MORPHOLOGICAL DEVELOPMENT OF GRADUAL NONTHERMAL MICROWAVE FLARES

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Abstract

Provisional results are presented for three gradual microwave bursts. Observations were made with the Nobeyama Radioheliograph at 17 GHz and simultaneously with the Yohkoh /Soft X-ray Telescope with partial coverage in time as well as radiometers at Nobeyama and Toyokawa. 1993 March 23 flare shows a cusp-type structure in soft X-ray images in late phase, where the 17- GHz images show weak emission in gradual phase. This new discovery is explained in terms of a simple model of trapped electrons in a weak field.

1. Introduction

Three gradual microwave bursts, occurred on 1993 February 18, March 23, and May 14, were well observed with the Nobeyama Radioheliograph at 17 GHz. These bursts, known as "gradual microwave/hard X-ray bursts", share common properties which allow us to distinguish them from impulsive flares characterized by smooth time profiles, microwave spectra with broad bandwidth and lower turnover-frequency. Gradual microwave bursts are microwave counterparts of gradual hard X-ray bursts which have properties of delays of high-energy peaks referring to low-energy peaks and energy- dependent spectrum hardening with time (Cliver et al., 1986; Kosugi et al., 1988; Bruggmann et al., 1994). Although a few hard X-ray imaging observations have been reported (e.g., Tsuneta et al., 1984), this is the first two-dimensional and simultaneous imaging observations of gradual microwave/hard X-ray bursts in microwaves and X-rays. In this paper, we present observations of the three gradual microwave bursts, with emphasis on their morphological developments. It is also manifested that this is associated with a new class of acceleration and heating geometry as evidenced by Yohkoh SXT for a long-enduring event (LDE) cusp sources (Tsuneta et al., 1992) and by HXT and SXT for impulsive loop-top cusp sources (Masuda et al., 1994, Kosugi, 1994).

2. Observational Results

The characteristics of the three events are summarized in Table 1.

2.1. The 1993 March 23 event

The H-alpha flare occurred at N18, W78 on the west limb (SGD, September 1993, No.589). The microwave time profile consists of two gradual peaks at 0137.7(the first peak), and 0144.2 UT(the second peak), respectively, as shown by the microwave time profile at 17 GHz in Figure 1 (a). These peaks occur after weak enhancements (pre-flare phase) during 0114 UT and 0135 UT. The microwave gradual burst is preceded by an impulsive burst about one hour before the pre-flare phase. Figure 1 (b) and (c) present microwave images in contours at the first peak (0137:45 UT) and at the valley (0142:30 UT) between the first and second peaks, respectively, overlaid on a soft X-ray image in negative gray scale at 0211:30 UT. No simultaneous soft X-ray observation was available due to the satellite night on Yohkoh. Accuracy of the overlays in this paper is estimated to be better than 5 arcsec. It is clearly seen in each overlay that the global structure of the microwave source is similar to that of the corresponding soft X-ray loop with an extension of about 1 arcmin.

At the first peak, an asymmetric double microwave source is seen, and the brighter source is located at the lower part of the south leg of the soft X- ray loop with an elongated structure along it. The peak brightness temperature is about 2.6×10^6 K, and the polarization degrees are 20% and 5% for the brighter source and the weaker source, respectively. At the valley, a symmetric double microwave structure is seen, and the double sources are located at the higher parts of both legs of the soft X-ray loop. These overlays suggest that accelerated high-energy electrons are distributed along or trapped in the soft X-ray loop. It should be pointed out that the microwave emissions are relatively weak at the brightest top of the soft X-ray loop. A simple explanation for this weak emission is that magnetic fields are low at the loop top. An average magnetic field is estimated by combining the spectral observations with radiometers at Nobeyama and Toyokawa, and the uniform source model of Dulk (1985) due to both relatively low turnover frequency of 4.5 GHz and relatively flat frequency spectral index of 2.3. Non-uniform field models, based on a solenoid coil model (Sakurai and Uchida, 1977), calculated by Choi (1994) show a very strong field dependence of microwave source structure, which explains weak 17-GHz emission at the loop top due to lower magnetic fields compared with foot points. It is also noted that our simple model implicitly assumes the existence of MeV electrons, which radiate microwaves at higher harmonics.

Table 1. Characteristics of the Three Events

	1993 Mar. 23	1993 Feb. 18	1993 May 14
H-alpha			
Site	N18, W78	N14, W02	N20, W48
Imp.	SF	2B	2N
Start	0129	0259	2154
Maximum	0144	0306	2249
End	0222	0406	2436
GOES Class	M2.3	M4.0	M4.4
Microwave at 17 GHz			
Start	0133.6	0259.3	2240.8
Maximum	0137.8	0303.9	2254.2
Duration(min)	50	43	60
Peak Flux	70	80	153

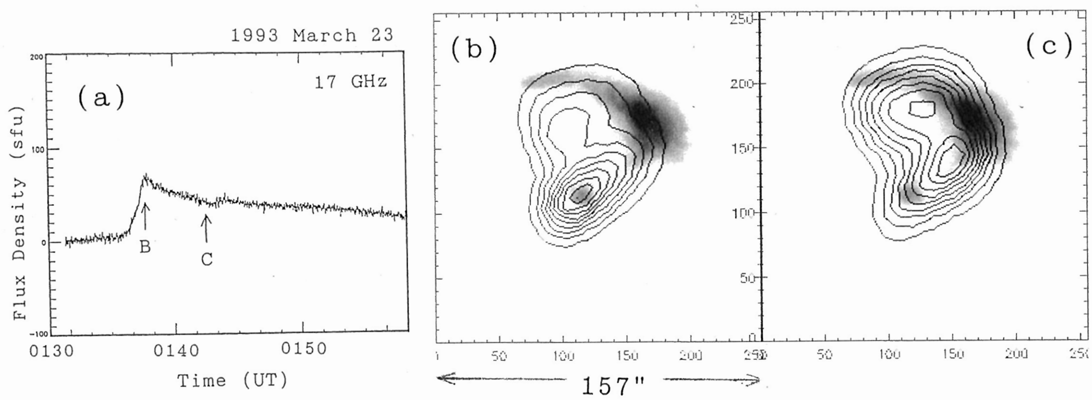

Fig. 1. Panel (a) shows a time profile of 17 GHz microwave emission for the 1993 March 23 event. Panel (b) and (c) shows overlays of the 17 GHz images in contours at the first peak (0137:45 UT indicated by B in the panel (a)) and at the valley (0142:30 UT indicated by C in the panel (a)), respectively, both of which are overlaid on a soft X-ray image (filter: Al12) in black and white (negative form) at 0211:30 UT in the decay phase. The 17 GHz contours are drawn in step of 10% from 10% level of the peak brightness. The solar north is up.

2.2. The 1993 February 18 Event

The H-alpha flare occurred at N14, W02 near the disk center (SGD, August 1993, No.588). Figure 2(a) shows the microwave time profile at 17 GHz. Figures 2 (b) and (c) show 17 GHz images at 0300 UT in the rising phase and at 0304:00 UT at the peak which are shown by arrows in Figure 2 (a). These microwave images are overlaid on the photospheric magnetic field map which was observed around 0302 UT with the Mitaka Flare Telescope, National Astronomical Observatory, Japan. In the rising phase, a slender microwave source with about 1 arcmin in length is seen to extend in the north-south direction. The brightest part of the microwave source is located above the weak N magnetic polarity region on the photosphere. At the peak time, the microwave source becomes much larger and straddles the photospheric magnetic inversion line, covering the slender microwave source in the rising phase. The structural change of the microwave source is explained by transition from a low-lying loop to a possibly overlying arcade-like structure. The peak brightness temperatures of the microwave source in Figure 2 (b) and (c) are 2.2×10^6 K and 3.5×10^6 K, respectively. The polarization degree is about 20% (maximum) both in the rising phase and at the peak time.

2.3. The 1993 May 14 Event

The H-alpha flare occurred at N16, W49 on the western hemisphere. This flare was associated with a prominence eruption around 2200 UT on 1993 May 14. This prominence eruption was observed with the Mitaka Flare Telescope. The soft X-ray eruption corresponding to the prominence eruption was observed from 2200 UT to 2210 UT with the Yohkoh/Soft X- ray Telescope. A weak microwave burst at 17 GHz started at 2203 UT and peaked at 2205 UT with the peak flux density of about 12 sfu at 17 GHz. Fifty minutes later, the more intense, gradual microwave burst started at 2241 UT, as shown in Figure 3 (a). The Nobeyama Radioheliograph observed this gradual burst after 2258 UT, about 4 minutes after the peak time of the microwave emission. Figures 3 (b) and (c) show 17 GHz images at 2258 UT slightly

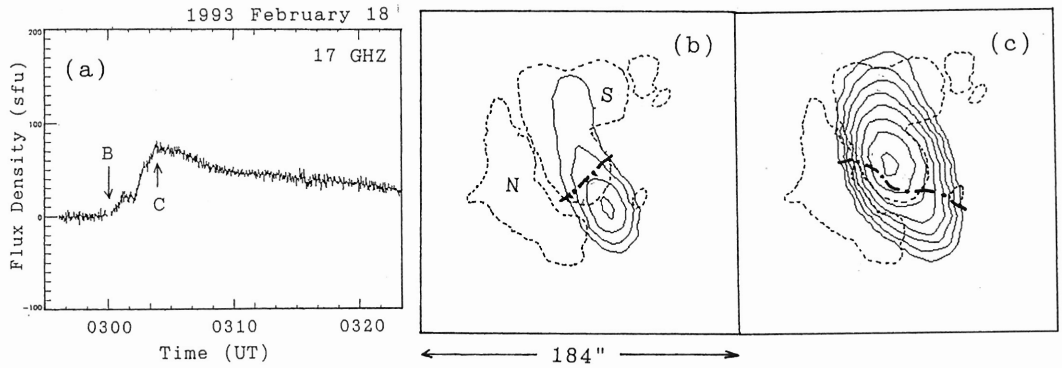

Fig. 2. Panel (a) shows a time profile of 17 GHz microwave emission for the 1993 February 18 event. Panel (b) and (c) shows overlays of the 17 GHz images in thick contours in the rising phase (0300:00 UT indicated by B in the panel (a)) and at the peak (0304:00 UT indicated by C in the panel (a)), respectively, both of which are overlaid on the photospheric magnetic field map (50 Gauss) in dotted lines. The 17 GHz contours are drawn in step of 2 times from 3×10^4 K. Dash-dotted lines show zero- polarization obtained from the microwave polarization maps. The solar north is up.

after the peak time and at 2334 UT in the decay phase, respectively. The 17 GHz emission is confined in a rather small region with $33'' \times 35''$ in size around the peak time. If the centroid of the 17 GHz source is assumed to be just above the photospheric magnetic inversion line, the height of the source is about $20''$. The peak brightness temperature is 2.5×10^6 K at 2258 UT. The polarization degree is about 22% (maximum). In the decay phase, when the thermal emission from hot plasmas dominates over the microwave spectrum, an arcade-like diffuse structure appears along the photospheric magnetic inversion line. Several bright regions, which are seen on both sides of the arcade-like diffuse structure, are interpreted to correspond to legs of loop-like structures embedded in the arcade-like structure. From comparison of the 17 GHz image near the peak time and that in the decay phase, the nonthermal emission observed near the peak time is located at the top of the microwave arcade- like structures seen in the decay phase.

3. Summary

The observational results from the three events are summarized as follows. (1) The microwave nonthermal emission in each event is emitted from a large scale loop or an arcade with about 1 arcmin in size. (2) The gradual bursts are preceded by an impulsive burst in the 1993 March 23 event or by a prominence eruption in the 1993 May 14 event. (3) The microwave source in the 1993 February 18 event develops from a slender loop-like structure in the rising phase to the larger, possibly overlying, arcade-like structure around the peak. (4) Comparison of the 17 GHz images around the peak time and the soft X- ray image in the decay phase, in the 1993 March 23 event, shows that the 17 GHz radiation is emitted along the soft X-ray loop which has a cusp-type loop structure. The cusp-type loop structure and the observed emission measure and temperature distributions along the loop are typical properties of long-duration soft-X-ray flares, in which large-scale magnetic reconnection in a neutral sheet at the loop top has been reported (Tsuneta et al., 1992). The reason why the

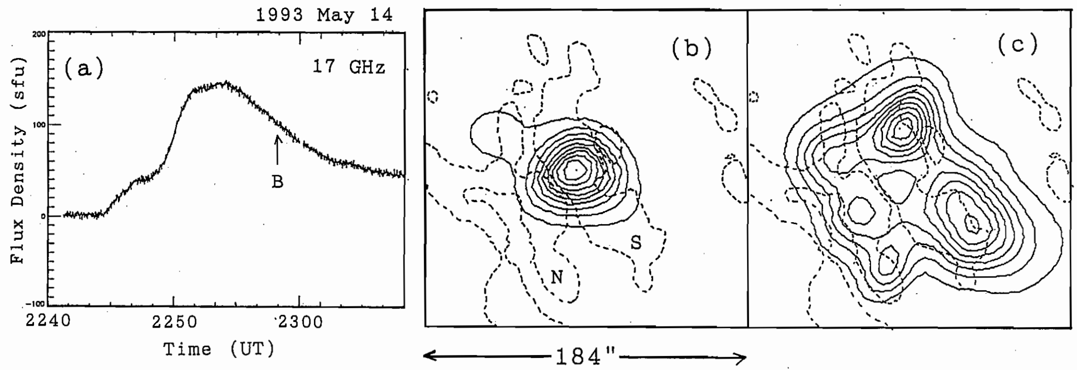

Fig. 3. Panel (a) shows a time profile of 17 GHz microwave emission for the 1993 May 14 event. Panel (b) and (c) shows overlays of the 17 GHz images in thick contours near the peak time (2258 UT indicated by B in the panel (a)) and in the decay phase (2334 UT), respectively, both of which are overlaid on the photospheric magnetic field map (50 Gauss) in dotted lines. The 17 GHz contours are drawn in step of 10% from 10% of the peak brightness. The solar north is up.

17 GHz emission is relatively weak at the brightest top of the soft X-ray loop is explained by weak magnetic field in the reconnection region. The gyrosynchrotron emission is strongly affected by the magnetic field structure (Choi, 1994) as well as strength (Dulk, 1985).

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