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Study of Solar Decimetric Bursts with a pair of Cutoff Frequencies

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Abstract

We compare radio dynamic spectra with images in soft X-rays, 17 GHz microwave, and Hα, for three solar flares. We find that negative drifts of cutoff frequencies in a series of radio decimetric bursts observed in the radio dynamic spectra correspond to plasma cloud ejections seen in the images. By relating the radio frequency drift-rate to a global morphological change in the flare region, namely, a loop expansion caused by plasma cloud ejection, we discuss where the decimetric bursts are produced, in conjunction with a possible flare scenario.

Key words: Sun: Solar flares — Radio decimetric bursts — Plasma ejections

1. Introduction

Solar flares produce various radio emissions over a wide range of frequencies and spatial locations (e.g., Kundu 1965; McLean and Labrum 1985; Bastian, Benz, and Gary 1998). Energetic electrons that precipitate along field lines toward the lower corona produce microwave (or cm-wave) emission, while m-wave emission is generally produced in more extended regions by ascending electrons directed from the upper corona toward interplanetary space. Because decimetric (dm-) wavelengths are intermediate to the m- and cm-wavelength range, it is plausible that dm-sources may be located midway between the m- and cm-emission regions, i.e., in the vicinity of the electron-acceleration region. This suggests that a detailed study of dm-wave bursts may provide a probe of the energy-release region. The origin and emission mechanisms of dm-bursts are, however, still not clear (e.g., Benz, Bernold, and Dennis 1983; Enome and Orwig 1986). Because individual dm-bursts often show fast-drift features, these dm-bursts are generally attributed to a coherent plasma emission, such as type III bursts, but the emission region must be a localized, high-density (10^{9-11} cm^{-3}) region due to the high plasma frequencies.

Recently, Aschwanden and Benz (1995) discussed when and where the coherent emission could be emitted without suffering from strong free-free absorption. They connect negatively-drifting (toward lower frequencies) cutoff frequencies of decimetric narrow-band spikes with an ascending *chromospheric evaporation* front in flare loops. In addition to simple numerical models of possible conditions for decimetric radiation, they analyzed 21 radio dynamic spectra from Phoenix (ETH Zürich) that show negatively-drifting high-frequency cutoffs between 1.1 and 3.0 GHz. The duration of the negative drifts ranged from a few seconds to a few minutes. Because a typical upflow velocity of evaporation plasma (v) is almost the same as the coronal thermal velocity, a few $\times$ 100 km s^{-1}, and a typical half-length of flare loops (l) is a few $\times$ 10^4 km, the upflow time in a single loop (t) is expected to be of order $t = l/v \sim 100$ s. Although longer upflow times can be explained by a sequence of subsequently filled loops (e.g., Hori *et al.* 1997), in that case the upflow would not appear as a smooth drift in dynamic spectra due to differences in density distributions among different loops.

In the following, we look for features on images that correspond to decimetric signatures with a group of narrow-band spikes, by comparing radio dynamic spectra and images taken at different wavelengths for three limb flares.

2. Analysis

Fig.1 shows time profiles of a flare of 1992 October 5. The bottom panel shows an example of drifting cutoff frequencies from Phoenix. The drift starts at 9:24:30 UT, in coincidence with an increase in emission, at which time a plasmoid eruption was observed in soft X-rays with the Soft X-ray Telescope (SXT) on board the Yohkoh spacecraft (see snapshot in the middle panel). A group of decimetric narrow-band spikes with a pair of almost *flat* envelopes is apparent in the preflare phase, when both soft X-ray (from BCS/Yohkoh, top panel) and hard X-ray

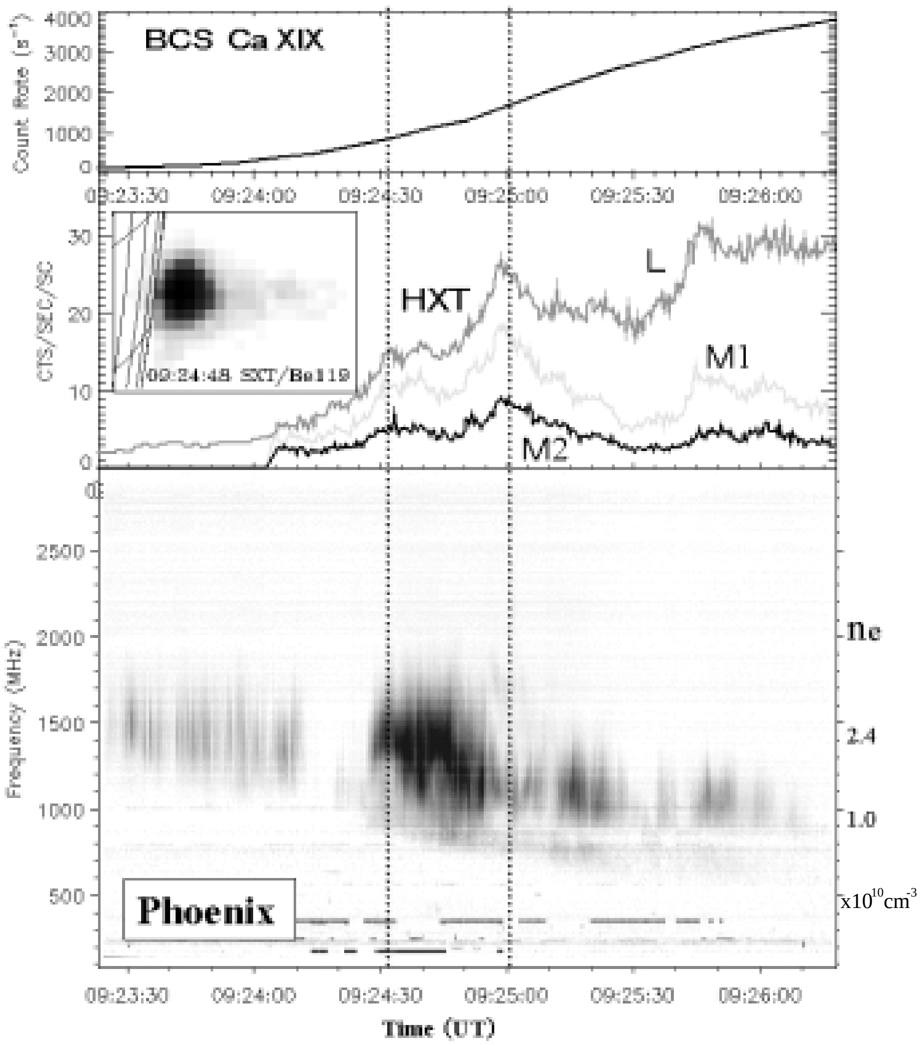

Fig. 1.. The 1992 October 5 flare. ¿From the top panel, light curve of the Ca XIX resonance line from Yohkoh/BCS, hard X-ray count rate from Yohkoh/HXT, and radio dynamic spectrum from Phoenix (ETHZ). The vertical dotted lines represent a time interval when a negative drift in the Phoenix data starts. ¿From Yohkoh/SXT, a soft X-ray image of the flare with a plasmoid ejection is also shown in the middle panel.

(Low channel, from HXT/Yohkoh, middle panel) intensities gradually start to increase. Ohyama and Shibata (1997) analyzed this flare in detail with Yohkoh/SXT and pointed out that not only the plasmoid but also the underlying flare loops expand during the flare. They estimated the electron densities in the plasmoid and the flare loops at 9:25:00 UT to 0.8-1.6 $\times 10^{10}$ cm^{-3} and 1.0-7.7 $\times 10^{10}$ cm^{-3}, respectively. At that time, we find the electron density corresponding to the local plasma frequency for the lower decimetric envelope to be about 1.0 $\times 10^{10}$ cm^{-3}. Thus the intense dm-bursts with the drifting envelopes may be emitted from the location between the moving plasmoid and the flare loops. After 9:25:00 UT, the drift almost disappears, while both the dm-bursts and the plasmoid eruption in the SXT images continue. These temporal relations are suggestive that there is a connection between the decimetric signature of negative drifts and the plasmoid ejection.

In order to further investigate this possible connection, we analyze more decimetric events from broadband (25-2500 MHz) radio dynamic spectra from HiRAS (CRL/Hiraiso). ¿From June 1993 when HiRAS started to operation to June 1998, we found 151 events with dm-bursts. ¿From these we selected three events that meet the following conditions:

1. simultaneously observed by Yohkoh/SXT or Nobeyama Radioheliograph (17 GHz),
2. flare location is at or near the solar limb, and
3. duration of the narrow-band envelope longer than 30 s.

The last requirement is added to take into account the poor time resolution of HiRAS (a few seconds).

Fig.2 shows one of the selected events, a June 28, 1993 flare (Hori 1999). At the peak of hard X-ray intensity in Yohkoh/HXT (01:08UT; second panel), the brightness temperature at 17 GHz from the Nobeyama Radioheliograph (NoRH; third panel) suddenly increases and a plasma cloud is ejected from the flare core (top panel) with a speed $\sim$390 km s^{-1} (fourth panel). The ejection was also observed in both soft X-rays (SXT) and Hα (NAOJ/Mitaka) images. Negative drift-rates in the envelope of dm-bursts appear simultaneously with the ejection (the bottom panel).

One of the other events, a November 12, 1993 flare, was followed by Type II burst. In that event, a faint, blob-like radio source appeared above bright active region loops during the preflare phase. When a pair of negative drifts appeared in the radio dynamic spectrum, the faint source suddenly stretched upward, although no ejection was distinguishable in NoRH images. The third event, a flare on June 12, 1993, had too few SXT images to investigate morphological changes.

3. Discussion and Summary

On the basis of the above analysis, here we discuss where and when dm-bursts are produced. First let us examine the following two assumptions:

1) The nonthermal electron beams that excite coherent plasma emissions (i.e., m- and dm-bursts) are produced by a magnetic reconnection process between coronal magnetic loops. In other words, the fine structure in the decimetric narrow-band may reflect the fine structure of current sheets created in the reconnecting diffusion regions.

2) When successive dm-bursts continue for more than 30s and both upper and lower cutoff frequencies show a pair of negative (from high to low) drift rates, a plasma cloud is ejected at the start of the frequency drift.

If both of the above assumptions are correct, dm-bursts may be produced inside a *prominence cloud* located above or nearby the flaring loops, through which reconnected field lines penetrate (upper panel of Fig. 3).

Because a prominence consists of cooler and denser plasma (e.g., 7000 K and 5 $\times 10^{10}$ cm^{-3}; Schmieder *et al.* 1989) than the surrounding coronal plasma, the free-free absorption coefficient becomes large inside the prominence. We also expect the density scale height at the prominence surface to be much smaller ($<$ 500 km) than its surroundings due to the large density gradient. As a result, the optical depth in the radial direction becomes small inside the prominence. It is thus expected that plasma waves excited by electron beams passing upward and/or downward along the reconnected field lines could easily escape from a *filamentary* prominence, without being absorbed by the surrounding dense plasmas. Then the upper and lower cutoff frequencies in the decimetric narrow-band will be given by the upper and lower limits of the electron densities inside the prominence.

If the prominence cloud is in a (quasi-) static state during the passage of the electron beams, the decimetric narrow-band will have nearly constant upper and lower cutoff frequencies (phase [a] in lower panel of Fig. 3). Due to the existence of the prominence, magnetic reconnection is not very efficient and most of the released magnetic energy is gradually accumulated inside the prominence (Shibata 1998). As a result, the prominence becomes unstable and

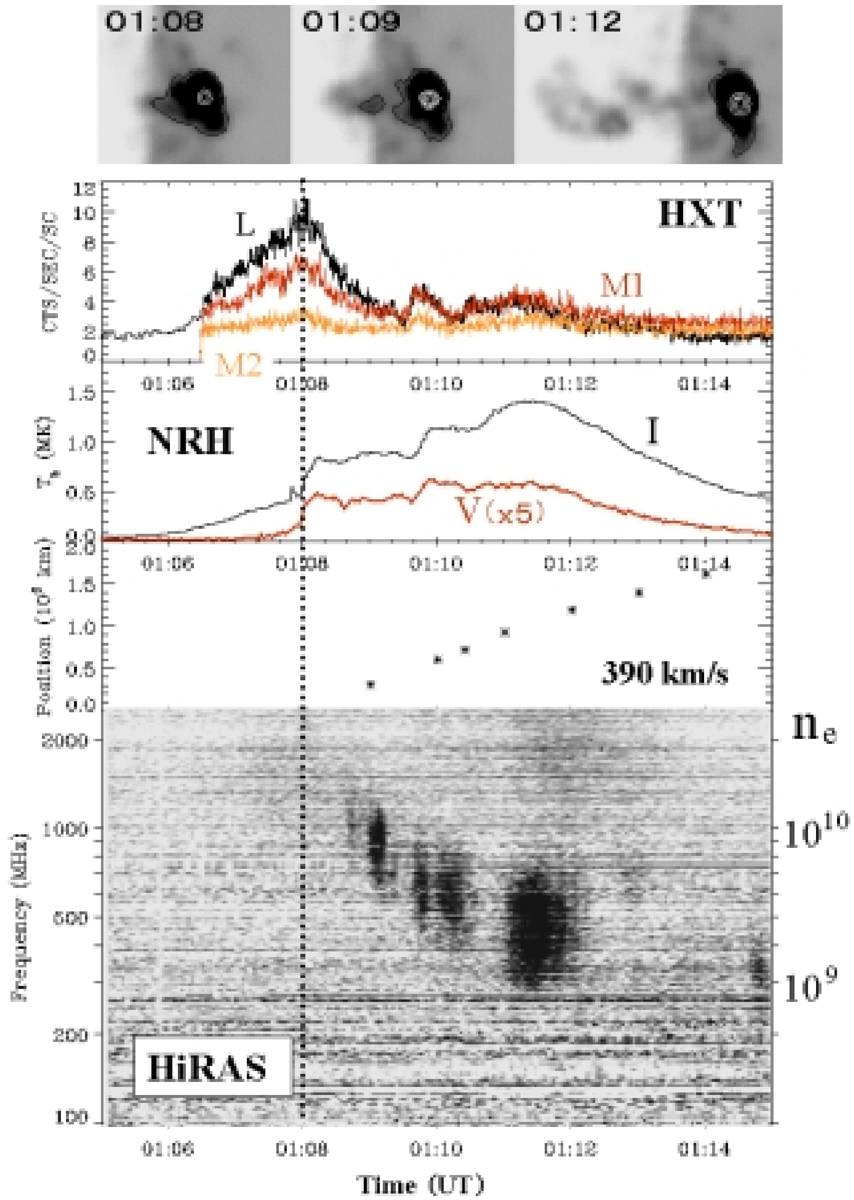

Fig. 2.. The 1993 June 28 flare. ¿From the top panel, snapshots of the flare and prominence eruption at 17 GHz from Nobeyama Radioheliograph (NoRH), hard X-ray count rate from Yohkoh/HXT, time profiles of the maximum brightness temperature at 17 GHz (Stokes I=R+L and V=R-L; NoRH), time evolution of the position of the 17 GHz prominence front measured from the solar east limb (NoRH), and radio dynamic spectrum from HiRAS (CRL/Hiraiso). The vertical dotted line represents the start of the prominence eruption.

starts to move upward. A part of the prominence plasma is lost as an ejection, which results in a sudden increase of the reconnection efficiency, leading to the occurrence of a flare. During this process, accelerated electrons continue to pass through the moving prominence and excite dm-bursts with a pair of negatively drifting cutoffs (phase [b]). After the upward movement, the rest of the prominence becomes (quasi-) stable and remains at the same height against gravity unless cooling occurs (phase [c]).

In summary, we analyzed flare radio decimetric signatures containing a group of fast-drifting substructures lasting longer than 30s. We connected the characteristic negative slopes in the envelope of the decimetric spikes to a global morphological change in the flaring region, specifically, a loop expansion caused by a plasma cloud ejection, rather than the local phenomenon of chromospheric evaporation (Aschwanden and Benz 1995). In fact, individual dm-bursts show both positive and negative fast-drifts in the 1992 October 5 event (Fig. 1), while only positive fast-drifts are expected if the dm-bursts are produced by precipitating electrons as argued by Aschwanden and Benz (1995). In order to verify our supposition regarding emission region of dm-bursts, we are currently continuing this study for decimetric events shorter than 30s.

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References

Aschwanden, M. J., Benz, A. O., Schwartz, R. A. 1993, ApJ 417, 790
Aschwanden, M. J., and Benz, A. O. 1995, ApJ 438, 997
Bastian, T. S., Benz, A. O., and Gary, D. E. 1998, ARAA 36, 131
Benz, A. O., Bernold, T. E. X., and Dennis, B. R. 1983, ApJ 271, 355
Enome, S., and Orwig, L. E. 1986, Nature 321, 421
Hori, K. 1999, Proceedings of 32nd COSPAR meeting, submitted
Hori, K., Yokoyama, T., Kosugi, T., and Shibata, K. 1997, ApJ 489, 426
Kundu, M. R. 1965, Solar Radio Astronomy, New York: Intersciences
McLean, D. J., and Labrum, N.R. (eds.) 1985, Solar Radiophysics., Cambridge: Cambridge Univ. Press.
Ohyama, M. and Shibata, K. 1997, PASJ 49, 249
Schmieder, B. 1989, Dynamic and Structure of Quiescent Solar Prominences, E. R. Priest ed., Kluwer Acad. Pub., p15.
Shibata, K. 1997, Proc. of Workshop on Solar Flares and Related Disturbances, T. Sakurai, E. Sagawa, and M.Akioka (eds.), Hiraiso/CRL

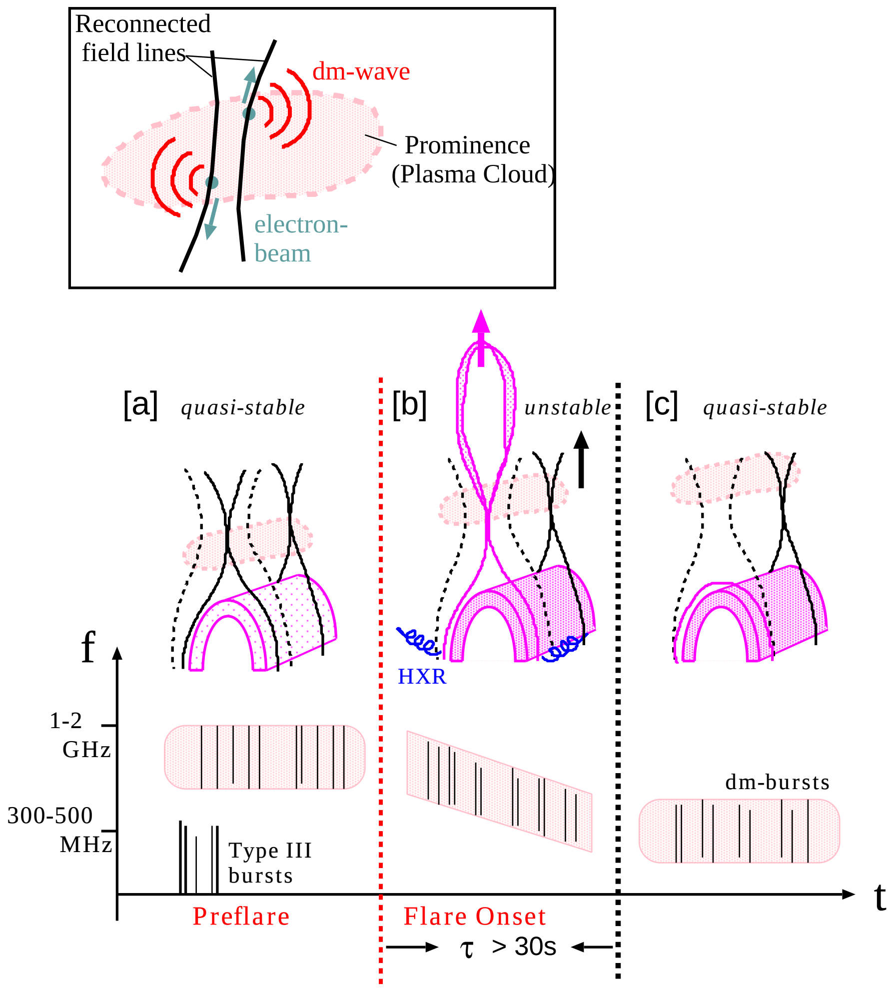

Fig. 3.. A schematic model for the environment of the decimetric radiation. Upper cartoon: emission region of dm-bursts with a fine structure. Bottom cartoon: a model flare scenario relating flare morphology to the evolution of dm-bursts in dynamic spectra.