AN ASSOCIATION BETWEEN SOLAR RADIO BURSTS AT METRE AND CENTIMETRE WAVELENGTHS

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Summary

From a study of simultaneous metre and centimetre solar radio bursts, it appears that the type III events which coincide with centimetre bursts are frequently followed by a particular form of broad-band emission. This last burst, termed type V, is observed mainly below 150 Mc/s on radio spectrum records where it resembles a bright glow lasting for about 1 min. Synchrotron radiation has been suggested as the mechanism for type V bursts.

The accompanied centimetre burst lasts a length of time comparable with that of the metre bursts, is indistinguishable in intensity from unaccompanied centimetre bursts, and, on present evidence, may be due to either thermal or synchrotron radiation.

A stream of highly energetic particles ejected from a flare region on the Sun is suggested as the cause of both events, exciting centimetre bursts in or near the chromosphere and type V bursts at large heights in the corona.

I. Introduction

It is well known that certain disturbances on the Sun generate radio emission over a very large range of frequencies, from wavelengths of a few millimetres up to tens of metres. The major radio outbursts are associated with large flares, and are to be observed on both short and long wavelengths, lasting for tens of minutes or more. Besides these, many smaller radio disturbances are known to occur in both wavelength bands.

The great majority of the smaller sporadic disturbances at metre wavelengths are known to belong to a definite spectral class, namely, type III (Wild, Roberts, and Murray 1954). The single type III burst is a brief disturbance lasting some 5 or 10 sec and drifting with time from high to low frequencies at the rate of some 20 Mc/s per sec. In general, groups of type III bursts are much more frequent than centimetre bursts.

The purpose of the present investigation is to find out if there is any connexion between type III bursts at metre wavelengths and the "lesser" disturbances at centimetre wavelengths; and if so, to search for features in the type III burst which distinguish those which are from those which are not accompanied by centimetre bursts.

In the present analysis, which covers the period July 1957 to March 1958, records from the Radiophysics Laboratory spectrograph at Dapto (40–240 Mc/s) were studied in conjunction with single-frequency data (1000, 2000, 3750, and 9400 Mc/s) from the Research Institute of Atmospherics, Nagoya. The

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sensitivity of the Dapto equipment is such that bursts of flux density less than about 50×10^{-22} W m^{-2} (c/s)$^{-1}$ in one plane of polarization are not recorded. The equipment used at Nagoya has been described by Tanaka and Kakinuma (1956, 1958). For 1000, 2000, and 3750 Mc/s the threshold of detectability is 10×10^{-22} W m^{-2} (c/s)$^{-1}$ and for 9400 Mc/s it is 20×10^{-22} W m^{-2} (c/s)$^{-1}$.

II. Observations and Analysis

A perusal of the records showed metre bursts to be far more frequent than centimetre bursts, so that the majority of metre bursts occur unaccompanied by short wavelength emission. Of some 2000 type III events less than 10 per cent. occurred while a centimetre burst was in progress. On the other hand, there are a number of centimetre bursts of comparable intensity which are unaccompanied by metre bursts.

(a) *Recognition of a New Feature—the Type V Burst*

On examining the spectrum records of those type III's accompanied by centimetre disturbances, it was noted that a particular feature tended to repeat itself. The burst normally began with a type III burst which was followed immediately or almost immediately by a second disturbance. The latter was a broad band enhancement of radio emission extending over a frequency range of 100 Mc/s or so and lasting for up to about 1 min. Three examples of this " continuum " radiation, which has been designated a type V burst (Wild, Sheridan, and Trent 1959), are given in Plate 1. In some cases the type V merges with the type III, whereas in others the two are detached, but in no case is there clear evidence of frequency drift in the type V event. On the high frequency side, the burst often shows a steep downward gradient in the energy spectrum, which occurs on the average at about 100 Mc/s.

(b) *Association of Type V with Centimetre Bursts*

To test the correlation of type III plus type V events with high frequency bursts, two groups of events were chosen.

Group A consisted of 27 clear and distinct cases of type III events followed by type V, which occurred during the period July 1957 to March 1958. The examples in Plate 1 are from this group. Of the group A events, 20 out of 27 occurred nearly simultaneously with bursts at centimetre wavelengths. Except in two cases where the centimetre disturbance lasted much longer than the metre burst, the durations of corresponding centimetre and metre bursts were similar.

Group B consisted of 26 spectrograph events selected at random from the same 9-month period, July 1957 to March 1958. The basis of selection was that the events be sharply defined type III bursts which were not accompanied or followed by continuum at metre wavelengths (see Plate 2). These events were used as a control group. Of the 26 events, it was found that only one burst occurred at the time of a centimetre burst.

While the number of events in groups A and B is not large, it seems sufficient to suggest strongly that the probability of a type III burst being accompanied by a centimetre burst is considerably increased by the type III being followed by a type V continuum.

(c) *Association of Type V Bursts with Flares*

Covington and Harvey (1958) have reported that " there is a strong probability, almost a certainty, that every 10 cm burst is associated with some flare ". Since type V bursts show a good correlation with centimetre bursts, one might expect them to be frequently associated with flares.

Such is the case. A list of 15 distinct type V events was compiled which occurred at times when flare data were available. Of these 14 occurred during flares, and in half the cases the radio burst began within a minute of the quoted maximum of the flare. These maxima all appeared to be of the sudden explosive type, described by Giovanelli (1958) as " puffs ".

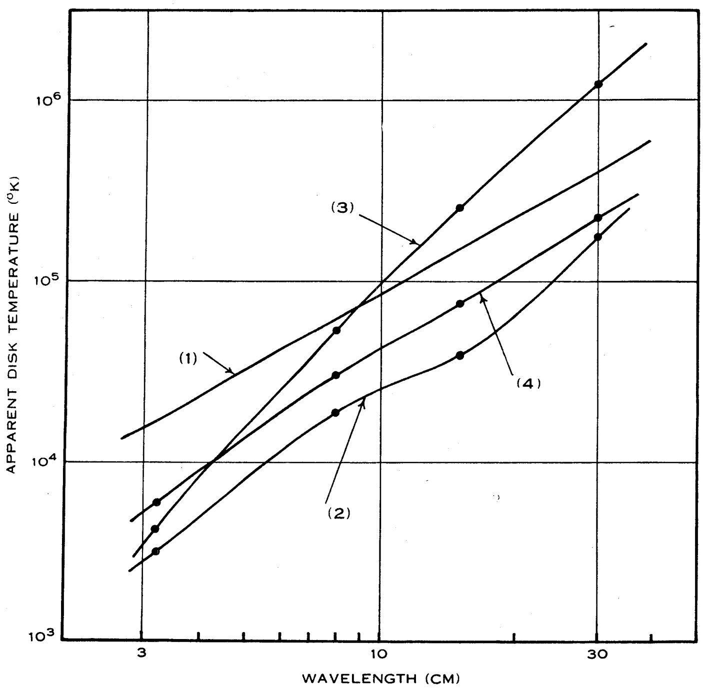


Fig. 1.—Intensities of various forms of solar radio emission in terms of apparent disk temperatures is given as a function of wavelength: (1) mean quiet Sun at sunspot maximum; (2) mean intensity of 20 centimetre bursts which accompanied type III–type V events; (3) maximum values of the accompanied centimetre bursts; (4) mean intensity of 25 centimetre bursts unaccompanied by metre-wavelength activity.

The association of puffs, high frequency events, and type III–type V events is neatly exemplified (Plate 3) by a flare, 0157–0226 Universal Time, December 9, 1957, which showed two sudden eruptions, or puffs, with an interval of about 15 min between peak intensities. During the 29 min while the flare was observed, radio emission recorded by the spectrograph was confined almost entirely to two short but outstanding bursts which coincide with the puffs at 0201 and 0216 hr.

During the same period only two events were reported on 2000 Mc/s, each lasting for 1 min and commencing at 0201 and 0216 hr respectively. Bursts at 3750 and 9400 Mc/s were also reported to begin at 0216 hr, lasting 2 and 1 min respectively.

(*d*) *Intensity of Centimetre Bursts*

Having found a feature which tends to distinguish between those type III's which are and are not accompanied by centimetre bursts, one now asks whether the centimetre bursts which accompany type III are distinguishable from other centimetre bursts. In particular, are the type V-accompanied centimetre bursts more intense as a group than unaccompanied centimetre bursts ?

Means of the peak intensities for these two classes of events are presented in Figure 1 in terms of apparent disk temperatures. Centimetre bursts which were associated with Group A events composed the " accompanied " group. Maximum values at the various frequencies for these events are also plotted, illustrating the considerable spread of the observations. The mean " unaccompanied " curve was derived from the intensities of 25 representative centimetre bursts chosen solely on the basis of their occurring at times when there was no activity at metre wavelengths. Mean values for the quiet Sun at sunspot maximum, based on international solar radio emission data as published in the I.A.U. Quarterly Bulletin on Solar Activity, kindly supplied by Mr. S. F. Smerd, are included for comparison.

It is evident from Figure 1 that the accompanied and unaccompanied bursts are of comparable intensity.

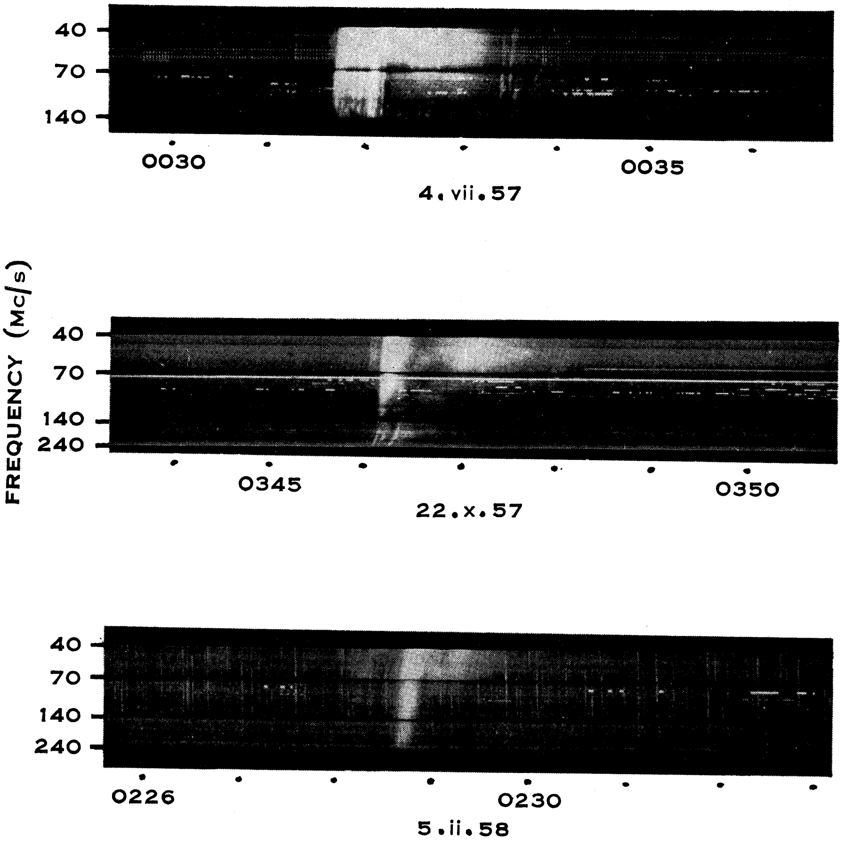
III. Discussion

The close association between type V bursts and centimetre bursts poses the question of what is the physical relation between the two phenomena.

Firstly, do both bursts come from the same region ? Interferometer data on source positions, supported by theoretical considerations of the levels of zero refractive index in the solar atmosphere, place the source of the type V emission in the upper corona. The accompanying centimetre burst is believed to come from a much lower level. For example, Christiansen (personal communication) states that, using his highly directive equipment at 20 cm, he has never observed a burst on the limb as high as 100,000 km. This implies that the centimetre burst is not merely a high frequency component of the type V radiation but is a distinct burst originating lower in the solar atmosphere. This inferred spatial separation of the sources of type V and centimetre bursts into coronal and probably chromospheric regions leaves unexplained the simultaneity of the two events.

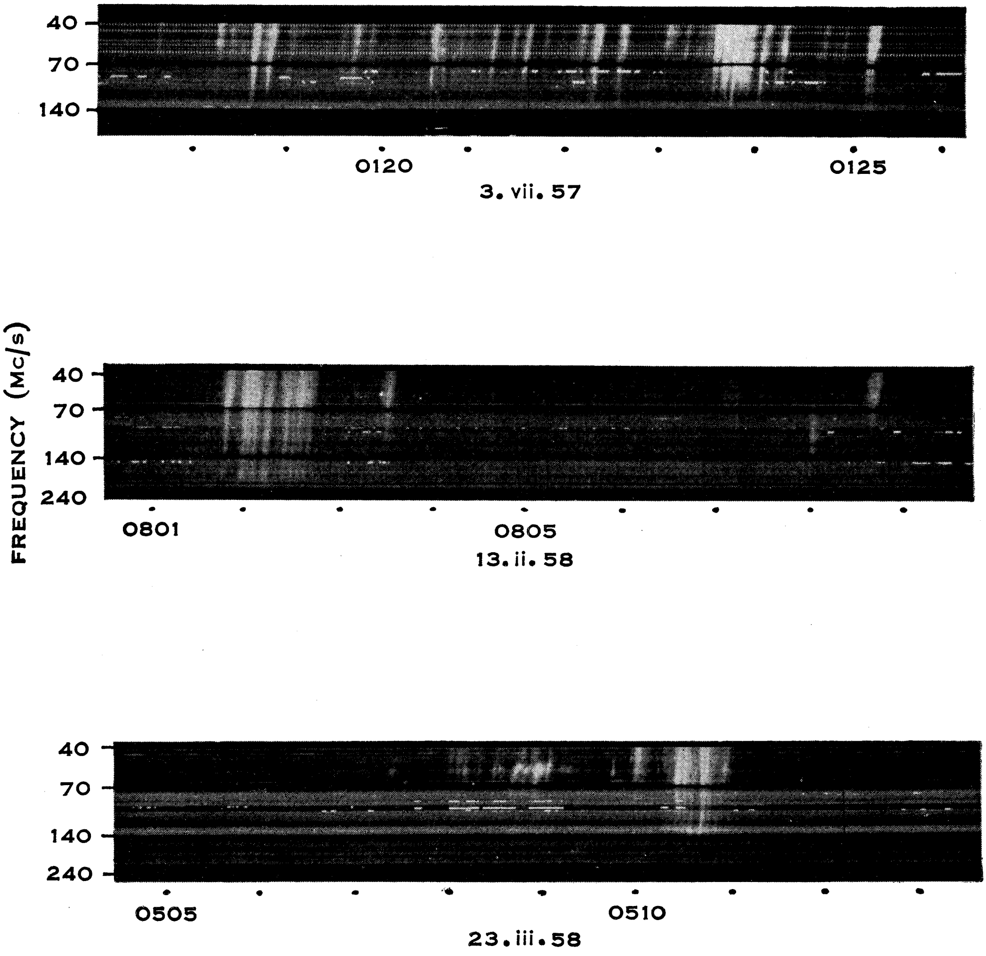
For the type V bursts, synchrotron radiation has been suggested (Wild, Sheridan, and Neylan 1959), and this involves the transport of a large number of highly energetic particles into the upper corona. It is now suggested that the particle stream acts as the physical link between the two bursts and that the centimetre burst occurs as a direct result of the passage of this electron stream through the chromosphere and lower levels of the corona. The radiation generated could be either thermal or synchrotron ; present evidence does not differentiate between these two mechanisms.

SOLAR RADIO BURSTS AT METRE AND CENTIMETRE WAVELENGTHS



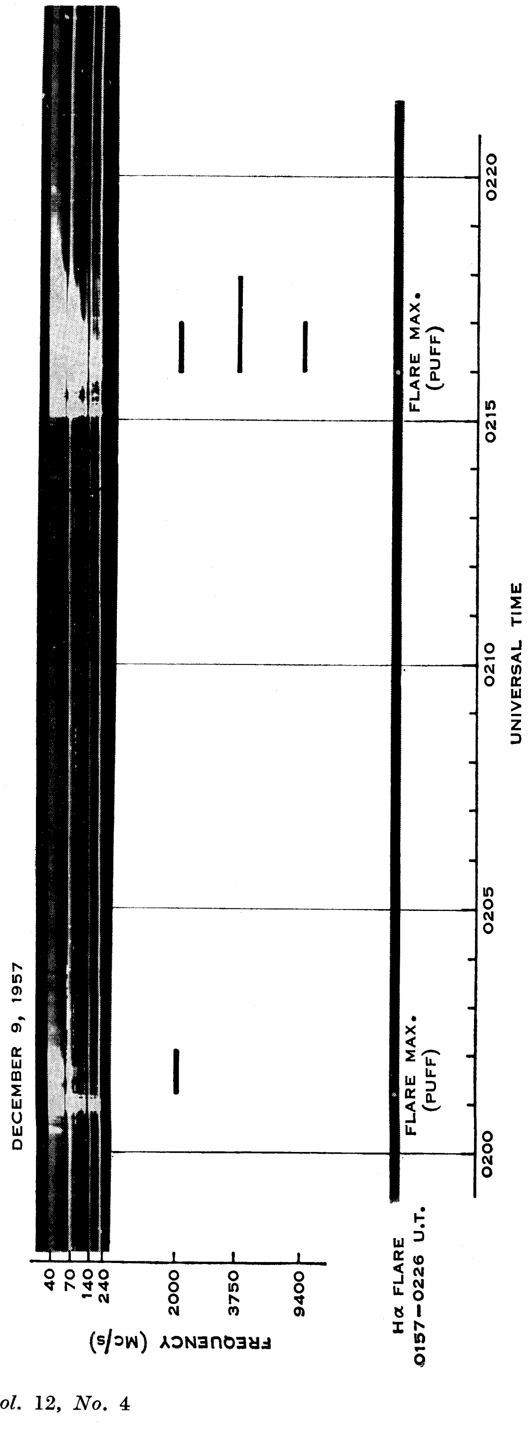
Three examples of type III bursts followed by the broad-band type V burst. These events tend to occur simultaneously with centimetre bursts.

SOLAR RADIO BURSTS AT METRE AND CENTIMETRE WAVELENGTHS



Three examples of " sharp " type III bursts of the kind which were found to be generally unaccompanied by centimetre bursts.

SOLAR RADIO BURSTS AT METRE AND CENTIMETRE WAVELENGTHS



Radio and optical data showing the association of type V bursts, centimetre bursts, and flare-puffs. At top, the Dapto radio spectrum record is reproduced. Heavy horizontal lines represent the duration of the centimetre bursts and of the flare.

On the one hand, the intensities of the accompanied bursts shown in Figure 1 seem to be low enough to permit the possibility of thermal radiation. Assuming a source size area of the order of one-tenth of the solar disk the corresponding mean brightness temperatures range from tens of thousands of degrees at 3 cm to some millions at 30 cm wavelength. It is feasible to think of a dense particle stream causing this emission by collisional heating. Observations of the angular size of the source are needed to develop this argument.

On the other hand, a consistent explanation of the centimetre burst can be given in terms of synchrotron radiation generated by the same stream of electrons in its passage through the chromosphere and lower corona. The strong tendency for a centimetre burst to accompany a type III burst only when the latter is accompanied by a type V burst is then readily explained by supposing that the stream must possess a minimum number of relativistic electrons in order to generate synchrotron radiation either in the chromosphere or corona. Furthermore, the common occurrence of centimetre bursts in the absence of type III bursts could be explained by the same (synchrotron) mechanism if it is supposed that in these cases the stream is prevented from reaching the upper corona, e.g. by a re-entrant magnetic field configuration.

IV. Acknowledgments

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