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Discussion

Waddington, C. J.: What is duration of act of generation?
Lebedinsky, A. I.: About 2-3 hours.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-II, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3A-2. Type IV (Continuum) Radio Bursts from the Sun

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The characteristics of type IV bursts are described from sweep frequency observations in the ranges 25-580 Mc/s and 2100-3900 Mc/s. The bursts typically commence a few minutes after the start of a flare of high importance, cover a wide frequency range, and may last for several hours. The association of the bursts with type II (slow-drift) bursts and type III (fast-drift) bursts is also discussed. Approximately 40 per cent of type IV bursts are followed by polar cap absorption and 75 per cent by magnetic storms.

This paper gives a brief description of type IV solar bursts, as observed at the Harvard Station, Fort Davis, on sweep frequency equipment covering the ranges 25—580 Mc/s and 2100—3900 Mc/s[1]. The bursts are believed to be produced by synchrotron radiation from electrons accelerated or released during the early stage of a solar flare, and are associated with the emission of solar cosmic rays.

On the sweep frequency records type IV bursts are characterized as a broad band continuum, as shown in the example in Fig. 1. The intensity of the radiation does not vary sharply in frequency or time, in contrast to the records of type II (slow-drift) and type III (fast-drift) bursts. During the period October 1956 through December 1960, an average of 20 type IV bursts per year was recorded with a daily observing period of approximately 11 hours. The durations of the bursts varied from a few minutes to several hours, the mean duration being 90 minutes. In some of the longer lived bursts the radiation died away and reappeared intermittently with a periodicity of the order of half an hour. In almost all cases type IV bursts recorded in the meter wavelength range were accompanied by bursts at centimeter wavelengths. Comparison with single frequency observations from the Naval Research Laboratory[2] shows that in some bursts the radiation extended from less than 25 Mc/s to over 70,000 Mc/s.

Type IV bursts are characteristically associated with flares of high importance; of the bursts recorded at Fort Davis, 24 were associated with flares of importance 3+ or 3, 18 with flares of importance 2+ or 2, and 17 with flares of importance 1+ or 1. In

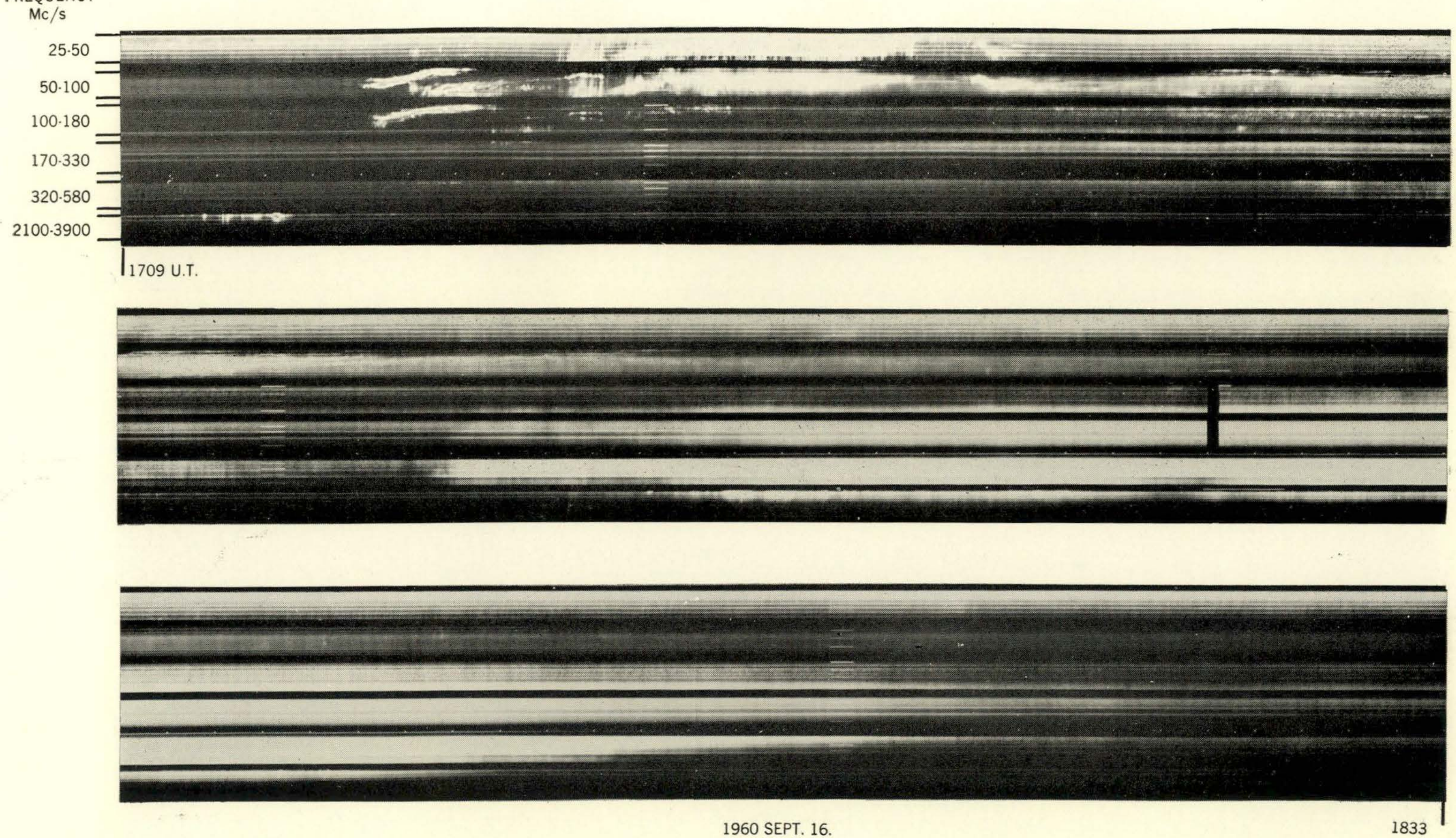

Fig. 1. A record of a type IV burst accompanied by type II and type III bursts. A flare of importance 1 started at 1710 U.T.

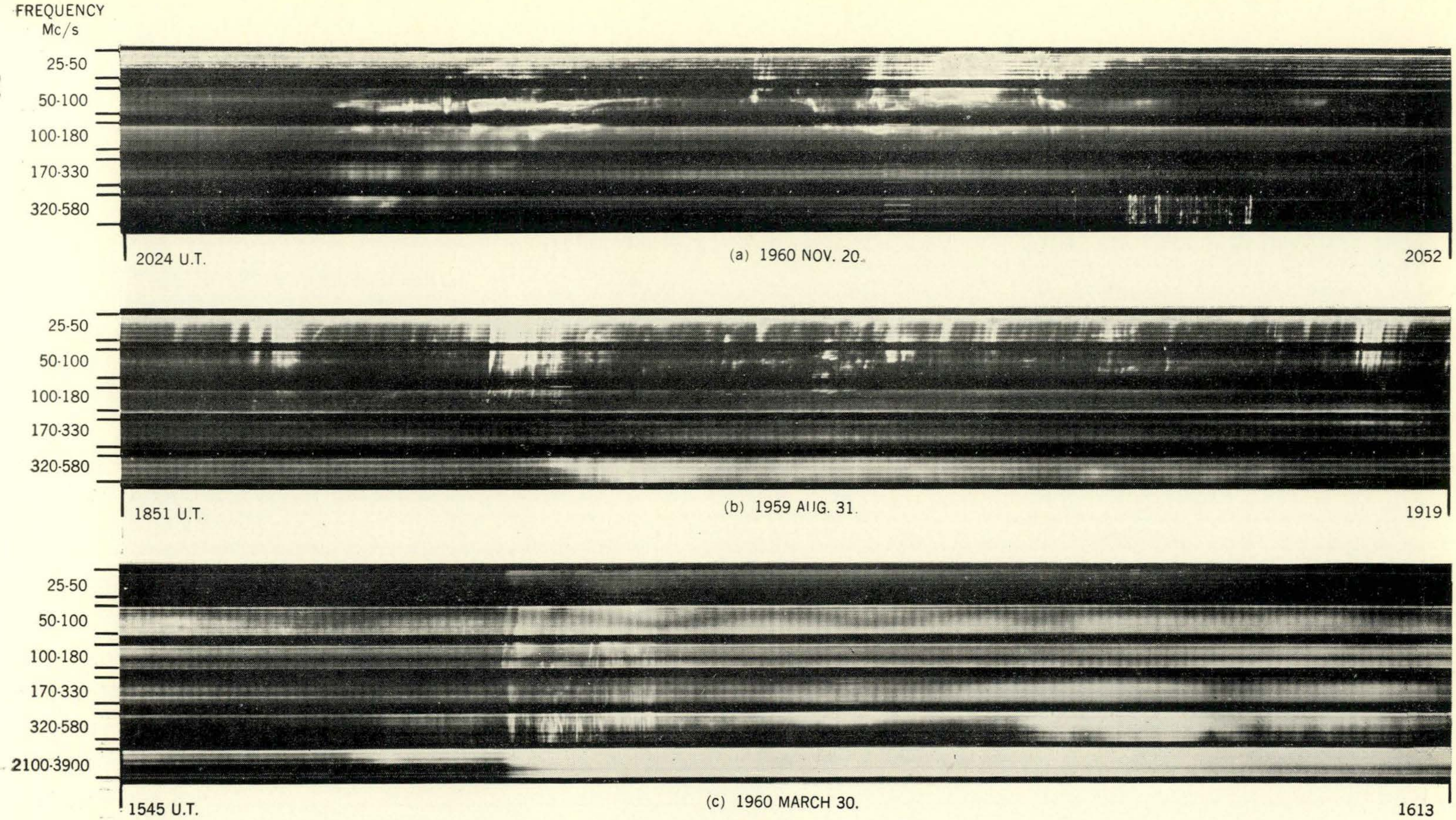

Fig. 2. (a) Type II and type IV bursts associated with a flare at the west limb of the sun, and a small increase in cosmic ray intensity at ground level. The radiation in the band 320-580 Mc/s from 2044 to 2048 is not solar.

(b) A small type IV burst, accompanied by type III bursts.

(c) A sudden increase in the intensity of type IV radiation in the frequency range 2100–3900 Mc/s, coincident with a group of type III bursts. The type IV burst started at 1526 U.T. and covers the whole frequency range of the equipment.

most of the remaining cases the flare data were incomplete or ambiguous. The mean delay time between the start of the flares and the start of the bursts in the 25—580 Mc/s range was 12 minutes. Thus the acceleration of the electrons occurs soon after the start of the flare. In many of the longer lived bursts the persistence of radio emission for several hours after the end of the visible flare, indicates that the radiating electrons remain trapped in a solar magnetic field, or that the supply of electrons continues after the end of the flare.

The positions of flares associated with type IV bursts recorded in the range 25—580 Mc/s show a definite concentration in longitude towards the central meridian of the sun. This effect indicates that at meter wavelengths the radio emission is concentrated in a radial beam, possibly by refractive effects in the corona. In all cases where type IV bursts have been associated with a flare at the limb of the sun, the radiation in the range 25—580 Mc/s was relatively weak and short lived, as in the example in Fig. 2(a). By contrast type IV bursts identified from centimeter wavelength observations comprise a slightly different sample, and the associated flares are essentially uniformly distributed in longitude.

Observations of polarization and position of type IV bursts have recently led to the development of a model of the bursts consisting of separate components at meter, decimeter, and centimeter wavelengths[3),4),5)]. In most cases the existence of separate components is not clearly apparent on the sweep frequency records, which show only the intensity of the radiation as a function of frequency and time. The original observations of type IV bursts by Boischot[6)] at 169 Mc/s indicated an outward motion of the source of the radiation with a velocity of the order of 1000 km/sec. This motion of the source may be attributed to an ejection of coronal plasma, carrying with it a magnetic field and trapped, radiating electrons. On the sweep frequency records an outward moving disturbance is manifested by the occurrence of a type II burst, which accompanies the onset of approximately 70 per cent of type IV bursts. At the higher frequencies in the 25—580 Mc/s range the onset of the type IV radiation often precedes the type II burst, whereas at frequencies of about 100 Mc/s and lower the type IV radiation usually appears only after the type II burst. The low frequency type IV radiation is not generated, or cannot escape from the corona, until an outward motion of the coronal material extends the source to higher levels in the corona.

In 80 per cent of cases the onset of a type IV burst is accompanied by one or more groups of type III bursts. There are also several examples on the sweep frequency records in which sudden enhancements in the type IV intensity are closely coincident with groups of type III bursts. An example is shown in Fig. 2 (c) in which an intensity increase in the 2100—3900 Mc/s band occurred 27 minutes after the start of the type IV burst. A possible relation between the two types of bursts is that both are generated by fast electrons. The disturbances which give rise to type III bursts have velocities of $0.3\,c$ and greater, and may be either streams of electrons or fast, transverse shock waves. The electrons which give rise to type IV radiation are principally those of a similar velocity range, 0.25—$0.9\,c$ (0.02—0.7 MeV), according to Takakura[7)].

In many type IV bursts the radiation shows a structure in which numerous individual bursts appear, with wide bandwidths and durations of a few seconds or less. These small bursts show a close resemblance to type III bursts, but their actual nature is uncertain. They occur in both the 2100—3900 Mc/s and 25—580 Mc/s ranges, mainly above 100 Mc/s, and have also been observed over 500—1000 Mc/s[8)].

The association of the bursts with corpuscular emissions from the sun is well known; in almost all cases the emission of solar cosmic rays, both of high energy detectable at ground level and of low energy detectable by polar cap absorption, is accompanied by a type IV burst[9),10),11)]. One example of a type IV burst associated with a major ground-level increase in cosmic ray intensity (1960 Nov. 12) has been recorded on the sweep frequency equipment; other major cosmic ray increases occurred outside the observing hours. At least four other type IV bursts were associated with small ground level increases. Approximately 40 per cent of type IV bursts which occur during the months May through September are followed by polar cap absorption in the northern hemisphere, and approximately 75 per cent of all type IV bursts are followed by magnetic storms. Examination of the sweep frequency records has, as yet, revealed no features to distinguish those bursts associated with the emission of cosmic rays of either high energy or low energy.

The author wishes to thank Dr. A. Maxwell for advice and criticism, and Mr. M.P. Hughes and Mr. D.R. Parenti who also participated in the observing program. This work is supported by the United States Air Force through the Geophysics Research Directorate and the Sacramento Peak Observatory.

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Discussion

Ney, E. P.: 1) Can you give an estimate of total energy emitted in a large event in the form of synchrotron radiation?

2) Could the shorter duration of the high frequency type III reflect the more rapid loss of energy by synchrotron radiation of high energy electrons than low energy electron?

Thompson, A. R.: 1) I can calculate it and give it to you later, but it certainly varies from event to event by a factor of at least 10 or 100.

2) Very possibly by synchrotron radiation or by collisions.

Ney: This would not be dependent on position in the corona, then.

Thompson: It would, if collisions were important.

Winckler, J.R.: The symmetrical distribution of type IV over the solar disc together with the very asymmetrical distribution of high energy cosmic ray flares towards the west limb shows the latter to be certainly a propagation effect in interplanetary space. A careful re-examination of neutron monitor data may reveal additional events of slow rise character originating in the eastern part of the solar disc.

Kundu, M. R.: I think one can predict the polar cap absorption events better by combining the meter-wave type IV bursts with intense broadband centimeter-wave bursts. This way one can predict the P.C.A events with a probability of about 80%.

Thompson: From the sweep frequency records we have not found any characteristics to distinguish the bursts accompanied by the emission of high or low energy cosmic rays from other bursts. However the probability that a type IV burst will be accompanied by cosmic ray emission is increased if the associated flare is of high importance and situated on the western hemisphere of the sun.

Takakura, T.: It will be mentioned later by Morimoto and also by Tanaka, but now I would like to make a comment. The position of radio sources at 200 Mc is not so high, say 0.3 $R_{\odot}$, and scarcely moves, so that there seems to be two components, one is above and one is below about 200 Mc. In some cases, we can see a clear frequency gap or an intensity minimum on dynamic spectra between about 200 Mc and 150 Mc or so.

Thompson: Yes, I think that there are presumably two components on which Kundu is going to talk in more detail. I might say that the evidence of existence of different components does not show up particularly well on the sweep frequency records and it will be shown up better by measurements on position and polarization. That is the reason why I did not go into more detail.

Uchida, Y.: Do you think that the acceleration of particles occurs some time after the beginning of flares? Because the intensity of type IV bursts becomes stronger and stronger on the dynamic spectrum, in the first phase.

Thompson: Yes, I would say that the emission of electrons comes mainly between the start and maximum of flare.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-II, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3A-3. Structure of the Type IV Radio Burst and Its Relation with Solar Cosmic Rays

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The type IV burst is actually made of at least two distinct parts. The first one is seen on centimetric, decimetric and sometimes metric wavelengths, and may be explained by a synchrotron mechanism.

The first part is followed by the second one, more intense on metric wavelengths, and which lasts generally a few hours. In some cases, the emission is received one day or more, and these long durative events have been named continuum storm. The source of the emission lies low in the corona and its diameter is relatively small. The radiation is strongly circularly polarized in the ordinary mode, like the noise storms.

A plasma Cerenkov mechanism is proposed to explain this second part. High energy electrons would diffuse in coronal streamer, exciting longitudinal plasma waves, which can transfer a part of their energy upon transverse electromagnetic waves in some regions close to the critical height.

It has been shown during the last few years that there exists a strong relation between solar radio emissions and cosmic ray increases. This is due to the fact that the radio emission, certainly non-thermal on metric wavelength, comes from high energy particles. These particles are mostly electrons, instead of the protons observed with cosmic ray detectors when the sun is active. But it is easy to believe that a mechanism of acceleration of particles in the solar atmosphere, such as Fermi's mechanism, would give acceleration of both positive and negative particles. The observation of radio solar emission is much more easy than that of cosmic rays, where we need balloons, satellites or some indirect methods such as polar cap absorption studies. The study of radio emission is then very important, not only for the knowledge of the solar physics, but also for the study of cosmic rays.

Among the different types of solar radio bursts, type IV is certainly the most important from this point of view. The synchrotron theory of its emission requires the presence of high energy electrons of a few million electron volts, the origion of which is certainly related to that of the protons observed in the neighbourhood of the earth.

But those protons are often observed two or three days after the flare; it is very improbable that the acceleration processes can last so long; it is more likely that we have to do with some storage around the sun, the particles diffusing slowly during a few days. It is then important to see if the radio emis-