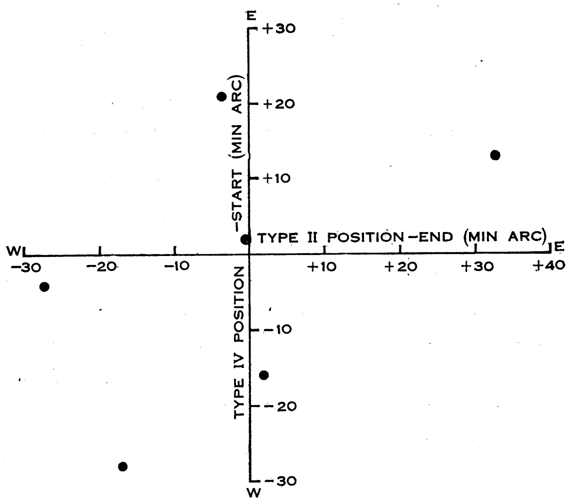


Fig. 6.—Comparisons of positions of type II sources, measured near the ends of the bursts, with initial positions of the associated type IV sources. The delay between the two measurements in each pair is less than 5 min.

whose intensity weakens as its outwards movement continues unabated, the other a stationary source whose intensity increases as the outwards-moving source weakens. On this view, which is supported by the great preponderance of stationary sources, the moving and stationary sources are separate phenomena.

(*d*) *Positions of Associated Type II and Type IV Sources*

The events shown in Figures 4 and 5 illustrate one further characteristic of the sources of type IV bursts, namely, that in general the initial position of the type IV burst, whether moving or stationary, is widely separated from the position of the associated type II burst. The best examples, in which the position of the type IV source is first measured within a few minutes after the end of the measurement for the type II source, are plotted in Figure 6.

In the record for August 26, 1958 (Fig. 5), the position of the source is observed to change by over 20′ arc in a little over a minute, as the interferometer switches from the type II to the type IV source. This is an extreme case of a fairly common occurrence, which provides compelling evidence that in some cases the type II and type IV sources are present simultaneously and in widely different positions in the solar corona. These cases emphasize that in general the sources of type II and type IV events, though related to the same initiating disturbance, must be regarded as moving independently through the corona.

(e) *Distribution of Sources across the Solar Disk*

The present sample of events is small, but, according to Figure 2, continuum storms, unlike the type II and type III bursts, seem to avoid the radio limb. In particular, a strong concentration of the ends of continuum storms to the centre of the disk is apparent. A similar result was obtained by Pick (1960). The narrow cone of emission implied by this feature is not shared by the less persistent bursts (and especially not by the moving bursts), whose sources may be located anywhere on the radio disk. A study of over 20 events by Boorman *et al.* (1961) also contains little evidence for directivity of the emission at our frequencies.

VI. Polarization

The polarization parameters* measured are inadequate for the complete specification of the state of polarization of the emission. The observations have been reduced on the assumption that the emission is circularly polarized. According to an unpublished investigation by Dr. J. A. Roberts of this Laboratory, this assumption cannot falsify conclusions as to the sense of polarization and provides a lower limit to the degree of polarization.

(a) *Sense of Polarization*

The sense of polarization has been determined for a total of 23 events. Of these, only four showed a definite reversal in the sense of polarization during the periods of observation. No unpolarized events were recorded. Data for all events are plotted in Figure 7 as a function of the disk coordinates of the associated flare. To interpret these points in terms of the magneto-ionic theory, we note that in the *northern* hemisphere *left-hand* polarization corresponds to emission in the *ordinary* mode, if we assume that the sense of polarization is determined by the magnetic polarity of the *leading* spot. It is evident from Figure 7 that there is a strong tendency for the sense of the polarization to be related to the hemisphere in which the disturbance originates. These tendencies, which are not without exceptions, are:

(1) Bursts with characteristic initial movement are initially polarized in the extraordinary mode (3 : 1). In two cases, the polarization changed to the ordinary mode between the moving and the stationary phases. Another, perhaps exceptional, case was the burst of June 27, 1960, whose source position stabilized, without reversal in sense of polarization (extraordinary), quite near to the extreme outward position reached during the initial movement.

* For a description of the parameters measured and the methods of measurement see Wild and Sheridan (1958) and Wild, Sheridan, and Neylan (1959). Degree of polarization is determined at 40 and 60 Mc/s, and sense of polarization at several frequencies in the range 40–70 Mc/s.

(2) After the source position of a burst has stabilized or when it is stable from the start of the burst, the polarization is in the ordinary mode (9:2).

(3) At the start of the present sample of continuum storms, the polarization is in the extraordinary mode (5:0). In one case, August 26, 1958, the sense of polarization reversed after approximately 1 hr. The reversal occurred during a period of very low intensity of the emission at 40–70 Mc/s. This event was also marked by initial movement of the source, although not at the high speeds characteristic of the moving bursts. In the remaining four cases the sense of polarization did not change during the course of the observations, that is, during 2–3 hr from the start of the continuum emission. Also, three of the storms in this group belonged to the outstanding

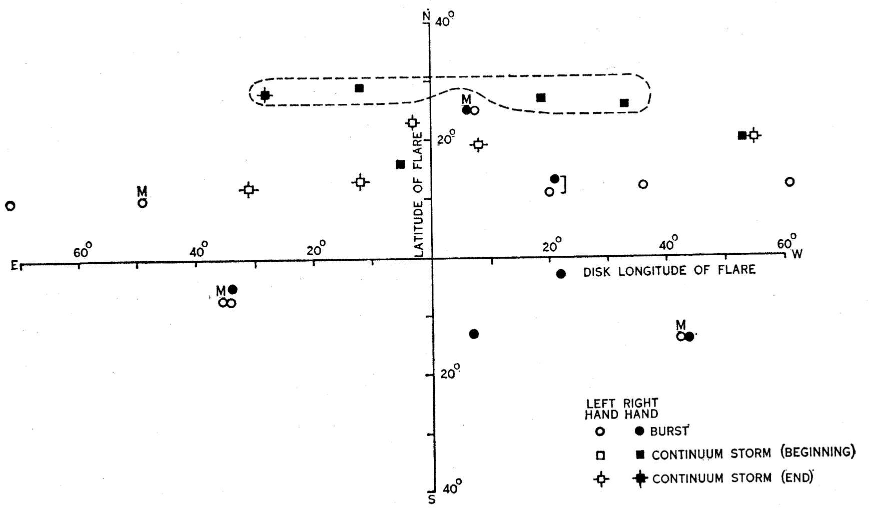


Fig. 7.—The sense of polarization of type IV emission plotted against the disk coordinates of the associated flare. Events in the November 1960 group are enclosed in a dotted envelope. Pairs of touching points represent moving and stationary bursts belonging to the same events; the moving bursts are designated by the symbol M. The pair of points linked by the symbol] are two type IV bursts occurring in the same active region but with opposite senses of polarization.

November 1960 activity; if the polarizations of these emissions are determined by a persistent magnetic field configuration, the events in this group may not be statistically independent.

(4) Ends of continuum storms are characterized by polarization in the ordinary mode (4:1). In one other case (March 29, 1960) the sense reversed from extraordinary to ordinary during our recording period; the reversal appears to be related to a marked increase in the intensity of the continuum emission at frequencies below 40 Mc/s.

These results support the French suggestion (e.g. Boischot and Pick 1962) that moving and stationary type IV bursts are distinguished by distinctive senses of polarization. On the leading spot hypothesis, the usual mode is extraordinary for the moving burst and ordinary for the stationary burst. That there are exceptions, perhaps common, to the association of unique modes of polarization with the moving and stationary type IV bursts is emphasized by the pair of points in Figure 7 for the bursts of April 29, 1960. Here a second type IV burst was generated in the same active region as that responsible for a type IV burst already in progress. The senses of polarization of the radiations from the two sources were reversed.

(b) *Degree of Polarization*

In the initial stages of a burst the degree of polarization appears to follow a typical development, whose nature does not vary from one burst to the next, although the rate of development may. When the continuum emission is first detected at 40 or 60 Mc/s, the degree of polarization is low, usually 10–20% only. After an interval which may range from a few minutes to almost an hour the degree of polarization begins to increase, without change of sense. The rise to a final high value may occupy from 10 to 30 min. For a given event the timing is much the same at either frequency. It also runs roughly parallel to, although somewhat more slowly than, the growth of the intensity of the continuum emission, with the result that the final high degree of polarization is not reached until after the intensity has attained its greatest (or steady) value. An illustration of the initial growth of the polarization will be found in Figure 9.

After the initial development, the emission in the early stages of continuum storms is strongly circularly polarized. The degree of modulation rarely falls below 50% and occasionally approaches 100%. There is a tendency, not very marked, for the polarization to be stronger at 40 than at 60 Mc/s. Fluctuations in the degree of polarization are small, rarely exceeding 10–20%.

The ends of three continuum storms have also been observed.

(i) *March 29, 1960*: Prior to 0210 UT the degree of polarization varied chaotically between 30 and 100% at both frequencies (40 and 60 Mc/s). A subsequent diminution of the degree of polarization, to 50% and less, was associated with the reversal in the sense of polarization and the notable extension of the low frequency limit of the continuum emission already noted above (Section VI (*a*)).

(ii) *March 30, 1960*: An abrupt increase from 20 to 70%, apparently related to an increase in the intensity of the emission, occurred simultaneously at both frequencies.

(iii) *March 31, 1960*: At both frequencies the degree of polarization varied chaotically between 0 and 60%.

Information on the degree of polarization of type IV bursts (as opposed to continuum storms) is fragmentary. Only one burst has been adequately observed. This showed an initial development identical in form with that characteristic of the continuum storm. The final degree of polarization was 80%.

VII. Source Size and Brightness Distribution

The measured parameter from which the source size and brightness distribution are estimated is the visibility ξ of the fringes in the adding interferometer.* ξ,

* The measurements are made at frequencies of 40 and 60 Mc/s and with both long and short base-line interferometers. The theory underlying the method and the derivation of brightness distributions from the observed visibilities are treated by Wild and Sheridan (1958) and Weiss and Sheridan (1962).

corrected for attenuation in the aerial feeders, is the relative modulus of the Fourier component of the source distribution at the spectral "frequency" corresponding to the aerial spacing.

Visibilities have been observed for only four sources, all stationary. Average values are summarized in Table 3. In all four cases the visibilities were subject to large fluctuations (random except in one instance) of up to ± 50–60% about the mean value. The random fluctuations are different at the two frequencies and are unrelated to the state of the spectrum, source position, or polarization. Further study is needed to establish the reason for these large fluctuations in the visibility. It is possible, though not likely, that they are ionospheric in origin.

In one instance (March 30, 1960) the fluctuations were quasi-periodic ($\sim$6 min) rather than random. This variation, which probably reflects a true change in the brightness distribution of the source, appears to be connected with broad-band

TABLE 3

VISIBILITIES OF TYPE IV SOURCES

Date	Type of Event	Duration of Observation	Time Lapse*	ξ_{40}		ξ_{60}	
				Long Base	Short Base	Long Base	Short Base
29.iii.60	CS(E)	4 hr	3·2 hr	0·27	0·48	0·20	0·43
30.iii.60	CS(E)	36 min	21 hr	0·32	0·54	0·24	0·2–0·9
29.iv.60	Burst	3 min	46 min	—	—	0·66	0·86
15.xi.60	CS(B)	55 min	20 min	0·45	0·69	0·57	0·88

* Time lapse between start of continuum emission and start of size sampling.

wispy bursts extending to much lower frequencies than the normal edge of the continuum emission. Unfortunately, confusion in the form of the variation precluded an estimate of the relative sizes of the sources of bursts and continuum.

The visibility data are inadequate for the determination of the brightness distribution of a source. Weiss and Sheridan (1962) have derived a plausible model for the source distribution of the type IV burst of November 15, 1960. In this model about two-thirds of the emission is concentrated into a Gaussian core of width (to half-power points) of $\sim 6'$ arc, and the remaining one-third of the radiation is emitted in a broad halo surrounding the core. The visibilities for the burst of April 29, 1960 require a similar halo but a still smaller core size for this source. For the ends of the continuum storms of March 29 and 30, 1960, however, the core diameter is larger, and a considerably greater proportion of the total radiation comes from the halo.

VIII. Comparison with Observations at Other Frequencies

(a) *Position and Movement*

Morimoto (1961) has pointed out that at 201 Mc/s the sources are stable in position, but show small movements (of a few minutes of arc) similar to those which we have found for stable positions at lower frequencies. For the burst of July 29, 1958, illustrated in Figure 4, there is a suggestion of initial movement at 201 Mc/s which resembles that characteristic of the moving bursts. The interpretation of the 201 Mc/s record is complicated by a co-existing type I noise storm, but it appears from Figure 4 that at 201 Mc/s the type IV source follows, perhaps with reduced amplitude, the movement observed at lower frequencies.

Average positions for seven bursts observed simultaneously at Dapto and at Mitaka are compared in Figure 8.* The only useful conclusion which can be drawn from this comparison is that the average height of generation of the continuum emission at 201 Mc/s is less than the height for the 40–70 Mc/s emission. Using more single-frequency data, Morimoto (1961) has deduced an average height above the photosphere of $\sim 0 \cdot 3 R_0$ for the sources of type IV emission at 201 Mc/s. This value agrees with the average height of $0 \cdot 3 R_0$ given by Pick (1960) for the sources of continuum storms at 169 Mc/s.

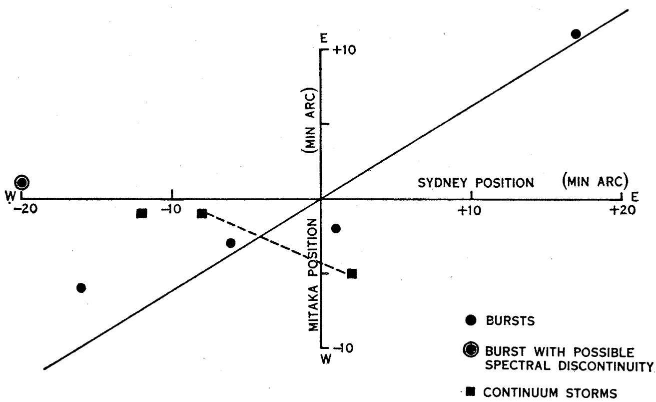


Fig. 8.—Comparison of position measurements of type IV bursts observed simultaneously at 201 Mc/s and at 40–70 Mc/s. The two points joined by the dotted line refer to two different and discontinuous positions for the 40–70 Mc/s source. The full line gives the relation expected from the average heights of type IV sources at the two frequencies.

These observations suggest that the stationary type IVm source is distributed in depth, with the emission at a given frequency originating from a height close to the local plasma level.

(*b*) *Polarization*

Six out of eight bursts observed simultaneously at 40–60 Mc/s and at 201 Mc/s were polarized in the same sense at the two frequencies. Of the two remaining bursts which showed reversals in the sense of polarization, one was polarized in the ordinary mode (the mode expected on the leading spot hypothesis) at 201 Mc/s, and the other in the extraordinary mode.

* We rarely observe gaps, even minor ones, in the spectra of type IV bursts between 40 and 210 Mc/s. We have therefore identified the events observed at 201 Mc/s with the type IVm burst. This agrees with the identification of Takakura and Kai (1961). Tanaka and Kakinuma (1962) have preferred to regard the 200 Mc/s observations as relating to the IVdm event.

With so small a sample it is not possible to decide whether reversals in the sense of polarization between different frequencies in the metre wavelength range are comparatively common, or should be regarded as rare. In neither of the two cases noted above is there any spectral discontinuity between the two frequencies, and it is unlikely that two widely separated sources are involved, Reversals in the sense of polarization may then be connected with differences in the direction of the magnetic field in different regions of a common extended source, or with propagation effects.

(c) *The November 15, 1960 Event*

Many of the properties of the type IV burst are well illustrated by a comparative study of the event of November 15, 1960. This study, undertaken by Dr. S. Suzuki, extended in frequency from 9400 to 15 Mc/s. The results are summarized in Figure 9.

The spectrum, and the degree of polarization, and the relations between them are of particular interest. We will confine our remarks to these aspects. The three intense features with type II-like drift at decimetre wavelengths between 0220 and 0235 UT can be traced to frequencies as low as 40 Mc/s on the original records. The drift of the low frequency edge of the continuum emission from high to low frequencies is especially prominent. There seems to be a similar drift in the time of onset of strong polarization. The parallel growth of intensity and of degree of polarization at fixed frequency is also evident. Although a gap in the spectrum seems to develop near 200 Mc/s after 0240 UT, this does not appear to be reflected in the source position or polarization.

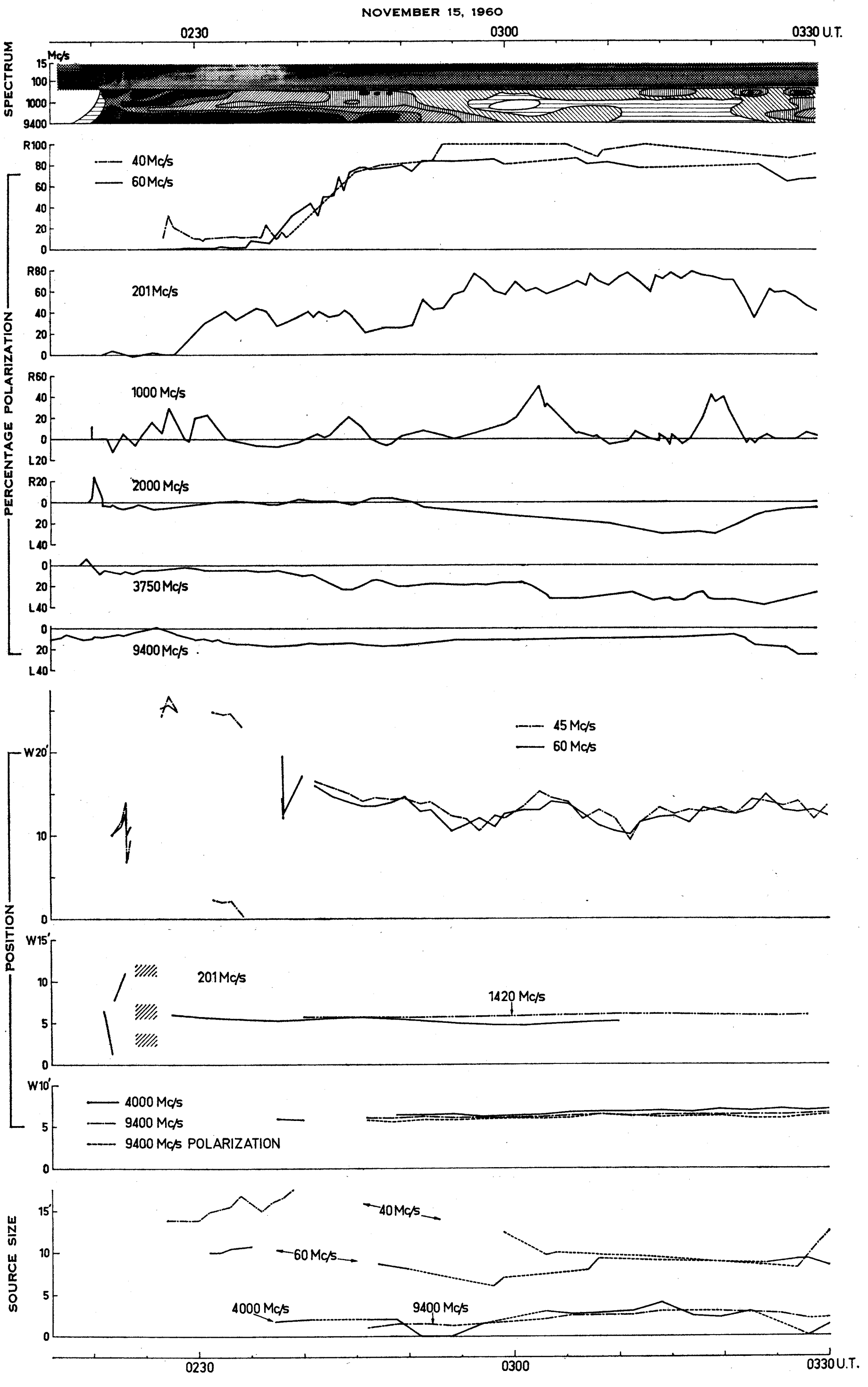
IX. Conclusions

In this paper we have examined a sample of type IV events which we expect to be representative of this phenomenon in the frequency range 40–70 Mc/s. The physical properties of the type IV sources *in this frequency range* are now briefly summarized.

(1) Two varieties of the type IV event have been recognized. On the available evidence it is possible, and indeed highly likely, that these are distinct phenomena related only through a common initiating disturbance low in the solar atmosphere. On the basis of position measurements, these two varieties have been designated "moving" and "stationary" type IV bursts.

(2) The moving type IV burst is characterized by fairly short-duration, ill-defined spectral features, rapid outward movement through the corona, broad cone of emission, and polarization in the extraordinary mode (if the defining magnetic field is that of the leading spot). This variety of type IV burst, which is comparatively rare around 50 Mc/s, seems to be identical with the first part described by the French workers (Pick-Gutmann 1961; Boischot and Pick 1962).

(3) The stationary type IV burst is characterized by long-duration, broad continuous spectrum, a height close to the local plasma level, little or no source movement, small source diameter, and strong polarization in the ordinary mode (on the leading spot hypothesis). It also shows a characteristic initial development in intensity and polarization and an initial spectral drift from high to low frequencies.


NOVEMBER 15, 1960
0230
0300
0330 U.T.
SPECTRUM
Mc/s
15
100
1000
9400
PERCENTAGE POLARIZATION
R100
80
60
40
20
0
40 Mc/s
60 Mc/s
R80
201 Mc/s
R60
1000 Mc/s
L20
R20
2000 Mc/s
L40
3750 Mc/s
9400 Mc/s
POSITION
W20′
10
45 Mc/s
60 Mc/s
W15′
201 Mc/s
1420 Mc/s
5
W10′
4000 Mc/s
9400 Mc/s
9400 Mc/s POLARIZATION
SOURCE SIZE
15′
40 Mc/s
60 Mc/s
4000 Mc/s
9400 Mc/s
0330 U.T.

It includes the long-lived continuum storms. It may occur with or without a moving type IV burst. It seems to be identical with the second part described by Pick-Gutmann (1961) and Boischot and Pick (1962), but we do not necessarily regard it as a continuation of the moving burst. Instead, we suggest that it may be a separate event whose initial stages may be obscured by the then more intense but short-lived moving burst.

(4) There appears to be no physical distinction between the stationary type IV bursts and the beginnings of the long-lived continuum storms. The aging of continuum storms is marked by the development of irregularities in the intensity, and burstiness in the spectrum; the bursts are often broad band, but in at least two cases the bursts were similar to the narrow-band type I storm bursts. The aging of a continuum storm is also accompanied by slow tangential wanderings of the source, by large chaotic fluctuations in the degree of polarization, and probably also by an increase in the size of the source.

(5) In neither variety of type IVm burst is there any detectable systematic variation of source position with frequency in the frequency range 45–65 Mc/s. The absence of such a systematic variation for the stationary type IVm burst is puzzling, since there is evidence that the stationary source is distributed in depth through the solar corona, with the emission at a given frequency originating from a height close to (perhaps slightly above) the local plasma level.

(6) The initial position of a type IVm source, whether moving or stationary, is often widely separated from the position of the associated type II burst. Hence the sources of related type II and IVm bursts, although they may be generated by a common initiating disturbance, do not always follow the same trajectories through the solar atmosphere.

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Fig. 9.—Properties of the sources of the type IV emission of November 15, 1960, as compiled by Dr. S. Suzuki. Observations below 200 Mc/s were made at Sydney, and above 200 Mc/s in Japan. The spectrum is composite, the positive (white) section below 200 Mc/s being a reproduction of the Sydney dynamic spectrum and the negative (dark) section above 200 Mc/s being compiled from several single frequency records. The dark bars crossing part of the dynamic spectrum are calibration marks for the Dapto swept-frequency interferometer. Note the initial development of the circular polarization at metre wavelengths, and the reversal of sense between 1000 and 2000 Mc/s. A more plausible interpretation of the 40–70 Mc/s position measurements is given in Figure 5. Source sizes have been determined under the assumption of Gaussian brightness distributions. The actual brightness distributions at metre wavelengths, which lead to smaller source diameters, are discussed in Section VII.

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