OBSERVATIONS OF RADIO CONTINUA AND TERMINOLOGY*

(Invited Review)

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Abstract. Different components and successive stages of type IV bursts are reviewed. Some simplifications in the schematic representation of well developed type IV bursts are proposed. The existence of two physically distinct acceleration/injection mechanisms is discussed. Suggestions for further work are proposed.

1. Introduction

Most of the topics discussed in this review, concern the type IV burst development. A type IV burst is defined as a long lasting flare associated event with large spectral width in the centimeter–decameter radiospectrum. The morphological aspect of type IV bursts is complex and has been extensively studied in the 1960's and a certain number of physically different components have been distinguished by various authors. Due to the complexity, a multitude of classifications of the main features have been proposed resulting in a puzzling picture. Moreover, these classifications were obtained through different observing technics: spectrography, single frequency patrols, polarization measurements, interferometer and later on radioheliograph observations (see for a review Krüger, 1979).

More recently, X-ray radiation has been detected in association with type IV bursts (Frost, 1974). This wide spectral range of electromagnetic radiations, from hard X-rays to decameter wavelengths, reveals the existence of non thermal electrons at various levels in the solar atmosphere. As it will be reviewed during this workshop, the comparison of the spatial and temporal evolution between these different electromagnetic radiations has led to a better physical understanding of the development of flare-associated radio continua.

It is now accepted that during large solar flares, the electrons are continuously or repetitively injected into different coronal structures where they emit hard X-rays and broad band continua from centimeter to decameter radio waves (Hudson, *et al.*, 1982, Kai *et al.*, 1983, Klein *et al.*, 1983, Trottet, present issue). The strongest argument supporting this conclusion is the similarity of time profiles, often observed, between hard X-ray, microwave and meter emissions.

Despite of this general agreement, several problems still remain confused. First of all, it seems that a great deal of ambiguity arises from the inhomogeneous terminology adopted by different authors to describe the successive stages of type IV events. This led some authors to suggest an association between hard X-ray emission and type IV

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burst without any clear distinction between the different components. The consequence has been a confusion in the electron energy responsible for the different components of a type IV burst. Secondly, type II bursts which are produced by shock waves are often observed at the onset of type IV bursts. The exact role of shocks in the acceleration of electrons responsible for type IV emission and other emissions is not yet understood.

In this review, the different components and successive stages of type IV bursts will be discussed. It will be seen that different components do not correspond necessarily to different electron populations. The different classifications which have been introduced in the litterature are redondant and some simplifications in the schematic representation of the overall picture will be proposed.

2. Type IV Burst Development and Terminology

2.1. Brief Description

The temporal evolution of the radio flux observed at different single frequencies is reported in Figure 1 for two type IV bursts. The gradual phase comprises mainly two components:

– The first one (before 12:40, in Figure 1(a)) corresponds to a broad band emission from centimeter to meter wavelengths and *starts* often during the impulsive phase (see Figure 1). This component designated as 'PART A' by Pick (1961) or PHASE A (see Kundu, 1965) comes from a source with no systematic motion, is generally *long lasting* (10 min to about 1 h), extends to *the microwave* range, presents an hard X-ray counterpart (Klein *et al.*, 1983). This component was later on called '*flare-continuum*' (Wild, 1970) and I shall adopt this terminology. It is sometimes associated with a *moving* type IV emission (Pick, 1961).

– The second component (after 12:40, in Figure 1(a)), Part B (Pick, 1961), is observed in the *decimeter–meter* wave range, comes from *stationary* sources and can last for several hours. When the duration is longer, the emission becomes restricted to meter–decameter wavelengths and is generally referred to as '*storm-continuum*' or '*stationary type IV burst*' (Wild, 1970). If microwave emission exists at the the time of this m–λ component, it is of the GRF type. Hard X-ray emission, if it exists, is restricted to the very low-energy channels. There is no indication for the presence of very energetic electrons in the low corona during this phase. This phase is associated with softer X-ray emission (Stewart *et al.*, 1980; Klein *et al.*, 1983).

– In addition to these two components, it has been proposed that type IV decimeter bursts form a distinct subclass with regard to their polarization, to their morphological and spectral characteristics (Wild, 1962).

Later on, in 1975, Robinson and Smerd (1975) proposed, from observations obtained with the Culgoora radiospectrograph and radioheliograph, the distinction between two classes of flare continua. The first class called FCM starts in the impulsive phase of the flare (Figure 2) and is often followed by a moving type IV burst. Its name was thus derived from this association. In the second class, designated as FC II, the continuum

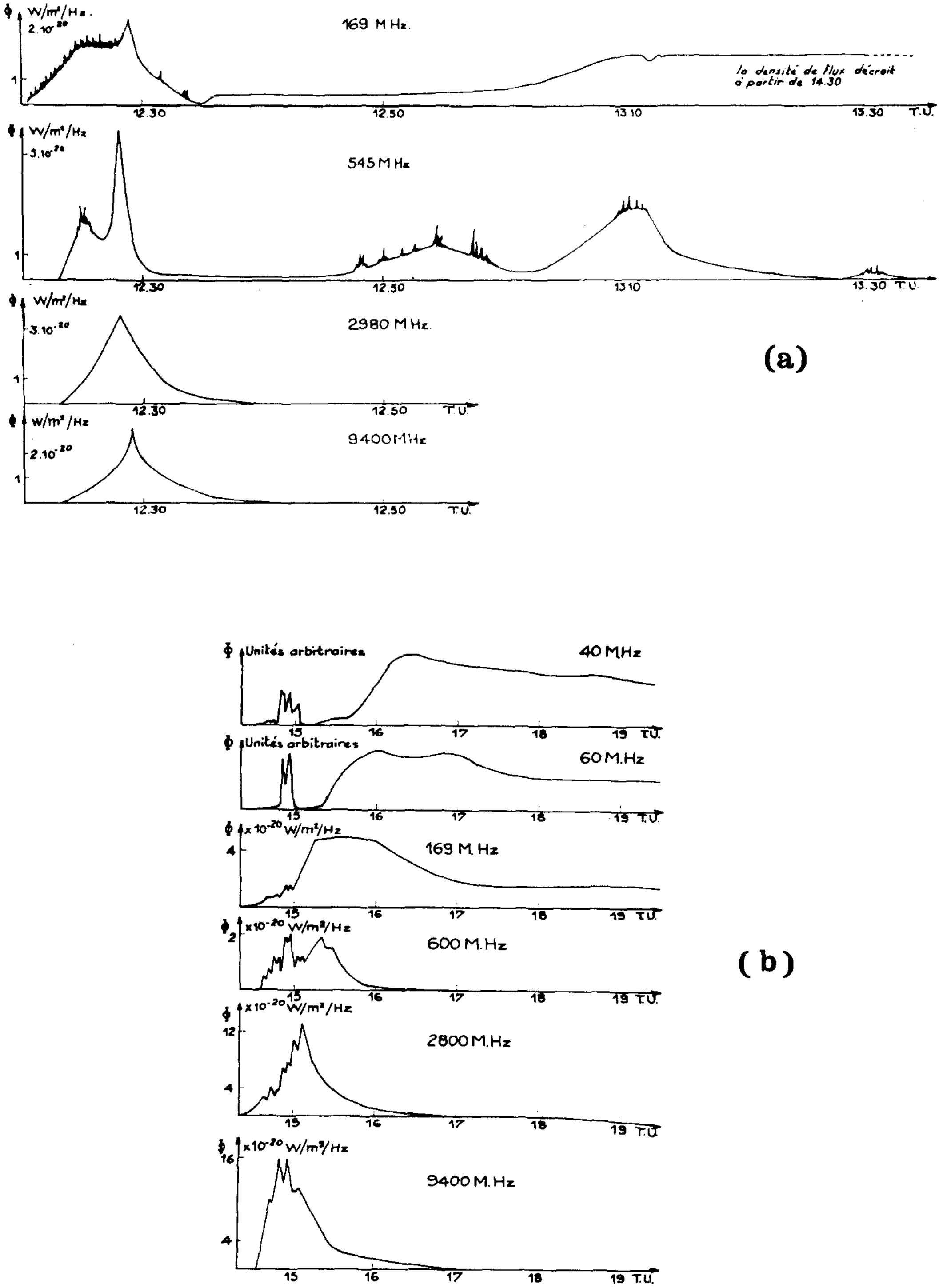

Fig. 1. Type IV bursts: comparative temporal evolution observed at different single frequencies (from Pick, 1961). (a) 28 June, 1957. (b) 22 August, 1958.

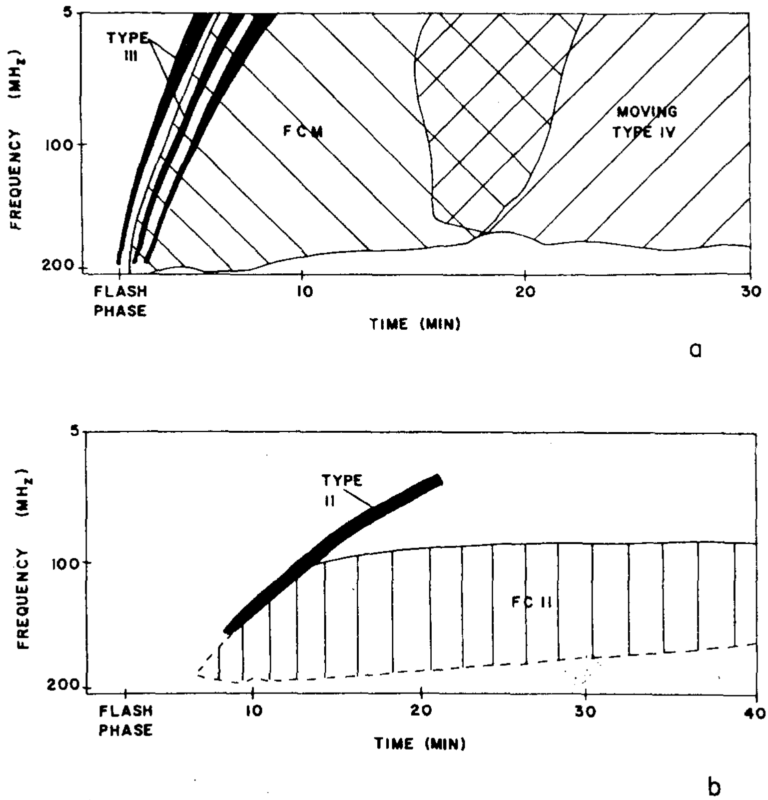

Fig. 2. Schematic representation of (a) an FCM and (b) an FC II (from Robinson, 1977).

occurs during and following a type II burst, i.e., some minutes after the impulsive phase. This distinction, however was based on a relatively narrow frequency range (decimeter–meter waves) and no comparison was made with former classifications taking account of the centimeter emission. Nevertheless *there is no doubt that the FCM corresponds to PART A or PHASE A.* As concerns the FC II continuum, the exact correspondance between this classification and the former one is not clear and this point will be discussed in this paper.

Finally, as the FCM is closely connected to the impulsive phase, Robinson recently suggested to modify its name, and he proposed the new name of 'Flare continuum early' (FCE, Robinson, 1985). Nevertheless, as this component may have a duration which often exceed tens minutes and then is typically observed during the gradual phase of flares, this new designation FCE '*Early*' does not seem to be convenient.

2.2. Flare continuum–[phase A–FCM]

Typical radio observations of this component are shown in Figure 3. It can be seen that the temporal behaviour of the continuum is similar at all frequencies. However, this component is not necessarily systematically observed at decameter wavelengths. This similarity led me (Pick, 1961) not to introduce a subdivision between the microwave type IV burst and the phase A. This is contrary to the current idea reflected in the literature. We note that the event presented in Figure 3(a) is also associated with a moving type IV burst. Radioheliograph observations have revealed that the moving type IV source emerges from that of the flare continuum one (Robinson and Smerd, 1975).

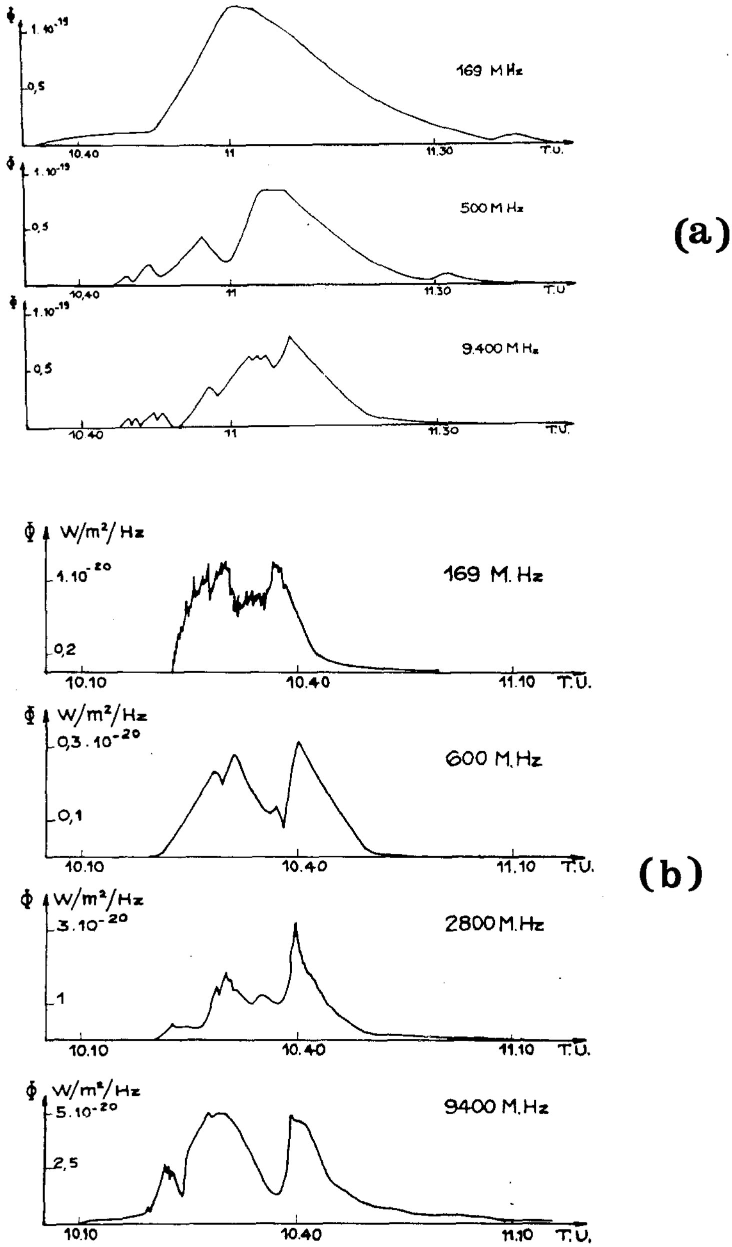

Fig. 3. Flare-continua (Part A, from Pick, 1961). (a) 14 November, 1966. (b) 28 August, 1958.

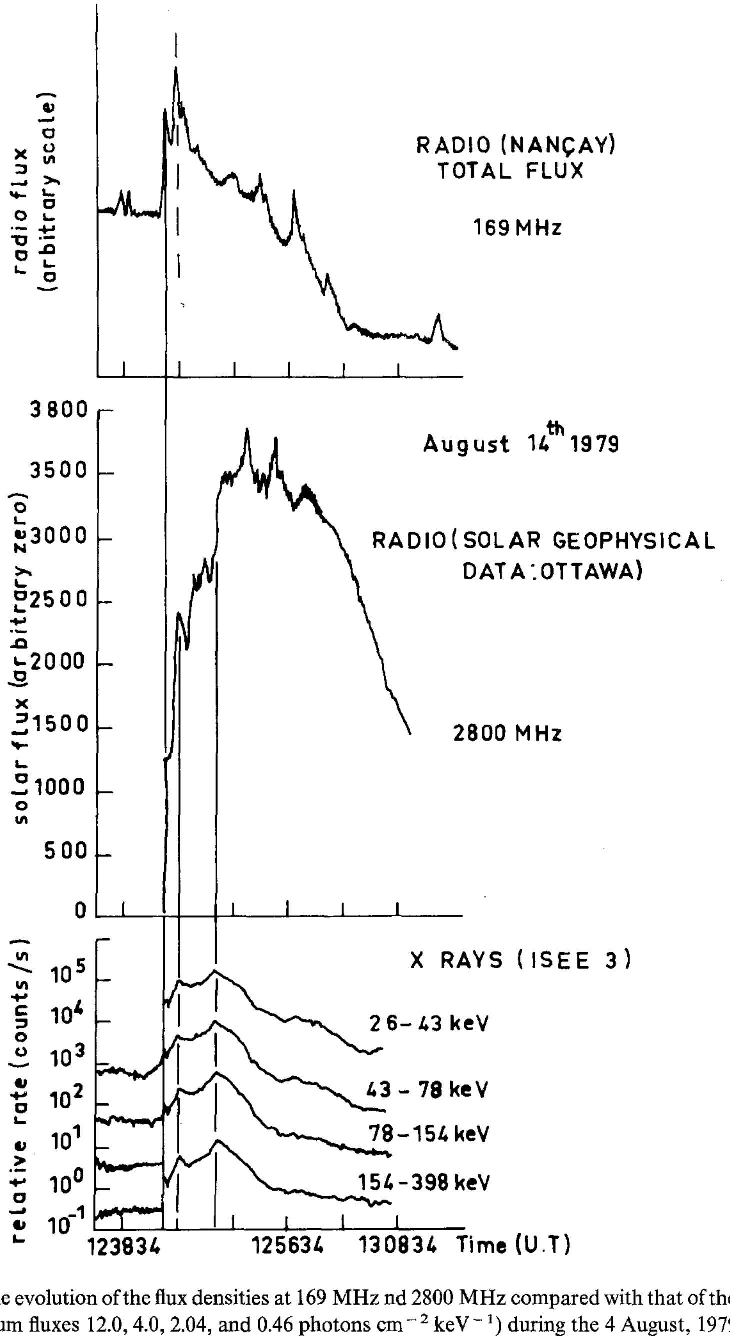

Fig. 4. Time evolution of the flux densities at 169 MHz nd 2800 MHz compared with that of the hard X-ray flux (maximum fluxes 12.0, 4.0, 2.04, and 0.46 photons cm^{-2} keV^{-1}) during the 4 August, 1979 event. The background level at 169 MHz is shown by the dotted line. The excess flux before the onset of the type IV burst is due to a noise storm which rose slowly from about 11:43 UT and peaked around 12:30 UT (from Klein *et al.*, 1983).

Figure 4 compares the temporal evolution of hard X-ray and radio emissions for one flare containing a flare continuum which starts at the time of the impulsive phase emission (Klein *et al.*, 1983). Flare continuum and hard X-ray emission start and finish approximatively together and present an overall similar temporal behaviour. The observed nearly simultaneous end of the burst and of some of its fine structure features in both spectral ranges, plus the fact that the lifetime of the energetic electrons in the HXR source is far shorter than the flare duration, indicates that the electrons are not efficiently trapped in the m–λ source. The electrons must be quasi continuously injected into different magnetic structures where they produce hard X-ray and the broadband flare-continuum.

The temporal evolution of the radiation reflects the combined action of successive electron injections and energy loss (Trottet, 1986). The so called 'secondary peaks' introduced by Tanaka and Kakinuma (1962), as well as Fokker (1963), are either a consequence of this evolution and not a distinct feature or for some events, the radiation coming from a secondary source (Nakajama *et al.*, 1984). There is no observational reason for a subclassification (IV μ_1 and IV μ_2) of type IV μ bursts in dependance of the number of fluctuations in them. In conclusion, *I suggest here to abandon this subclassification and to consider the microwave type IV burst as the highest frequency part of the flare-continuum.*

2.3. Type IV B and stationary type IV bursts–FC II events

The second phase, of type IV bursts (IV B) is resticted to decimeter–decameter wavelengths. The most distinctive characteristic of this phase is the directivity (Pick, 1961). This emission starts typically after the impulsive phase, during or after the decreasing part of the flare-continuum. At a given frequency, the increase in intensity is relatively

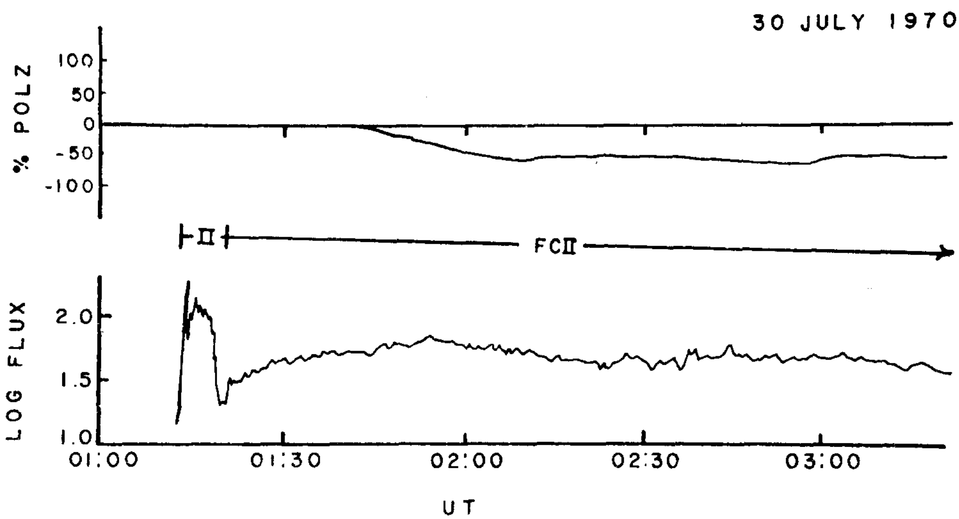

Fig. 5. Flux and polarization dynamics for a typical FC II event (30 July, 1970; from Robinson, 1977).

smooth (Figure 1(b)). For events of long duration, the emission called 'storm continuum' or 'stationary type IV burst' becomes strongly polarized and restricted to meter–decameter wavelengths. The main distinction from the type 1IV B) component to the storm continuum appears to be the degree of polarization which is stronger during the storm continuum (Pick, 1961). It may be suggested that the type (IV B) component is just the early development of the storm continuum.

Though the presence of a type II burst is not a necessary condition for the type (IV B) production, by many aspects, the FC II continuum looks nevertheless similar to the type (IV B) component: starting time delayed from the impulsive phase–polarization characteristics–frequency range. As an example, Figure 5 shows a FC II event described by Robinson (1977). This event clearly starts after the type II burst occurrence, is not associated with a microwave outburst and may effectively correspond to a IV B component.

On the other hand, for other FC II continua described by Robinson, some problems must be clarified:

In many events, a flare continuum (FCM–PART A) is under development when the type II burst occurs (Figure 6): though there is no reason why both FCM and FC II continua should not be present in an individual event, there is no definite way to

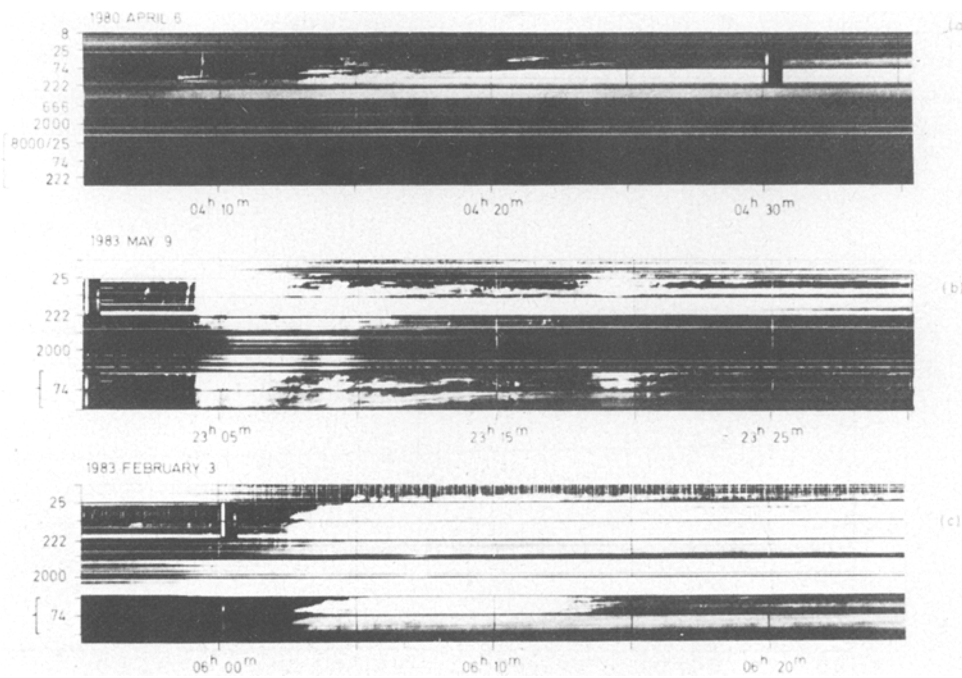

Fig. 6. Dynamic spectra of FC II bursts. (a) An isolated FC II event. (b) An FC II with flash phase activity. (c) An event associated with strong microwave activity (From Robinson, 1985).

distinguish on spectrograph data FC II from FCM, especially when a strong microwave activity exists (Figure 6). As another example, Figure 7 compares the temporal evolution of hard X-ray and radio emission for one flare containing a flare continuum. The onset of the flare continuum at meter wavelengths clearly occurs during the flash phase, before

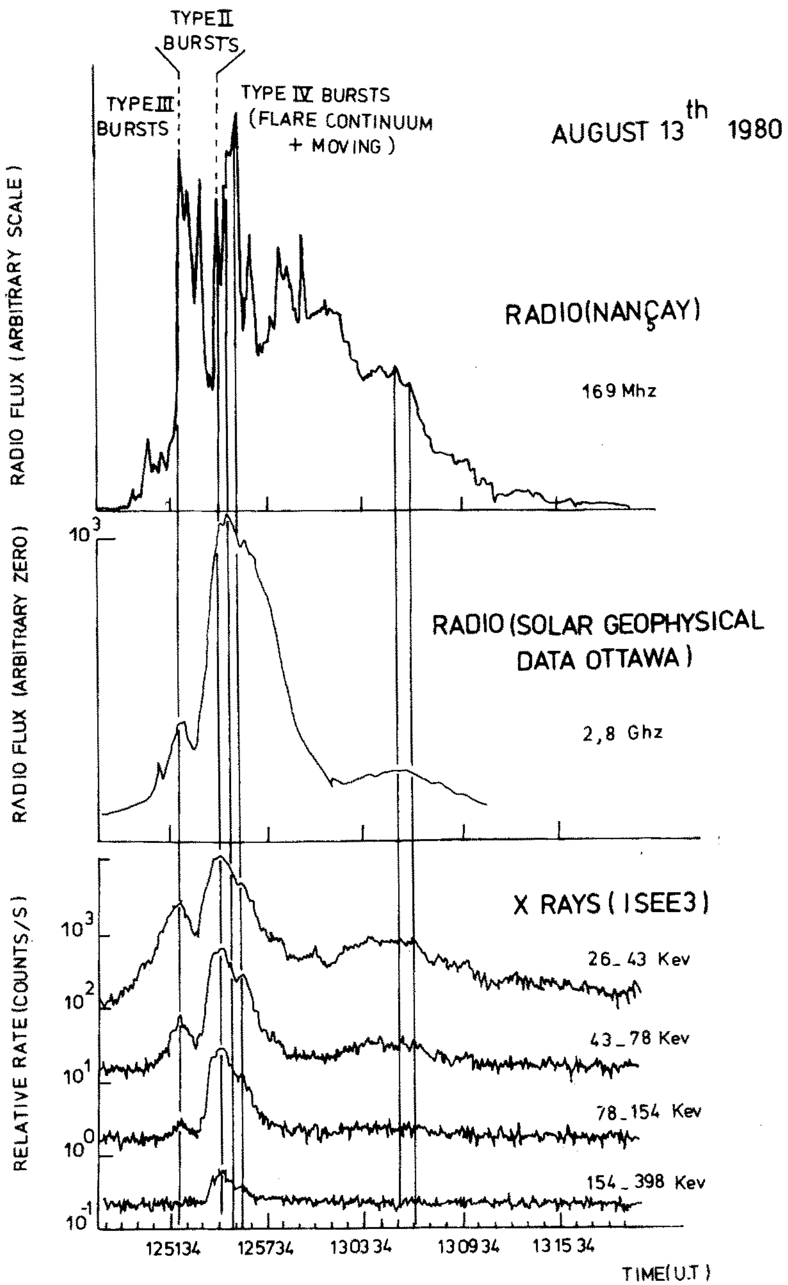

Fig. 7. Same as Figure 4 for the 13 August, 1980 event (maximum X-ray fluxes: 6.9, 1.3, 0.33, and 0.03 photons $cm^{-2} s^{-1} keV^{-1}$) (from Klein *et al.*, 1983).

the type II occurrence. At a given frequency, the intensity does not increase particularly after the type II burst. It is then hard to distinguish a part of this event as a FC II emission. Robinson and Smerd (1975), proposed that the acceleration of radiating electrons is probably achieved by the interaction of the type II shock with a coronal loop, this mechanism corresponding to an *in situ* process acting on preaccelerated electrons. It must be noted that in the cases presented here (Figures 6 and 7), the electrons do not appear to be accelerated locally, after the passage of the shock.

Robinson noticed that sometimes, FC II activity is accompanied by an unclassified continuum burst having the properties of the type III/V (Robinson, 1977). For those events, he proposed that the acceleration operates on previously injected subrelativistic particles. This interpretation is contradicted by recent observations of hard X-ray and γ-ray line events: relativistic electrons are already accelerated at the onset of the impulsive phase during the occurrence of the type III/V event (Figure 8).

An explanation different of an *in situ* process may be also proposed. There is an acceleration/injection site located in the corona acting continuously or repetitively. Indeed comparative studies between stationary type IV bursts and soft X-rays have

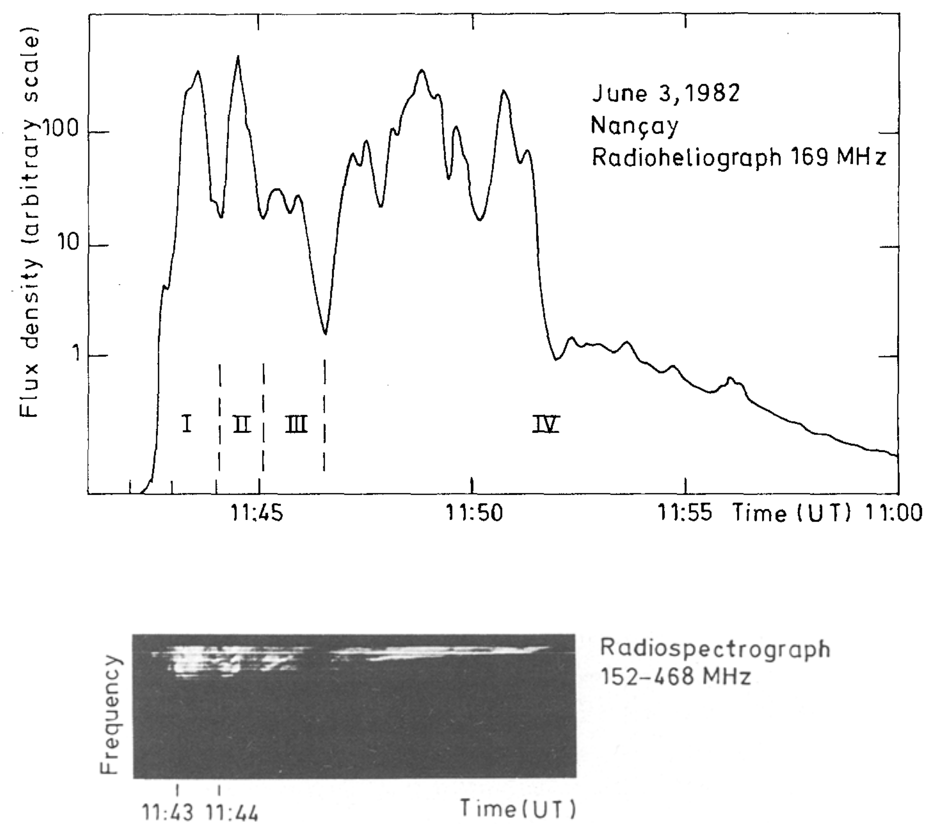

Fig. 8. Radiospectrograph (with the courtesy of J. L. Bougeret) and radioheliograph observations obtained at Nançay of a type V/IV event. The gamma-ray line emission is observed during part I of the burst.

revealed that a long-lasting storage of electrons cannot explain the observations and that a continuous input of energy is necessary (Trottet, 1986). During the early period of an event, the electrons may be injected in a system of low coronal arches which can then expand in the corona, as now currently observed with coronograph observations aboard SMM. The start of the radio emission is then observed when the plasma frequency in the expanding loop becomes lower than the observing frequency. It must be noted that this schematic evolution is compatible with the existence of motions of a few tens kilometers per second, often observed during the early development of type B continua (Clavelier *et al.*, 1968). The frequency drift of the emission with time would then be due to the rising arch which may be *preceeded by a shock wave, but the latter would not be the principal accelerating agent.* The fact that FC II events/IV B components and stationary type IV bursts start in the decimeter region may be due to the altitude of the acceleration site, or to the energy of the radiating electrons. As noted in Section 2.1, for these events, soft X-radiation is observed and if microwave emission exists, it is of GRF-type.

In conclusion, the properties of FC II events must be carefully reexamined: some of them probably correspond to the early phase of stationary type IV bursts, others associated with a strong microwave activity are probably flare continua FCM of long duration.

2.4. Do decimeter type IV bursts form a subclass?

The frequency range of the decimeter type IV bursts extends from below 200 MHz to about 2000 MHz (Wild, 1962; Tanaka and Kakinuma, 1962).

2.4.1. *Polarization*

It was noted that the sense of circular polarization of decimeter continuum component is often reversed with respect to that of the type IV μ bursts. In fact, polarization characteristics of type IV bursts have been systematically investigated by Kai (1965). From the polarization measurement, Kai suggested that there is *no reason* to distinguish the type IV dm component from the meter component (see Figure 9). Decimeter and meter components have always the same sense of polarization (flare continuum and part B).

An inversion in the polarization can be observed during the flare continuum between the microwave burst (extraordinary) and the dm – m burst (ordinary). There are several explanations for the polarization reversal:

- change of the magnetic field orientation,
- intrinsic property of emission mechanism,
- mode coupling during propagation in a magnetically structured region.

For a discussion of polarization and its interpretation, see Alissandrakis (1986).

2.4.2. *Spectral and Morphological Characteristics*

Fine structures are especially observed in the decimeter range: pulsating structures, ‘sudden reduction’ in continua, bands of limited bandwidths (Slottje, 1972). Most of

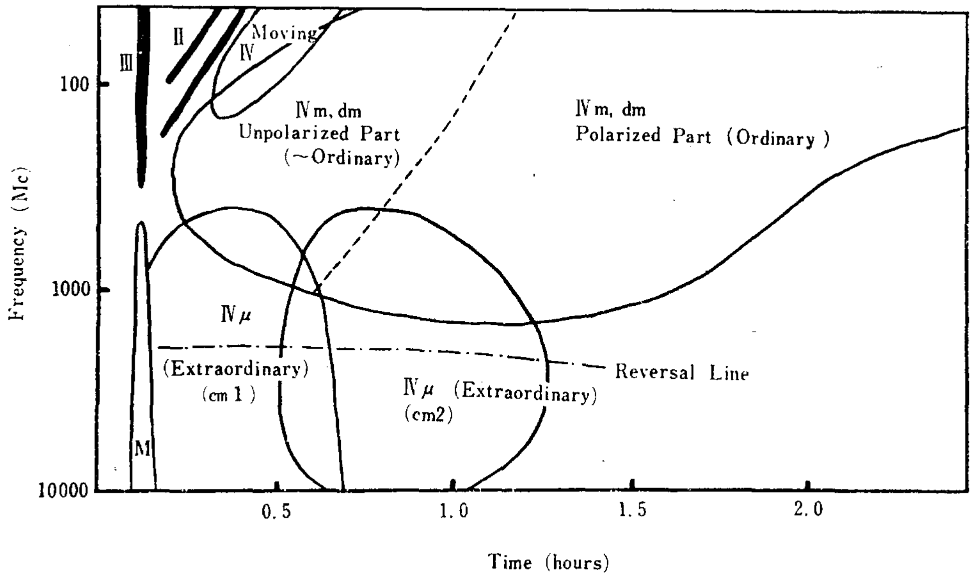

Fig. 9. A schematic illustration of dynamic spectrum for fully-developed type IV bursts (from Kai, 1965). Sense of polarization. Note that the meter flare continuum can be occasionally polarized in the extraordinary sense.

these features have been explained in terms of plasma instabilities. For example, processes where the plasma emission of trapped particles is inhibited by perturbations of the loss cone distribution have been proposed to explain the sudden reductions (Benz and Kuipers, 1976) and the pulsating structures (Trottet *et al.*, 1981). These perturbations can correspond to repetitive injections of fast electrons as suggested by Benz and Kuijpers (1976). In conclusion, the morphological aspect of dm continua type IV burst does not allow to consider them as a specific subclass. Most of their properties can be explained by the characteristics of the injection/acceleration source itself and by the physical conditions inside the radiating source when the plasma becomes instable. The terminology of the fine structure in the decimeter burst should be considered separately.

3. Discussion and Conclusion

3.1. Suggestions for a simplification in the schematic representation of type IV bursts

I suggest the following simplifications:

– Do not consider any more the subdivision of microwave burst (μ_1 and μ_2) and realize that the type IV μ burst is the microwave extension of the flare continuum.

– Do not consider any more decimeter continuum type IV bursts as a distinct subclass. The following terminology is proposed:

• The first PART A is called *Flare-continuum*. The *microwave type IV burst* is the highest frequency emission of the flare continuum. FCM and FCE should be simply called flare continua.

• For the second part, a few points must still be clarified before suggesting a classification:

– What is the exact nature of FC II with respect to the type IV B component?

– Are there physical reasons and/or morphological characters strong enough to distinguish the type IV B component separately from the *continuum storm*? (also named *stationary type IV burst*?).

3.2. Do two different electron acceleration mechanisms exist?

Electrons are accelerated quasi-continuously during all the phases of a flare. The differences in the characteristics of the successive components of a type IV burst can be explained by the evolution in the properties of the acceleration/injection mechanism itself; flare continua and moving type IV bursts are associated with hard X-rays, thus with energetic electrons, 100 keV or more. IV B components and type IV bursts are associated with soft X-rays, i.e., with electron energies below 30 keV (see Trottet, 1986).

In conclusion the properties of FC II events must be carefully reexamined. It is finally not clear enough, whether two physically distinct accelerating mechanisms exist; one corresponding to an injection/acceleration site located relatively low in the corona and producing electrons continuously or repetitively during the whole development of the event; another one corresponding to *in situ* acceleration during the passage of the shock wave. Kundu and Stone (1984) have expressed some doubt on the existence of acceleration *in situ* events for so-called shock-associated (SA) events (Cane *et al.*, 1981).

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