II-3B. Particles

Chairman: L. BIERMANN
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Date	Time	Paper Numbers
Sept. 5	15 : 30 – 17 : 30	from II-3B-1 to II-3B-6
Sept. 6	11 : 30 – 13 : 30	from II-3B-7 to II-3B-11
Sept. 6	15 : 30 – 17 : 30	from II-3B-12 to II-3B-17
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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-3B-1. Some Relations between Centimeter-Wave Radio Bursts and Solar Cosmic Rays and X-Rays

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The dynamic spectrum observations of Michigan have shown that cm-λ outbursts exhibit a broadband continuum radiation. The cm-λ outbursts associated with ground level cosmic ray increases have usually a long duration and a strong intensity (peak flux $>2000\times10^{-22}$ wm^{-2}[c/s]$^{-1}$) over a wide range of wavelengths between 3 and 30 cm.

The polar cap absorption (PCA) events are all associated with broadband cm-λ outbursts having a duration greater than 10 minutes. The delay of PCA events with respect to cm-λ outbursts is statistically dependent both on the intensity of cm-λ outbursts as well as the position on the disc of the associated flares. Intense broadband cm-λ outbursts having a duration longer than 10 minutes and a peak intensity greater than 500×10^{-22} wm^{-2} (c/s)$^{-1}$ over the entire range of wavelengths 3 to 30 cm are followed by PCA events in 80% cases.

The cm-λ bursts are very closely associated with the production of flare X-rays as observed by rocket and balloons. The association of meter-wave type III bursts with flare X-rays is very weak.

It has been shown by several authors that there is a close association between type IV bursts on meter waves and solar cosmic rays causing ground-level cosmic ray increases and polar cap absorption (PCA) events. It is the purpose of this paper to discuss the characteristics of cm$^-\lambda$ outbursts associated with cosmic-ray increases and also to show that intense broadband centimeter-wave bursts provide a better indication of the production of PCA particles than meter-wave type IV bursts. Also, it will be shown that cm$^-\lambda$ bursts are closely associated with the production of flare X-rays.

A. Centimeter-wave outbursts associated with ground level cosmic ray increases.

Dynamic spectral observations of Michigan in the 2000—4000 Mc/s range have shown that centimeter-wave outbursts are broadband continuum radiation[1]. It is known[4] that meter-wave type IV bursts are always associated with centimeter-wave outbursts preceding them, but not all centimeter-wave outbursts are associated with type IV bursts on meterwaves. Fig. 1 shows the dynamic spectra in the 100—600 Mc/s and 2000—4000 Mc/s ranges of two radio outbursts associated with solar protons. Also shown in the figure are a Hα picture of the sun and a 8000 Mc/s scan (with a pencil beam of 6') of

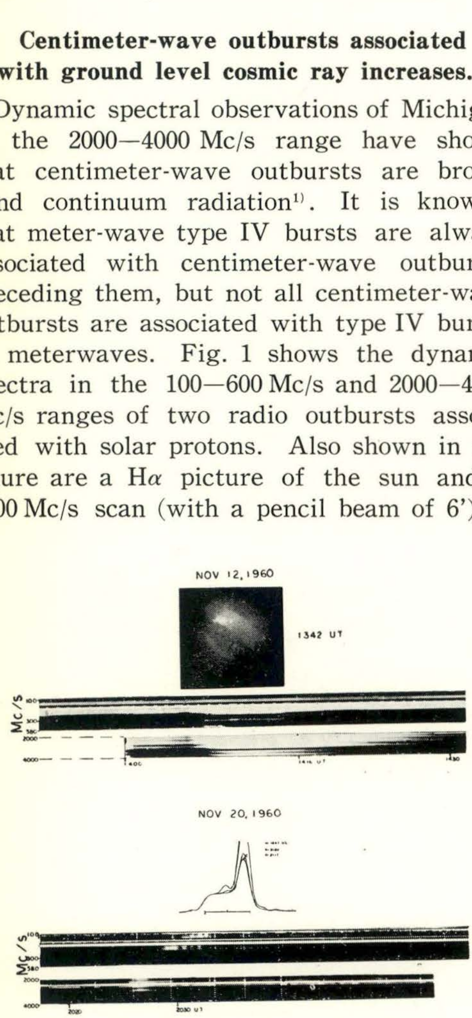

Fig. 1. Dynamic spectrum records in the 100-600 Mc/s and 2000-4000 Mc/s ranges of two radio outbursts associated with Cosmic Ray Increases of Nov. 12 and Nov. 20, 1960. Also shown are an Hα picture of the sun during the flare of Nov. 12 and an 8000 Mc/s scan in R. A. of the sun through the region where the flare occurred on Nov. 20. The 8000 Mc/s scan was done with the 85′ dish of the University of Michigan; the beam width is about 6′ on 8000 Mc/s.

the sun at the time of the flares. The cm$^-\lambda$ outbursts associated with cosmic ray increases have a long duration and are usually very intense ($>2000\times10^{-22}$ Wm^{-2} [c/s]$^{-1}$). The associated meter-wave bursts are of type IV with the exception of the event of May 4, 1960, when no meter-wave event was reported. This may be due to the high directivity of type IV bursts on meter waves.

B. Centimeter-wave outbursts and polar cap absorption.

During the periods August, 1956—July, 1959, March 31—May 13, 1960 and November 12—November 21, 1960, 39 polar cap absorption events were reported. The associated cm$^-\lambda$ outbursts have a duration of 10 minutes to several hours; their peak intensity is greater than 100 units [1 unit$=10^{-22}$ Wm^{-2} (c/s)$^{-1}$] over the whole wavelength range 3—30 cm. We have divided these broadband cm$^-\lambda$ outbursts into two intensity classes: 1) the cm$^-\lambda$ outbursts having peak intensity greater than 500 units over 3—30 cm are considered as intense, and 2) those having peak intensity greater than 100 but less than 500 units are considered as moderate.

The cm$^-\lambda$ and meter-λ outbursts associated with the 39 PCA events are listed in Table 1, together with the delay of PCA w. r. t. cm$^{-\lambda}$ outbursts. It is seen that of 28 meter-λ bursts for which spectral observations were available, 23 are of type IV and 5 non-type IV (3 type II, 1 noise storm and 1 no event). The 11 meter-λ bursts for which no spectral observations were available are believed to be of type IV on the basis of single-frequency observation.

The PCA event usually follows the associated solar radio event with a delay varying from 1 to 50 hours. As shown in Table 1, this delay is statistically smaller (<5 hr) for intense cm-λ outbursts than for moderate cm-λ bursts (>5 hr). Fig. 2 shows the dependence of PCA delay on the position on the solar disc of bursts as determined by the associated flare positions. It appears that for a given intensity class of cm-λ bursts the delay has a tendency to be *statistically* shorter for the bursts occurring on the west side than on the east side of the disc. Consequently, the delay of onset of PCA is probably a function of both the intensity of

Table I. Centimeter-wave Events Associated with Polar Cap Absorption Events Aug., 1956—July, 1959, March 31—May 13, 1960, Nov. 12—21, 1960.

Centimeter-wave intensity class	Number of centimeter-wave outbursts	Number of associate meter-wave outbursts			Delay of polar cap absorption events	
		Type IV	No Type IV	No spectral observations	$<5^h$	$>5^h$
Intense	25	16	4	5	21	4
Moderate	14	7	1	6	4	10

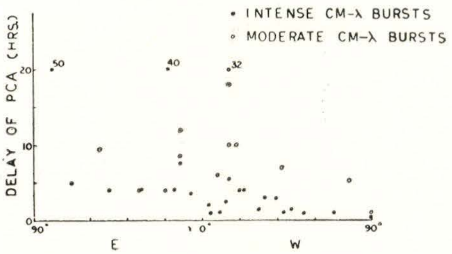

Fig. 2. Distribution on the solar disc of delay of PCA events w. r. t. cm-λ outbursts for the two classes (intense and moderate) of cm-λ outbursts. The points ·50, ·40, etc., correspond to delay of 50 hours, 40 hours, etc.

Table II. Relation between PCA Intensity and Cm-λ Outburst Intensity

cm-λ outburst intensity	Number of cm-λ outbursts	No of PCA events with max. absorption	
		>5 db	<5 db
Intense	25	20	5
Moderate	12	4	8

cm-λ bursts as well as its position on the solar disc.

The absorption in db of the PCA events appears to be *statistically* related to the intensity of the cm-λ outbursts, as shown in Table 2.

In an attempt to determine the characteristics of cm-λ outbursts most likely to be associated with PCA, we have analyzed the cm-λ outbursts during the period May, 1958—July, 1959 during which PCA observations were continuous. From our knowledge of cm-λ outbursts associated with PCA, we have selected only the outbursts having peak intensities greater than 100 units over the entire wavelength range 3—30 cm, and having duration longer than 10 minutes. We have selected 34 such cm-λ outbursts and their association with PCA events is shown in Table 3. Also shown in the same table is the association between type IV meter-wave outbursts and PCA events. It is apparent from the table that intense broadband cm-λ outbursts are more closely associated with PCA events (association 83%) than type IV meter-wave bursts (association 55%). It

Table III. Association of Radio Outbursts with Polar Cap Absorption Events (May 1958-July 1959)

Radio outbursts	Centimetre-wave intensity	No. of radio events	Polar cap absorption events		Percentage of polar cap absorption association
			Yes	No.	
Broad-band centimetre-wave outbursts independent of metre-wave outbursts occurrence	intense and moderate	34	12	22	35
	intense only	12	10	2	83
Type IV metre-wave outbursts independent of centimetre-wave outbursts occurrence		19	10	9	53
Type IV metre-wave outbursts associated with broad-band centimetre-wave outbursts	moderate	7	0	7	0
	intense	12	10	2	83

should be noted that the intensity of type IV bursts on meter wave is not directly related to the intensity of cm-λ outbursts.

The above results show that the fast protons are accelerated by the same process as the fast electrons responsible for the emission of cm-λ outbursts. However, unlike cm-λ outbursts which do not last more than several hours, PCA events can last longer. This long duration of PCA events can probably be explained as due to the storage of fast protons in some regions near the Sun. The presence of magnetic fields over the sources of cm-λ or type IV bursts, as evidenced by their strong polarization, can make this storage possible.

C. Centimeter-wave Bursts and Flare X-rays.

High energy solar X-ray emission during flares has been measured with the help of rockets and balloons by various workers[5)-8)]. The observation of X-ray in the quantum energy range 10—70 Kev during flares accompanied by S I D's led to the suggestion that flare time enhanced *D*-layer ionization (S I D) is caused mainly by hard X-rays. It has been shown statistically by Hachenberg[9)] and Kawabata[10)] that centimeter-wave bursts are closely associated with S I D's. Kawabata and Elwert[12)] have theoretically computed the intensity of X-rays by thermal emission from very hot regions and have shown that the effective temperature of centimeter-wave bursts (10^7—10^8°K) is sufficient to explain the X-rays observed by Friedman during rocket flights. Peterson and Winckler[7)] first proposed a non-thermal mechanism for the production of X-rays and suggested that the hard X-rays originate as Bremsstrahlung due to the braking of high velocity electron jets in the flare or the photosphere. In the development of this concept De Jager[11)] predicted a close association between meter-wave type III bursts (fast frequency-drifting bursts) and flare X-rays. De Jager implied that the passage of "type III" electron streams through the corona would be sufficient to produce the X-rays. This appeared to be confirmed by subsequent observations of Winckler[6)].

In view of the apparent difference of opinion regarding the production of flare X-rays and the associated solar radio bursts, we have carefully examined the solar radio bursts observed in different meter and centimeter-wave frequency ranges, simultaneously with the X-rays directly measured by balloons and rockets.

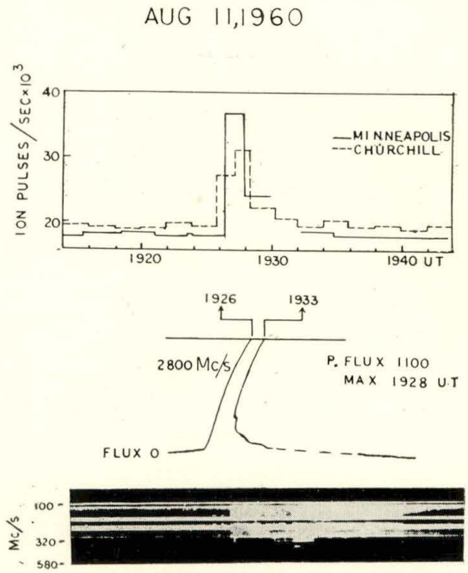

Fig. 3. Record of the X-ray events of Aug. 11, 1960, together with the records of solar radio bursts on 2800 Mc/s (Ottawa) and in the 100-580 Mc/s range (Michigan).

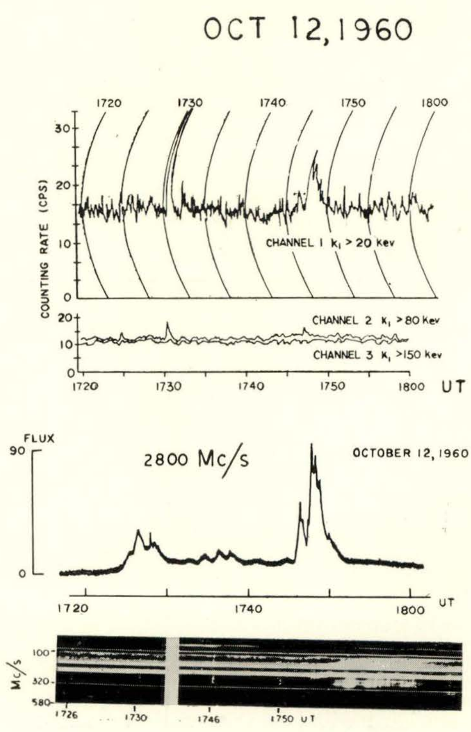

Fig. 4. Same as Fig. 3 for Oct. 12, 1960.

We find that during all seven cases of flare X-rays observed by balloons and rockets, there were simultaneous centimeter-wave bursts. Of these three cases, in only one (August 11, 1960) there was a strong group of type III bursts simultaneously with X-rays; in the other two cases (October 12, 1960) there are a few weak isolated type III bursts at the time of X-rays and it is questionable if the association of these type III bursts with the observed X-rays (whose duration is much longer) is significant. In two of the three cases the type III bursts were followed by type II and type IV bursts during which time X-rays were no longer observed. Of four X-ray maxima observed, in three cases the time of maxima agreed precisely with the peaks of centimeter-wave emission. In the fourth case, the maximum occurred during the 6 minutes duration of the cm-λ burst. Figs. 3 and 4 show three X-ray events simultaneously with the solar radio bursts on 2800 Mc/s (Ottawa) and in the 100—580 Mc/s range (Michigan). It is seen that the second X-ray event of October 12, 1960 agrees even in fine structure detail, involving four peaks, with the centimeter-wave burst and the ratio of X-ray and cm-λ intensities are nearly constant.

The centimeter-wave bursts associated with flare X-rays are characterized by sharp rise time and a short impulsive phase; in one rare case (March 20, 1958) the burst source had a very large size (about 4′ and 8′ on 3 cm and 21 cm respectively) as compared with 2′ and 4′ for average bursts. Also, the spectra of the X-ray associated cm-λ bursts show a rather sharp low frequency cut-off, except when they are associated with type III bursts (Fig. 5). If we assume a burst size of about 2′ on 3 cm, in agreement with interferometric observations[2], we find a brightness temperature of about 10^6—10^7°K for the X-ray associated cm-λ bursts which are not accompanied by any event on meter waves. These temperatures and the spectra of the cm-λ bursts are consistent with thermal radiation from an isothermal plasma whose optical thickness at centimeter wavelengths is greater than unity over the long wavelength and of wavelengths between 3 and 30 cm. The spectra of the two cm-λ bursts associated with meter-wave type III (followed by types II and IV) bursts do not show any sharp low-frequency cut-off (Fig. 5). These cm-λ bursts are usually more intense and have higher temperatures (10^7—10^8 °K) than in the previous cases. Such high temperatures of the centimeter-wave continuum bursts are probably due to an additional component of Synchrotron radiation of electrons generated during the flare.

The above discussion shows that solar flare X-ray bursts are intimately associated with centimeter-wave bursts from the sun, while the relation with type III bursts is much looser. This result provides strong evidence that flare X-rays are generated not in the higher levels of the corona, but rather in the region of origin of emission of centimeter-wave bursts *i.e.*, within about 15,000—30,000 Kms above the photosphere as determined by interferometric and eclipse observations.

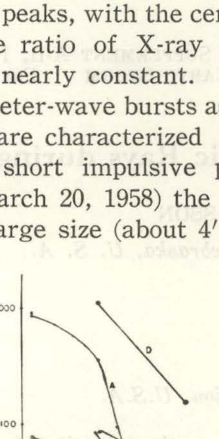

Fig. 5. The spectra of cm- bursts associated with X-ray events. The curves marked A, B, C, D and E correspond to the X-ray events of Mar. 20, 1958; Aug. 31, 1959; Sept. 1, 1959; Aug. 11, 1960 and Oct. 12, 1960, respectively.

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Discussion

Athay, R. G.: What is the evidence for the cm bursts being of thermal origin? Isn't the lifetime of about 2 minutes a difficult feature to explain with a supposed thermal origin?

Kundu, M. R.: Only a portion of cm-λ bursts may be of thermal origin. For weak cm-λ bursts, the brightness temperature could be of the order of 10^6°K and also the spectrum of the cm-λ bursts (with no meter-λ association) often follow a λ^2 law.

I think the short lifetime (a few mimutes) of cm-λ bursts can be explained if we assume the source as a very dense region.

Wild, J. P.: There may be no difficulty in the first observed relaxation time if we suppose the centimeter-wave radiation to be due to Bremsstrahlung from the fast electron passing through a region of dense plasma.

Takakura, T.: Microwave bursts are explained by synchrotron radiation from 0.5 Mev electrons in the sunspot magnetic field. The heights of radio sources is about 5×10^4km. While, X-rays may be Bremsstrahlungs due to collisions between neutral hydrogens and the electrons streaming into the chromosphere ($>10^4$ km) through the radio source. Thus both X-rays and radio waves are attributed to about the same electrons. The spectrum and the polarization of the microwave bursts are explained by the synchrotron radiations.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3B-2. Characteristics of Solar-Flare Cosmic Rays during IGY

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The effect of solar flares of class 2+ and greater on the intensity of the low-energy nucleonic component of cosmic rays at different locations on the earth has been studied by the Chree method of superposed epochs. (Data analyzed were from Chicago, Climax, Mexico City, Lincoln, Sacramento Peak and Wellington for the period July 1957-December 1958). The sun was divided into regions and possible differences between the effect of eastern, central, and western groups of flares have been studied. It seems that no coherent result is evident when comparing several stations during the same year; furthermore, no self-consistent results between 1957 and 1958 for individual stations were found.

§ 1. Introduction

Neutron monitor data from Chicago, Lincoln, Climax, Sacramento Peak, and Mexico City for the period July, 1957, through December, 1958, have been used to study possible effects of small solar flares on the intensity