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Temporal and Spatial Evolution of Microwave Spikes Observed by Beijing and Nobeyama Observatories

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Abstract

Preliminary results of an analysis of data with high spatial resolution and high temporal resolution are presented for the event of May 14, 1993. Observations were made with the three-channel 10 cm band radiotelescope of the Beijing Astronomical Observatory (BAO) and simultaneously with the Nobeyama Radioheliograph (NoRH) at 17 GHz. The results show that the microwave spike emission was produced in a region with lower brightness temperature, high degree of polarization, high and compact magnetic field and small dimension. The microwave spike emission has a frequency drift rate of more than 30 GHz/s and in X-mode. These results are consistent with the mechanism of electron cyclotron maser (ECM) instability.

Key words: Sun: radio bursts

1. Introduction

Temporal fine structures (FS) in microwave bursts are an important signature for understanding the energy release and particle acceleration in solar flares. Microwave spike emission is a specific type of FS with surprising features. The features of extremely short duration and narrow frequency band imply that their spatial dimension may be small, but unfortunately the instruments with high time resolution are almost all without spatial resolution, or vice versa. There are few reports of spatial information about spike bursts (Gary et al. 1991, Correia et al. 1995, Krucker et al. 1995, and Altyntsev et al. 1998). In these examples, the temporal and spatial evolution of the radio spikes are still unknown, and there is no new idea provided for the mechanism of spike emission.

A special event on May 14, 1993 was selected from the coincident observations with radio spectrometer at BAO and NoRH. Some interesting results of the temporal and the spatial evolution have been revealed. This work gives preliminary results of this first effort to combine these two data sets.

2. Instruments

The NoRH is a 17 GHz radio interferometer dedicated to solar observations. The spatial resolution is $\approx 10''$ and the temporal resolution is 1 s and 50 ms for selected events (Nishio et al. 1994). The data with high temporal resolution presented in this paper were recorded with the 2545-2645-2840 MHz system of BAO. With an IBM 486 computer the 2545-2645-2840 MHz system came into operation in November of 1991 and records in five channels (2545, 2645 MHz: RCP, LCP respectively, and 2840 MHz: I) in continuous sampling mode with a time resolution of 10 msec (it can be switched to 1 msec or 5 msec if necessary). So, some microwave spectral information can be obtained (Fu et al. 1997).

3. The Event of May 14, 1993

Fig. 1 shows the time profiles of the event. It is a long duration event (LDE; Nakajima 1994). The relevant data are listed in Table 1. From Fig. 1 it can be seen clearly that in the descending phase there was a narrow band decimeter (NBD) burst, with RCP converse to the polarization sense of the main burst, superimposed on the LDE. This NBD only appeared on the time profiles between 2.0 GHz and 2.84 GHz, not at 1.0 GHz and 3.75 GHz (Toyokawa fixed frequency data). During the time interval of the NBD, there were a wealth of spike emissions

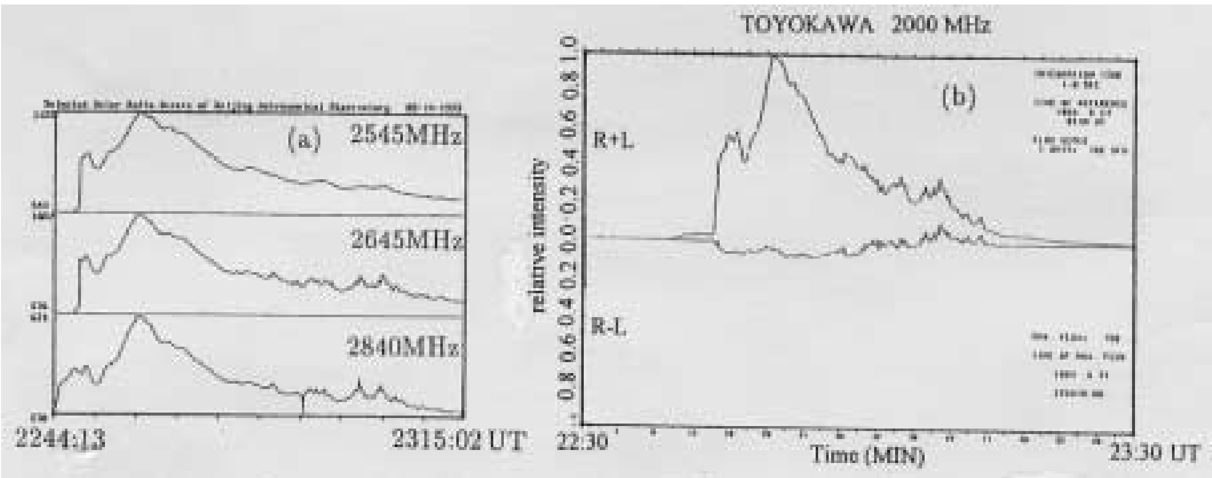

Fig. 1.. The time profiles of the May 14, 1993 event, (a) at 2.545, 2.645 and 2.84GHz (BAO) and (b) at 2.0GHz (TYKW)

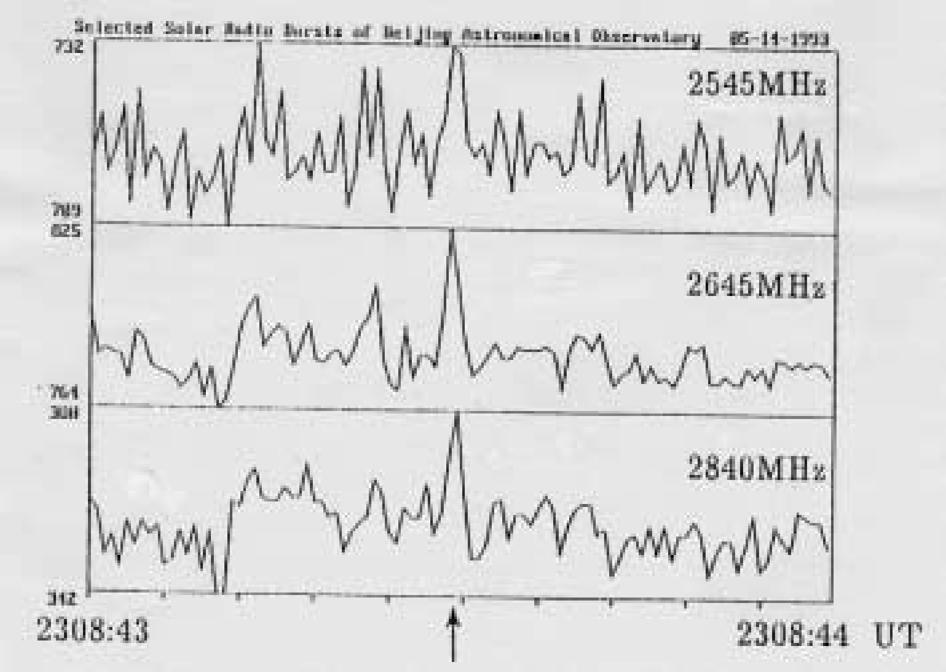

Fig. 2.. The time profile of a section of spike emission. The arrow shows the spike with the frequency drift rate of 30 GHz/s.

occurring in clusters recorded with BAO's instrument (Fig. 2). The microwave spike emission uccurs during a short period of time. The intensity and the duration of individual impulse of spike are about 100 s.f.u. and 20–30 msec, respectively. In crowded groups, there are impulses of 25–30/sec. Some of them show frequency drift rate of 30 GHz/s, although most of them are spectrally unresolved.

4. Identification of the Sources Associated with the Spike Emission at 10 cm Wavelength

Using NoRH data which are available beginning four minutes after the peak time of the burst, from 22:58:00 UT to 23:11:43UT, 822 one-second-maps were synthesized. There are five sub-sources (Fig. 3), and their parameters are listed in Table 2. The $T_{b\,max}$ is the maximum brightness temperature of these sub-sources, ΔS is the flux density,

Table 1..

	Time (UT)			Dur.	Peak flux	Imp.	Pos.	Remark
	start	peak	end	(min)	(s.f.u.)			
H_α	2154	2249	2436			M4.4/2N	N20W48	
17 GHz	2240.8	2254.2		60	153			Nobeyama
2.84 GHz	2239.0	2250.5		> 39	1386			BAO
18–80 MHz	2250		2313			Type II	1200 km/s	Culgoora
	2305		2401			mass ejection		

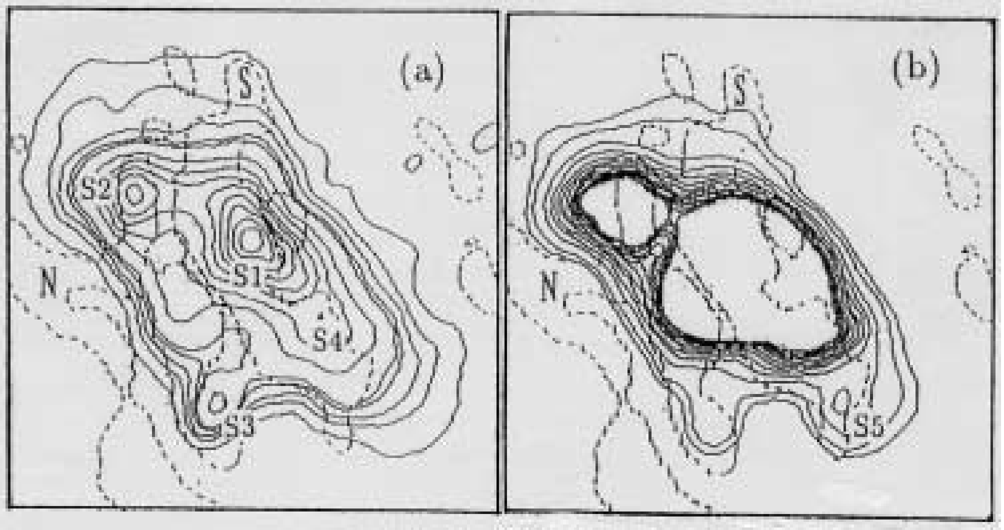

Fig. 3.. The 17GHz images in thick contours overlayed on magnetic field data in dotted contours (a) for S1, S2 S3 and S4 at 23:07 UT and (b) for S5 at 22:58 UT.

Table 2..

Sub-source	S1	S2	S3	S4	S5
$T_{b\ max}$ (10^6 K)	5.4	0.92	0.62	0.3	0.6
ΔS (s.f.u.)	82	13.2	4.4	1.7	3.4
p.d.(%)	23	5.0	78	0	0

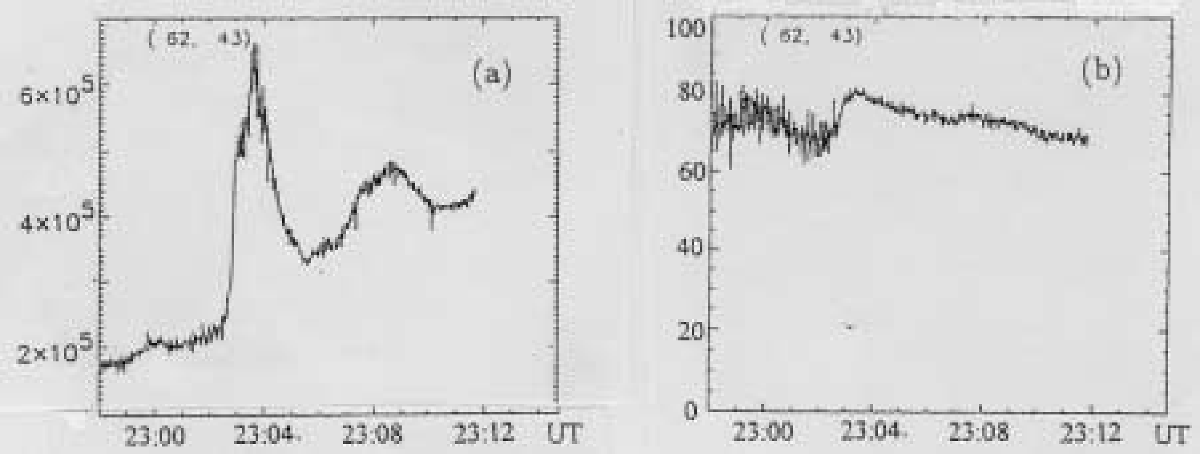

Fig. 4.. The time profiles of the peak S3: (a) brightness temperature (K), (b) polarization degree (percent).

and p.d. is the polarization degree. Figs. 4 consists of the time profiles of flux density (a) and polarization degree (b) of the source S3. From this figure, several interesting features can be pointed out:

1. The source S3 has a peculiar nature of low intensity ($< 6 \times 10^5$ K, about one tenth that of source S1) and of high p.d. ($> 78\%$). There are two peaks (P1 and P2) superimposed on the slower rising burst background. P1 has a half power duration (HPD) of 1.5 min, and the peak time is 23:03:40 UT. P2 has a HPD of about 2 min and the peak time is 23:09:42 UT.

2. Overlaying the radio map on the magnetic field map of Huairou station, it was found that the position of the source S3 overlaps the strong N-plarity with a magnetic field strength of 1600 G. The magnetic field strength at the location of the source S1 is less than 100 G.

3. By plotting the time intervals of the spike emission at 10 cm on the time profile of the source S3 (Fig. 5), it is obvious that the occurrence of the spike emission at 10 cm is around P1 and P2 of the 17 GHz source S3.

4. Rapid fluctuations of the oreder of seconds do not exist in S3 at 17 GHz except for the noise which are due to maily the system noise and the noise introduced in the image restoration process. The source size is not resolved with the NoRH beam.

From the identifications mentioned above, it can be concluded that S3 is the sub-source associated with the NBD, and the spike emission sources are correlated with S3, which has a high polarization degree, strong and compact magnetic field, and small dimension. These properties are in favor for the ECM instability. According to the polarity and polarization sense of the emission from S3, the emission is X-mode. The most probable emission mechanis of 17 GHz S3 source is enhanced gyororesonance emission due to very strong magnetic field above the sunspot.

5. Summary and Discussion

In this paper, spatial information of the narrow band decimetric (NBD) spikes was inferred from the temporal association of the 17 GHz radio source:

1. The position of the 17 GHz source associated with the NBD spikes is different from that of the main source of the burst. In the present case the distance between the two is more than 37 arcsec.

2. The 17 GHz source associated with the NBD spikes has lower brightness temperature (one tenth of the main source of the burst) and has a very high degree of polarization ($> 78\%$) in RCP, opposite to that of the main source of the burst.

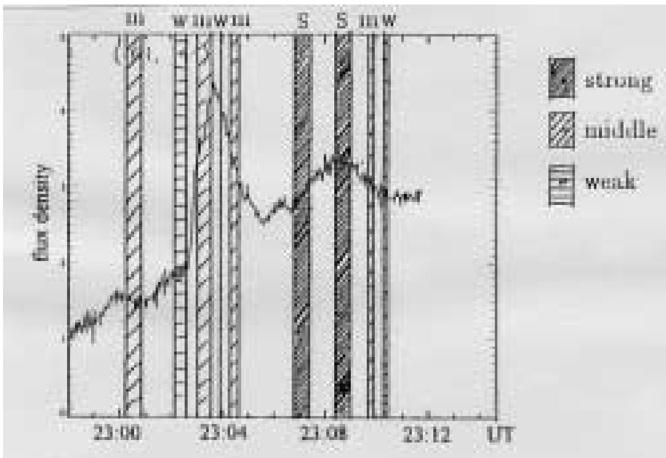

Fig. 5.. The time intervals of the spike emission at 10 cm wavelength superposed on the time profile of the flux density of the source S3.

3. The 17 GHz source associated with the NBD spikes is located on the main N-polarity spot with the magnetic field strength of 1600 G. The spike emission is in the sense of the X-mode.

The most favorable mechanism for microwave spikes in decimetric wavelength is the ECM instability (Melrose and Dulk, 1982), which can amplify electromagnetic waves in a very short time with a very narrow bandwidth due to a resonant wave-particle interaction in velocity space. There are three necessary conditions for this mechanism to operate, all of which are supported by this event. The first one is the presence of energetic electrons. The velocity of the electron beams is estimated as 0.3c by the frequency drift (30GHz/sec) and the height of the sources. The second point is the strongly magnetized plasma, the ratio between the electron plasma and cyclotron frequencies in the spike source is 0.32, which is ten times smaller than the value in the main source. The third condition is the strong convergence of magnetic field, which is inferred from the small size of the radio source and strong magnetic field. The remaining question is whether the evolution of the spikes are due to a quasi-periodic penetration of the electron beam from an acceleration site or a fast avalanche process of the instability as suggested by Lu et al.(1991), which will be studied further by the authors.

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