ON CORONAL INSTABILITY AND MOVING RADIO FEATURES ASSOCIATED WITH A FLARE SPRAY

G. DAIGNE

Meudon-Nançay Observatory, France

Abstract. A solar radio outburst with its different parts well seen on metric wavelengths is described. A stable source shows successively two kinds of emission before the flash-phase of the event, and a moving type IV burst ($V \simeq 1000$ km/s), initiated $\frac{1}{4}$ solar radius high, is directly associated with a spray-type prominence. Parameters of this radiating source are discussed.

A type II burst seen on lower frequencies with a spectrograph ($V \simeq 3200$ km/s) seems to start after the flash phase. Two possible cases are considered for the generation of the shock-wave responsible for type II burst.

1. Introduction

A solar radio outburst occurring on 1968 December 11th, on the East limb of the Sun, is described with its different parts: one part preceding the flash-phase, a moving type IV burst, and a type II burst. The first part of this event may be similar to the coronal instability before the onset of a flare reported by Wild (1968).

Observations of radio outbursts induced by flares or prominence eruptions (Wild *et al.*, 1968) have allowed to associate their moving part with arch expanding structures (Wild, 1969; Kai, 1970). The association of the moving type IV burst, reported here, with a spray-type prominence is of special interest because density and maybe magnetic fields are then quite different than in conditions preceding flares.

The only optical observation of this event was by an amateur solar observer. Bruzek (private communication) reported this observation: at 11^h46^m UT "a giant flame with two branches" had a height of approximately 0.25 $R_\odot$, it was disrupted at 11^h53^m UT having reached a height of 0.7 $R_\odot$, and at 12^h06^m UT its upper parts. The phenomenon was interpreted as a huge eruptive spray-type prominence; it was produced or accompanied by a flare which may have started at about 11^h40^m UT. According to Warwick (1957) flare-sprays are characterized by extraordinarily high speed, by clumpiness, and by virtually straight line trajectories outward from a small center of origin in the flare (Orrall and Smith, 1961).

2. Radio Observations

Total flux measurements were made by the Nançay station at three frequencies: 9400 MHz, 408 MHz, 169 MHz. Other data were communicated by different observatories: 900 MHz (Bordeaux), 408 MHz (San Miguel), 260 MHz (Ondřejov), 111 MHz (Potsdam) and spectral observations in the frequency range 950–32 MHz (Weissenau). Position measurements were made by the Nançay's East-West interferometer at 408 MHz and East-West radioheliograph at 169 MHz (Vinokur, 1968).

The radio event begins at 11^h41 UT and lasts until 12^h00 UT. The total flux

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observed at different frequencies are given in Figure 1 (9400, 900, 408, 169 and 111 MHz). The most important time for such a complex event is the occurrence of the flash phase (Wild *et al.*, 1963). Even if we have no idea on the optical flare we can take $11^h47^m30^s$ as beginning of the flash-phase. It corresponds to the start of the fast increase in flux at 9400 MHz as well as on decimetric wavelengths, and the occurrence

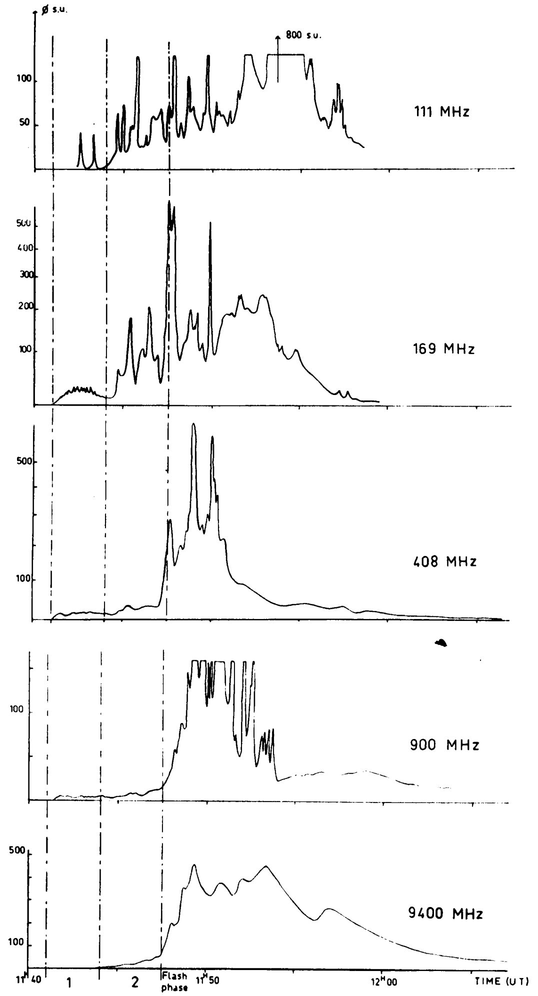

Fig. 1. Observed flux at different frequencies for the radio event (1968, December 11).

of strong type III bursts on metric wavelengths (between 11^h48^m and 11^h50^m UT). Before this flash-phase, we can distinguish two kinds of emission occurring in the corona: first a small noise storm, and then the beginning of what may be the Flare Continuum as recently defined by Wild (1970); these two parts are respectively labelled 1 and 2 on the different figures.

A. BEFORE THE FLASH-PHASE

As can be seen from the total flux on Figure 1, the difference between the two parts 1 and 2 is mostly important at low frequencies. The part 2 may be characterized by (a) an increase of the continuum emission (169 and 111 MHz), (b) strong flux variations (169 MHz) slower than for typical type III bursts at this frequency. In the same time a classical gradual rise occurs on high frequency (9400 MHz); this precursor may have started earlier, at about 11^h41^m UT, in the same time as for the other frequencies. In such a case the delay would be due to the poor sensitivity of our total flux measurement at 9400 MHz (about 10 s.u.).

Positions measured at 408 MHz and 169 MHz are plotted on Figure 2; they remain stable during the two parts defined earlier. Two centers can be seen at 408 MHz, their distance being 2′5; only one center is present at 169 MHz, but our resolving

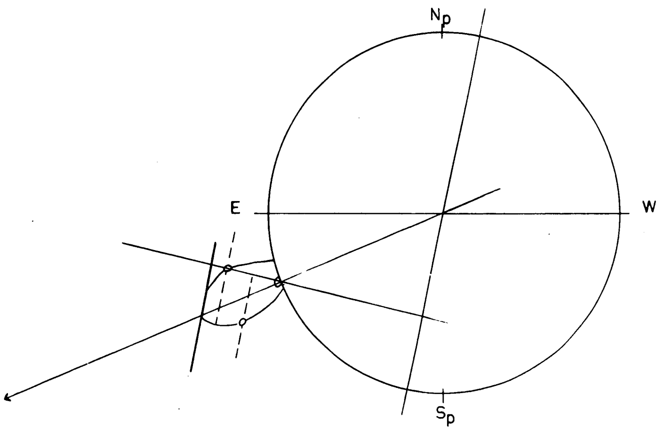

Fig. 2. East-West positions of the radio emission at two frequencies (– – – – –:408 MHz; ———————: 169 MHz). A loop has been drawn over the active center (20°*S*).

power is only 3′4 at this frequency instead of 1′7 at 408 MHz. A hypothetic loop has been drawn over the optical center which may be an explanation for the double center at 408 MHz; this emission would come approximately from the same height in the two feet of the loop.

The altitude of the radio sources will be now measured assuming they occur radially on the active center; this is certainly not true at 408 MHz, but it enables us to compare different bursts. With this radial hypothesis, the deduced height is 0.5 $R_\odot$ at 169 MHz; it seems to show a very high density in the corona before the flash-phase if we assume that plasma radiation is the main mechanism.

On Figure 3 (a) the flux densities at different frequencies are summarized; the frequency scale is deduced from a density model (twice Newkirk's density model above active regions (Wild *et al.*, 1963), that is four times Newkirk's density model in the quiet corona in period of maximum activity $Ne = 4.2 \times 10^4 \times 10^{4.32/R}$). We assume that each frequency is emitted at the plasma level, except for the high frequencies (408 MHz to 9400 MHz) for which the model is no longer valid. This figure is only a rough picture of the event to give a more general view of the event, without physical significance for the moving type IV burst.

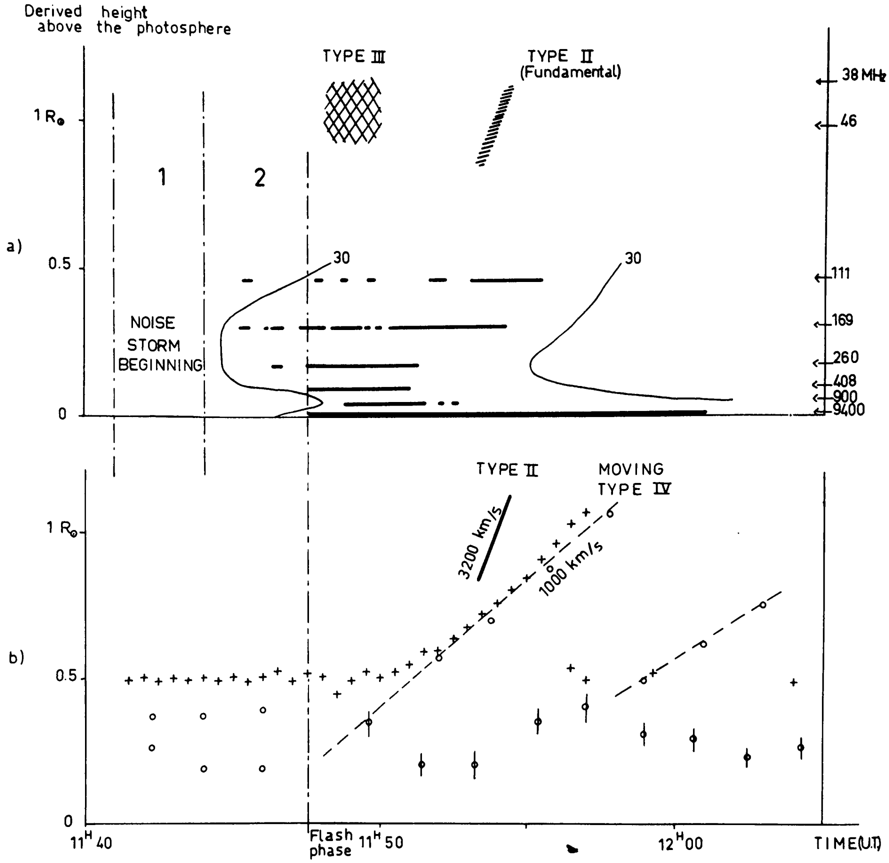

Fig. 3. (a) Summarized picture of the radio event. Horizontal bars are for radio flux greater than 100 s.u. at the corresponding frequencies (right side on the picture). The thin line indicates the region where radio flux is greater than 30 s.u. (b) Derived height above the photosphere with a radial hypothesis from measurements at two frequencies (○ 408 MHz; + 169 MHz); vertical bars at 408 MHz are for large sources (2′ or 3′ in diameter). Altitude of the type II burst is deduced from a density model (twice Newkirk's model above active regions).

B. THE FLASH-PHASE

Its beginning, between $11^h47^m30^s$ and 11^h48^m, is seen at all frequencies:

- start of the impulsive part of the type IVμ.
- strong burst on decimetric wavelengths, lasting about half a minute (408 and 169 MHz).
- beginning of a type III bursts cluster on low frequencies (about 40 MHz).

– start of a continuum enhancement between 300 and 600 MHz (from spectral observations).

C. AFTER THE FLASH-PHASE

A moving type IV burst is visible both at 408 MHz and 169 MHz, with the same position at the two frequencies; these positions are plotted on Figure 3(b). According to the radial hypothesis the moving type IV burst rises with a velocity of 1000 km/s. At 408 MHz position measurements are separated by a lapse of time of 2 mn, due to the fringes of the interferometer; one of this position cannot have been measured because of the too high emission level at that time (about 11^h48^m UT). Nevertheless we can say that the moving type IV burst is seen *first* at 408 MHz, and visible at 169 MHz only when the disturbance reaches the height of the preceding source at this frequency.

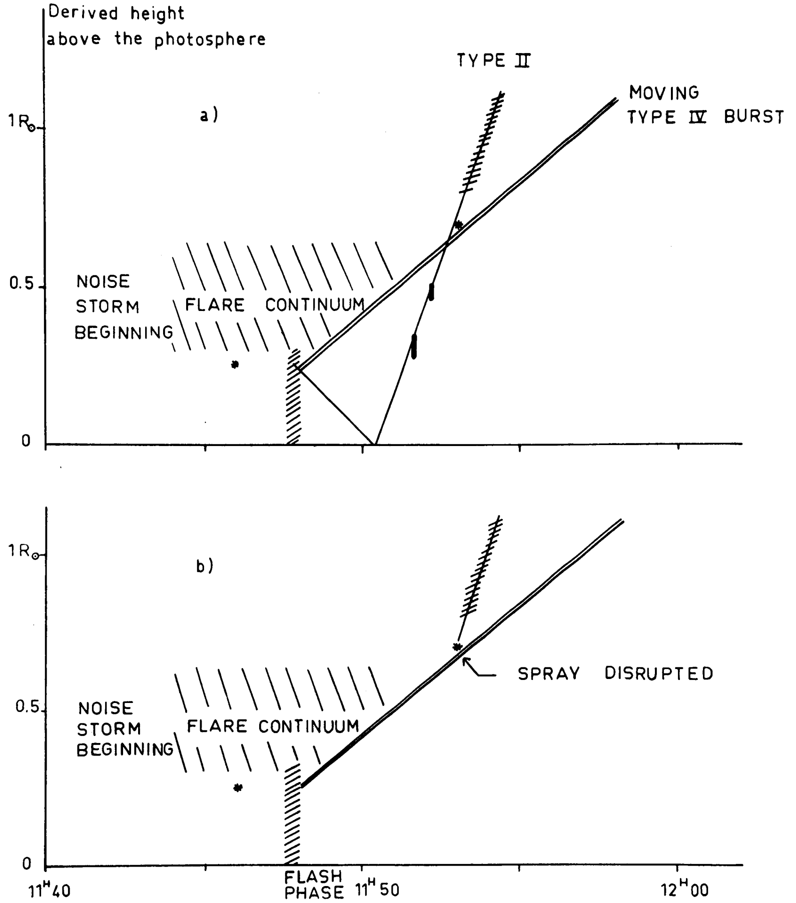

Fig. 4. Two possible paths for the shock-wave responsible for type II burst, and positions of spray (*). (a) Reflection on chromospheric levels (vertical bars are for peculiarities at 169 MHz and 111 MHz). (b) Directly from the spray.

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As positions at different frequencies are the same, the moving type IV burst has been interpreted as a synchrotron source (Boischot *et al.*, 1968); but in our case the source at 169 MHz nearly reaches its maximum in flux during the beginning of its movement, so that plasma radiation cannot be neglected in the emission process of some moving type IV burst, as pointed out by Wild *et al.* (1968).

The remaining source at 408 MHz is large and seems to fluctuate between the two previous positions, but this may be due to a second moving feature produced 8 mn after the first, with a velocity of about 800 km/s. It is fainter than the first moving type IV burst and seen only at 408 MHz. After that the radio sources at 169 MHz and 408 MHz are still there, with flux and position similar to what they had during the noise storm beginning (part 1); their flux decrease slowly and sources disappear 30 mn later.

D. TYPE II BURST

Spectral observations show a type II burst with harmonic; its fundamental band is the frequency range 60–38 MHz; it occurs between $11^h53^m20^s$ and $11^h54^m20^s$. The altitude of the fundamental emission, deduced from a density model (still twice Newkirk's model) is plotted on Figure 3(a) and (b). From this model, the deduced speed of the shock wave responsible for the type II burst is found to be 3200 ± 400 km/s.

Two peculiarities observed on the flux at 169 MHz and 111 MHz seem to be produced by the passage of the shock wave through the corresponding plasma levels. When it occurs at 169 MHz ($11^h51^m40^s$ UT), the diameter of the source is strongly enlarged from about 4 or 5′ arc to 7′ arc. These peculiarities are plotted on Figure 4(a) in the same density model. The departure time from chromospheric level, assuming a constant speed, is not greatly influenced by the density model. When changing the model, we change also the speed of the disturbance deduced from the frequency drift of the Type II burst.

3. Discussion

A. CHARACTERISTICS OF THE RADIATING ELECTRONS

The three features of the decimetric and metric radio emission are: noise storm beginning (Part 1), Flare Continuum (at 169 MHz *it lasts until the passage of the rising disturbance* – type IV burst – through this radio source), moving type IV burst. They may be associated with three orders of magnitude for the energy of the radiating electrons: some keV during the noise storm, tens of keV during the Flare Continuum (in fact little is known on the radiation mechanism of this part, but it cannot be synchroton radiation, the source being much too low in the corona). We can estimate the electron energy of the moving type IV burst, supposed to be a synchroton source, with the method developed by Ramaty *et al.* (1968). We obtain a mean energy of about 1 MeV in a magnetic field of 4.5 G at 0.6 $R_\odot$; the density has been taken twice Newkirk's density model ($Ne = 8.3 \times 10^7$ cm^{-3} at 0.6 $R_\odot$).

The Flare Continuum *starting before* the flash-phase may be due to a pure coronal acceleration mechanism by turbulence in a closed magnetic structure as proposed by Pneuman (1967) for an explanation of flares.

B. DEVELOPMENT OF THE FLARE PHENOMENA IN THE CORONA

Even if we know little on the associated optical phenomena, its nature and the position of the spray at two different times is important enough to try to associate optical and radio observations. Chromospheric material must have been expelled about 11^h40^m UT to produce the spray-time prominence. This optical feature has never been observed as the very first phenomenon of a flare (Bruzek, 1968).

The spray is directly associated with the moving type IV burst, optical and radio positions being the same at 11^h53^m UT (Figure 4), and velocities being very similar. The radio emission of the moving type IV burst starts only when the spray has reached an altitude of about 0.3 $R_\odot$, at the time of the flash-phase; may it be a critical height for the acceleration of particles in this event's conditions?

Density generally adopted for spray type prominences is about 10^{10} cm^{-3}; with a speed of 1000 kms^{-1}, its kinetic energy is balanced by magnetic energy for a field strength of 45 G, which is an order of magnitude greater than the value usually found at 0.6 $R_\odot$ above active regions (Newkirk, 1967). Whatever the magnetic structure over the ascending spray, it must be disrupted or carried out. This may explain the disappearance of the Flare Continuum at 169 MHz after the passage of the disturbance.

C. TYPE II – MOVING TYPE IV BURST

These two slow drift radio features have been attributed to a common flare-induced shock wave by Kai (1970), Stewart *et al.* (1970). In the observation reported here, they have quite different speeds, they cannot be attributed to a common shock wave. Moreover the moving type IV burst is not necessarily produced by a magnetic shock, its velocity being nearly the Alfvén velocity in the surrounding plasma (outside the spray). In the same medium the shock wave responsible for the type II burst would have a Mach number greater than 3, but according to Sagdeev (1966) a perpendicular collisionless shock breaks before its Mach number reaches 2. So that it seems necessary to invoke a different shock mechanism than the perpendicular case proposed by Zaitsev (1969) for the generation of type II burst.

The problem is now to study the travelling path of this shock wave through the inner corona; two possible cases are represented on Figure 4(a) and 4(b).

(a) The shock wave would be emitted at the time of the flash-phase, in the explosive center which produces the moving type IV burst (0.25 $R_\odot$ high). Then it would be reflected on high density levels at 11^h50^m to escape outwards with a constant velocity. When passing through the corresponding plasma level at 169 MHz and 111 MHz it would have produced the two peculiarities previously mentioned ($11^h51^m40^s$ UT at 169 MHz).

(b) As pointed out by the amateur solar observer, the spray-type prominence disrupted at 11^h53^m UT. A straight line from the type II burst intersects the moving type IV burst trajectory at that time, so that the shock wave responsible for type II burst may be produced by the spray when it encounters a convenient magnetic structure. This interpretation is plotted on Figure 4(b). In fact the spray disruption may also be produced by the shock wave.

We need further observations to decide between the two possible generations of the shock wave. A very similar radio outburst occurring on the disk has been observed on 1970 March 25; type II and moving type IV burst have still different velocities (ratio about 3), they will be studied in more detail.

Riddle (1970) has recently reported a radio event in which the moving type IV burst is not directly associated with a flare spray, but time delayed. A type II burst occurred in the same time as the optical feature, but its deduced speed is greater than the ascending spray velocity, as in our case. If it is confirmed that type II and moving type IV bursts are associated with expelled chromospheric materials, such as flare sprays, prominence eruptions, or more generally plasma clouds, their radiating parameters could be quite different than in stable coronal conditions.

Acknowledgements

I am grateful to Dr Bruzek who has made available the optical data, to Dr H. Urbarz who sent me his radio spectral observations, and to Drs A. Krüger, M. Greco and Poumeyrol for total flux measurements at 111, 408 and 930 MHz respectively. I thank Dr. M. Pick for helpful discussions.

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Discussion

Sweet: What electron energies are required during the pre-flash phase?

Daigne: Some keV for the noise storm, and may be tens of keV for continuum enhancement 3 mn before the flash phase.

Erratum

The optical observation reported in the Introduction of this paper has to be corrected in the following way (Bruzek, second private communication):

"At 11^h46^m UT it (the spray-type prominence) had the shape of a slightly distorded *Y* or of a fork (with a height of 0.5 $R_\odot$) and was very bright; at 11^h53^m UT the branches of the *Y* were disrupted into at least 3 knots in such a way that the center of gravity does not appear to be lifted much; the brightness was reduced considerably. The stem of the *Y* kept its place and existed at a reduced height and brightness probably at least until 12^h55^m UT. Unfortunately, there was no observation before 11^h46^m and none between 11^h46^m and 11^h53^m UT! Therefore we know virtually nothing about the rate of growth. The only thing we may be sure of is that the upper part of the prominence was disrupted between 11^h46^m and 11^h53^m UT."

I apologize for having built the discussion only on two optical positions; part B of the discussion 'Development of the Flare Phenomena in the Corona' is quite erroneous, also the position of the spray-prominence reported on Figure 4 at two different times.

The main problem would be to know at what time, between 11^h46^m and 11^h53^m, occurs the disruption of the *Y* shape? One possibility is that it occurs at the beginning of the flash phase, seen on the radio emission, between $11^h47^m30^s$ and 11^h48^m UT. In such a case the moving type IV burst, emitted at that time, and from a height of about 0.25 $R_\odot$, would be associated with the spray-type prominence disruption. It is to be noted that the height of 0.25 $R_\odot$ corresponds approximately to the upper part of the stem of the *Y* shape, and this stem remains stable.

There is no evidence to associate the type II burst with the optical phenomena, so that I retain only the first interpretation: the shock wave responsible for type II burst would be seen after reflection on high density levels.

I am grateful to S. F. Smerd, doubtful on the direct association of radio and optical observations; his criticisms enable us to determine precisely the optical phenomena and I thank A. Bruzek very much for it.