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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3A-6. The Nature of Tpye IV Solar Radio Bursts

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From an analysis of spectral observations of Michigan, Fort Davis and Sydney in the 25–600 Mc/s range, combined with simultaneous interferometric and single frequency observations in the range of frequencies 1000–9400 Mc/s and on 87 and 340 Mc/s, we find that type IV emission in the range of frequencies 25–580 Mc/s occurs in two distinct phases: a) the first phase, usually observed at frequencies higher than about 250 Mc/s, appears to be an extension of the associated centimeter-wave burst which is also a broadband continuum emission. This emission occurs earlier than the associated type II burst and can even occur independent of any type II burst. The source of this emission is situated low in the chromosphere, has no significant movement and has a small angular size, usually less than 4′. The observed properties of this phase of continuum emission are consistent with the suggestion that it is caused low in the chromosphere by synchrotron radiation of electrons generated during the flare. When this phase occurs alone, the geomagnetic activity index ΣK_p increases slightly, 2–5 days after the type IV burst. b) the second phase, usually observed at frequencies lower than about 250 Mc/s, is closely associated with a type II burst preceding it. The source of this continuum emission is situated high in the corona and moves with velocities of more than 1000 km/s. It has a large angular size, usually 10′ or larger. This second phase of type IV emission was previously explained as due to synchrotron radiation of electrons higher in the corona, when a cloud of gas with a shock front (which excites the type II burst) moving at high velocities carries a frozen-in magnetic field to the appropriate heights in the corona. There is a great increase in geomagnetic activity index ΣK_p, 1–2 days after the second phase of type IV burst.

Type IV solar radio bursts was identified by Boischot (1) in 1957 on 169 Mc/s interferometric records, and it was suggested by Boischot and Denisse (2) that it could be produced by synchrotron emission from high-energy electrons spiralling in a magnetic field. This identification was confirmed by dynamic spectral and interferometric observations in Australia (3, 4) and the U.S.A. (5, 6) in the range of frequencies 25–600 Mc/s. Recently, the concept of type IV burst-radiation has been extended to include the associated radiation on centimeter and decimeter waves. From an analysis of spectral observations of Michigan, Fort Davis and Sydney in the 25–600 Mc/s range, combined with simultaneous interferometric and single frequency observations in the range of frequencies 1000–9400 Mc/s and on 87 and 340 Mc/s, we find the following properties of type IV emission in the centimeter, decimeter and meter wavelength ranges (7, 9).

1. Recent dynamic spectral observations in the 2000–4000 Mc/s range at the University of Michigan (8) have shown that centimeter-wave bursts exhibit a smooth broadband continuum radiation, similar in nature to type IV emission on meter waves. Now, in the 100–600 Mc/s range, in addition to type IV with type II bursts, we also observe type IV without type II bursts. When a type IV without type II burst is compared with the associated centimeter-wave outburst, it is found that the type IV emission usually begins more or less simultaneously with the centimeter-wave burst emission, and in some cases its maxima correspond to the maxima of centimeter-wave burst. When a combined type IV-type II burst is compared with the associated centimeter-wave outburst, it is found that the centimeter-wave emission always starts earlier than type II burst,

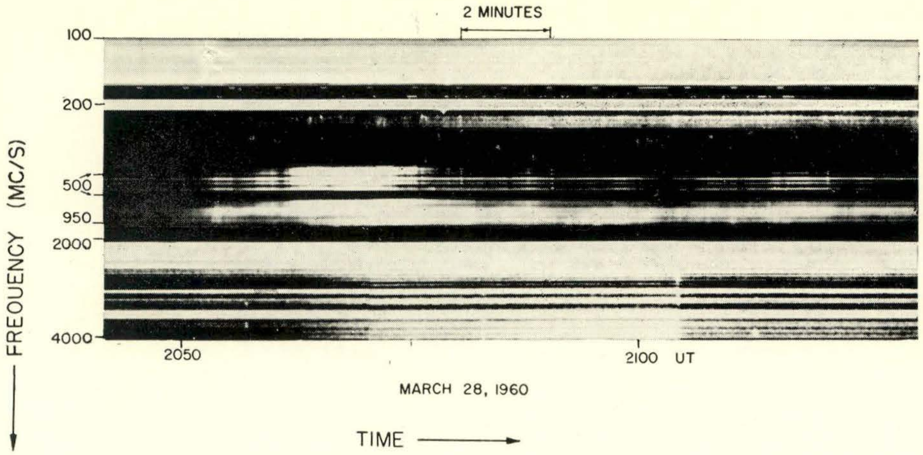

Fig. 1. Dynamic spectrum records of a type IV-type II burst in the 100-580 Mc/s, 500-950 Mc/s and 2000-4000 Mc/s ranges. The type II burst starts at 2056.5 U.T. and ends at 2112 U.T.(data from Fort Davis), and the type IV burst, as observed on the spectrum records, starts at 2050 U.T.

which usually occurs around a centimeter-wave maximum. The type IV emission on frequencies higher than about 250 Mc/s follows closely the centimeter-wave emission and so precedes the type II burst; whereas the type IV emission at frequencies lower than about 250 Mc/s usually follows the type II burst (Fig. 1). Even on frequencies lower than 250 Mc/s, type IV emission sometimes starts earlier than type II burst. The starting times relative to type II burst of type IV emission on frequencies higher and lower than 250 Mc/s are shown in Fig. 2.

2. The centimeter-wave bursts associated with type IV without type II bursts are usually weaker in intensity than those associated with type IV-type II bursts. Also, the flares associated with type IV without type II bursts are usually of less importance than those associated with type IV-type II bursts. These statistical relationships are shown in Table I. A type IV-type II burst does not always extend to frequencies lower than about 250 Mc/s. This low-frequency cut-off of type IV emission appears to be statistically related to the intensity (peak flux) of the centimeter-wave outburst. When the centimeter-wave peak flux exceeds 1000 units (1 unit$=10^{-22}\mathrm{wm}^{-2}(\mathrm{c/s})^{-1}$), then type IV emission is always extended below 250 Mc/s. The radial distributions on the solar disc of type IV emissions (with and without type II bursts) in the two cases (when they are restricted above 250 Mc/s and when they are extended below 250 Mc/s) are shown in Fig. 3.

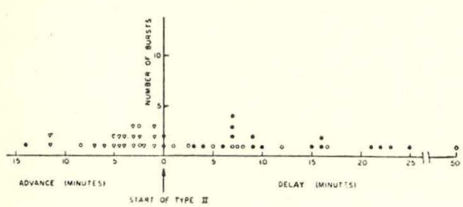

Fig. 2. Distribution of the starting times of type IV bursts in the two frequency ranges (above and below 250 Mc/s) relative to associated type II bursts.

▽ 250-580 Mc/s (Michigan & Fort Davis).

○ Below 250 Mc/s (Michigan & Fort Davis).

● Below 210 Mc/s (Sydney).

Table I. Type IV (with and without Type II) Bursts.

	Number of type IV bursts		Total
	With type II	Without type II	
Centimeter-wave burst intensity*			
>1000	19	4	23
<1000	16	25	41
Flare importance			
2^+ and 3	25	8	33
1, 1^+ and 2	10	21	31

* Centimeter-wave burst intensity is expressed in units of $10^{-22}\mathrm{wm}^{-2}(\mathrm{c/s})^{-1}$.

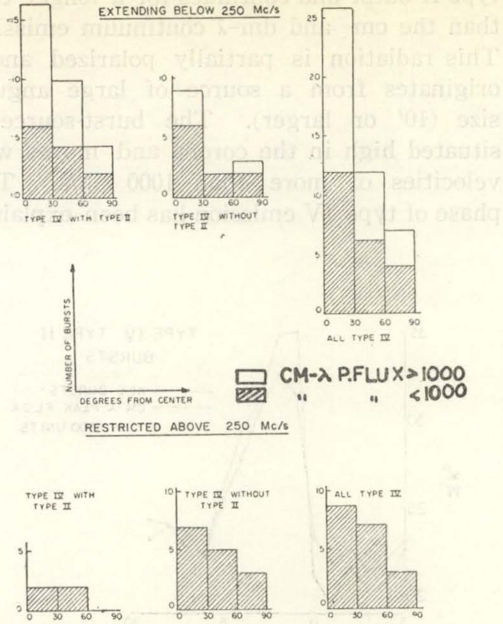

Fig. 3. Radial distributions of type IV (with and without type II) bursts restricted above 250 Mc/s and extending below 250 Mc/s.

3. It is known (1) that the type IV emission on meter waves is polarized and it originates from a source of large angular diameter (10′ or larger); the burst-source is situated high in the corona and moves with velocities of more than 1000 km/s (1, 3, 9). On the other hand, the associated centimeter-wave continuum emission originates from a source of small angular diameter (2′–3′); the burst source is situated low in the corona and it shows no significant movement (10).

Recent interferometric observations (9) made on 340 Mc/s and 87 Mc/s show that type IV emission on 340 Mc/s resembles the centimeter-wave continuum emission insofar as the angular diameter, motion and altitude of emission are concerned, whereas on 87 Mc/s the type IV emission has properties similar to that originally observed by Boischot on 169 Mc/s (Figs. 4 and 5).

4. Type IV-type II bursts which are mostly associated with very intense centimeter-wave outbursts (peak flux >1000 units) show a very significant increase in geomagnetic activity index K_p, within 1–2 days after the type IV bursts. Type IV without type II bursts (usually associated with centimeter-wave bursts of peak flux less than 1000 units) show a very slight increase in K_p, within 2–5 days after the type IV bursts (Fig. 6).

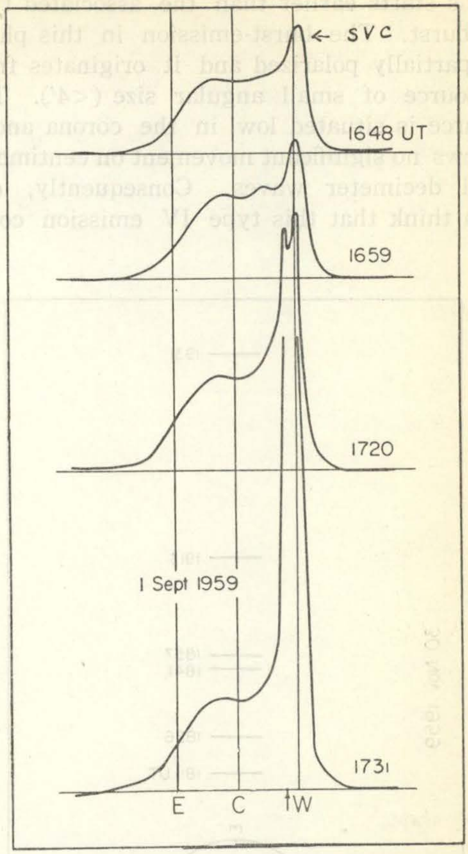

Fig. 4. Example of a type IV burst on 340 Mc/s. These scans were made with an antenna having a fan-shaped beam, and they indicate that the burst source lay along the same position as did the source of slowly varying component. This figure is reproduced from Kundu & Firor (9).

From the observations as described above, it appears that we have to deal with two distinct phases in the evolution of type IV emission in the centimeter down to meter wavelength ranges: (a) In the first phase, the continuum emission starting at centimeter waves extends to frequencies as low as about 250 Mc/s. In some cases, particularly if the cm-λ intensity is very high, the continuum emission extends even to frequencies below 250 Mc/s. This phase occurs independently of any type II burst. A type II burst is likely to be associated with a type IV emission when the associated cm-λ outburst is very intense (peak flux >1000 units) and in that case the continuum emission above 250

Mc/s starts earlier than the associated type II burst. The burst-emission in this phase is partially polarized and it originates from a source of small angular size (<4′). The source is situated low in the corona and it shows no significant movement on centimeter and decimeter waves. Consequently, one can think that this type IV emission could be caused low in the corona by synchrotron radiation of electrons generated during the flare. Some cm-λ and dm-λ continuum emission (such as "gradual rise and fall") associated with weak type IV (without type II) burst on lower frequencies have brightness temperatures of 10^6–10^7°K and are probably of thermal origin.

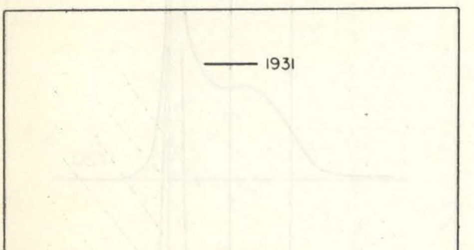

Fig. 5. Successive position lines measured for a type IV burst on 87 Mc/s. The actual source positions could lie anywhere along extension of the short position lines shown. This figure is reproduced from Kundu & Firor (9).

(b) The second phase of type IV emission usually occurs when the associated cm-λ outburst is very intense, and it occurs below about 250 Mc/s. It starts after the associated type II burst and continues for a longer time than the cm- and dm-λ continuum emission. This radiation is partially polarized and it originates from a source of large angular size (10′ or larger). The burst-source is situated high in the corona and moves with velocities of more than 1000 km/s. This phase of type IV emission has been explained (4) as due to synchrotron radiation of electrons higher in the corona, when a cloud of gas (ejected at the start of the flare) with a shock front (which excites the type II burst) moving at high velocities carries a frozen-in magnetic field to the appropriate heights in the corona. The rather high increase of geomagnetic activity within 1–2 days after type IV-type II bursts (first and second phase) as compared to its increase following a type IV without type II burst (only first phase) appears to be consistent with this explanation. The distinguishing characteristics of type IV emission in the two phases are summarized in Table II.

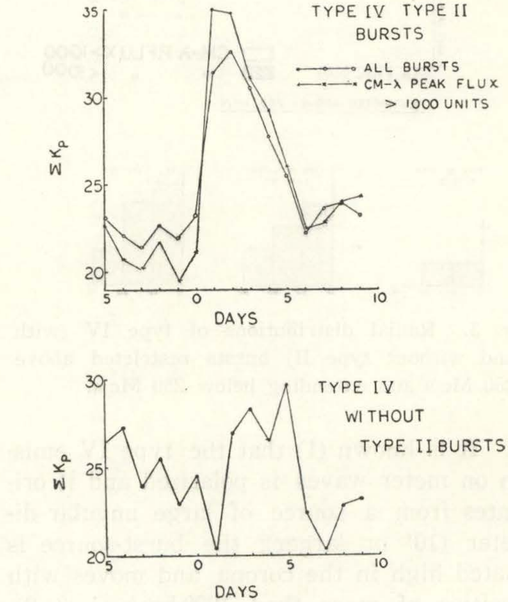

Fig. 6. Average geomagnetic activity index ΣK_p plotted as a function of days preceding and following type IV (with and without type II) bursts.

Table II. Type IV emission in two phases.

	Type IVa	Type IVb
Wave-length extent	Centimeter and decimeter waves; sometimes meter waves	Meter waves
Association with type II	Occurs with or without type II	Occurs with type II
Start relative to type II	A few minutes before type II	A few minutes after type II
Altitude of emission	≥40,000 km above the photosphere	The source does not remain fixed in the corona; maximum altitudes vary from 10^5 to 10^6 km above the photosphere, or higher
Movement of the source	Practically no movement on centimeter and decimeter waves	Large movement with a velocity of more than 1000 km/sec
Diameter of the source	Usually less than 4′ on centimeter and decimeter waves	About 10′ or larger
Polarization	Circularly polarized on centimeter and decimeter waves; weakly polarized on meter waves	Circularly polarized
Duration	Usually 10^m-2^h; sometimes up to 6^h	1^h to several hours; usually longer than in phase "a"
Radial directivity on the disk	Directive toward the center	Highly directive toward the center
Place of origin	Near the flare; at about the same place as the source of slowly varying component on centimeter and decimeter waves	Near the flare
Temperature	10^6-10^9°K	10^7-10^{10}°K
Suggested origin	Synchrotron; some probably thermal on centimeter and decimeter waves	Synchrotron
Effect on geomagnetic activity index ΣK_p	When phase "a" occurs alone, ΣK_p increases slightly after 2-5 days	When both phases "a" and "b" occur ΣK_p increases greatly after 1-2 days

References

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Discussion

Bachelet, F.: What are the statistics in the curve of the geomagnetic effect of type IV with type II and type IV without type II? And in which year?

Kundu, M. R.: For type IV with type II bursts, we had about 40 bursts, and for type IV without type II bursts, we had about 20 bursts. Between 1957 and 1960.

Boischot, A.: When you observe large motions outward the limb, is the diameter of the source increasing with time? Is the region of emission an isolated cloud moving in the corona or an extending region always with some emission low in the corona?

Kundu : I don't know the diameter is always increasing with time; it is hard to say anything about the short time variation of diameter with a 12′ fan beam on 87 Mc/s, but after some time (say 1-2 hours), the diameter seems to decrease and so also outward movement. We had interferometric measurements on 340 Mc/s and 87 Mc/s and in only a few cases we had simultaneous measurements. We have no definite knowledge about the extension of the type IV source from interferometric measurements.