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Harmonically related decimetric fine structures

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Abstract

We report rare events, above 1000 MHz, in which emission at the fundamental and at second harmonic frequencies show nearly identical fine structures. These high resolution observations are obtained from the Brazilian Solar Radio Spectrograph operating in the frequency range (2150 ± 100) MHz, and the Ondrejov observatory Solar Radio Spectrograph operating in the frequency range of (800–2000) MHz. These bursts have flux values of about 300 s.f.u. and total duration between 100 and 500 ms. The frequency and flux ratios of the harmonically related narrow band bursts varied from 1.76 to 2.29 and 1.28 to 3.57, respectively. The lower observed flux of the fundamental component in comparison to the second harmonic could be due to its higher collisional absorption assuming that the generation mechanism of these bursts is due to the beam plasma interaction. The heights of the acceleration regions estimated from the starting frequencies of the decimetric fine structures are $\leqslant 10^4$ km.

Keywords: Solar flares; Radio radiation; Harmonically related decimetric fine structures; Plasma emission; Acceleration region

1. Introduction

Solar bursts in the decimetric range associated with flares are rich in their frequency and time structures (Fernandes et al., 2001; Sawant et al., 2002). In this paper, we report, we believe for the first time, an event in which the entire fine structure at a fundamental frequency is also seen to at the second harmonic. This has been possible due to the availability of simultaneous observations from the Brazilian Solar Radio Spectrograph (BSRS) and the Ondrejov Solar Radio Spectrograph (OSRS). The harmonically related fine structures observed are of several shapes, including patches, inverted U-type, split pairs, and complex groups of emission patterns. We briefly describe the data acquisition, the analysis and the possible interpretation of the emission structures. The height of the acceleration region is estimated assuming beam plasma interaction to be the generation mechanism of these bursts.

2. Instrumentation

The BSRS is in regular operation at INPE for solar observations since 1998 (Fernandes, 1997; Sawant et al., 2001) in conjunction with a 9-m diameter polar mounted parabolic antenna. During the above mentioned period of the observations BSRS was operating in the frequency range of (2150 ± 100) MHz with time and frequency resolutions of 20 ms and 3 MHz, respectively. The data are recorded in 100 digital channels (Sawant et al., 2000), with absolute timing accuracy of about 3 ms. Thus, the BSRS has the capability to detect fine structures with narrow bandwidth and short durations (Fernandes et al., 2001). The Ondrejov Solar Radio Spectrograph operates

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in the frequency range of (800–2000) MHz with time and frequency resolutions of 100 ms and 10 MHz, respectively (Jiricka et al., 1993). However, it should be noted that for detailed analysis data in the narrow frequency range of (800–1300) MHz has also been used.

3. Data acquisition

High frequency (3 MHz) and time (20 ms) resolution observations were carried out in the frequency range of (2150 ± 100) MHz from August 2001 for about 2 months, totaling nearly 300 h of data, with the BSRS (Sawant et al., 2001). About 30 groups of solar bursts were recorded. Some of them were also recorded by the OSRS. Harmonically related structures such as the split pairs (doublets) and other hitherto unclassified fine structures are reported for the first time at frequencies above 1000 MHz.

4. Observations

On August 22nd, 2001, associated with a sub flare (15:02–15:23 UT) and a C3.7 class X-ray flare (15:02–15:10 UT), a variety of harmonically related fine structures were observed, including split pair bursts, with BSRS and OSRS operating in the frequency range of (2050–2250) MHz and (800–2500) MHz, respectively. Fig. 1 shows the dynamic spectra of the 23 harmonically related fine structures (sequentially numbered in Table 1). Fig. 2 shows the detailed dynamic spectrum of the four structures (nos. 2, 6, 10 and 14). The main characteristics of these fine structures are given below (Table 2).

4.1. Bi-directional structure (~15:13:33 UT) (Fig. 2a)

This burst seems to consist of two components drifting opposite to each other. The sign of the drift rate changes at a frequency of 1093 MHz for the fundamental (OSRS) and 2182 MHz for the harmonic emission (BSRS). The low frequency portion shows frequency drift rate of the order of 250 MHz/s. Narrow band fine structures at the fundamental along with all its details at the harmonic are also observed at ~0.5 s before and after the bidirectional bursts.

4.2. Inverted U-type burst (~15:14:32 UT)

Fig. 2b shows the variation of intensity as a function of the frequency. The turnover frequencies for the fundamental and its harmonic emissions are ~980 and ~2050 MHz, respectively.

4.3. Type V structure (~15:16:02 UT) (Fig. 2c)

A group of fine structures in a "V" shape pattern with the vertices at the high frequency (~2191 MHz) consist of two branches showing both reverse (~300 MHz/s) and normal (~600 MHz/s) frequency drift rates at the harmonic emission.

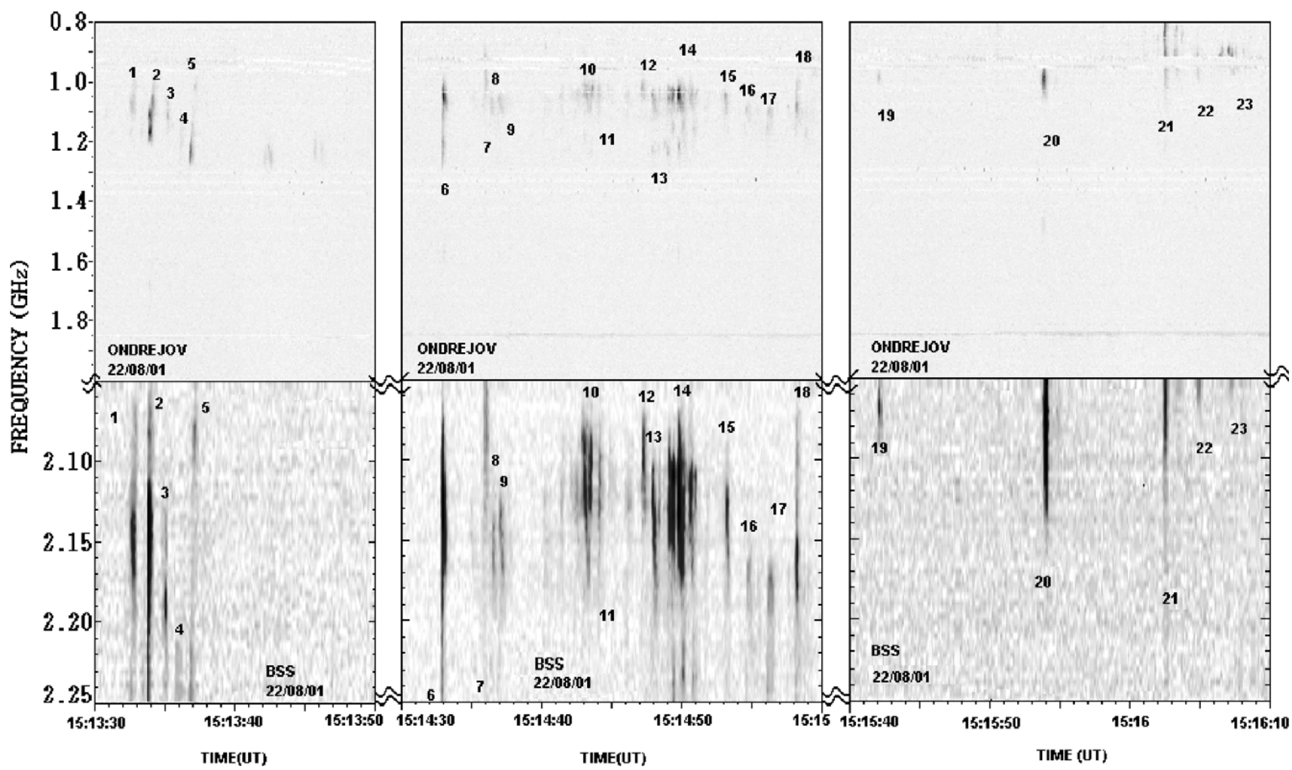

Fig. 1. Varieties of harmonically related bursts observed on August 22nd, 2001 simultaneously by the OSRS (above) and by the BSRS (below).

Table 1
Details of the decimetric fine structures observed on August 22nd, 2001

No.	Start (UT)	End (UT)	OSRS initial–final (MHz)	BSRS initial–final (MHz)	BSRS/OSRS initial frequency ratio	Comments/morphology/ parameters
1	15:13:32.8	15:13:33.0	983–1128	2061–2250	2.10	Weak patch
2	15:13:33.9	15:13:34.2	978–1212	2050[a]–2250	—	Bi-directional burst
3	15:13:35.1	15:13:35.3	1048–1166	2128–2250	2.03	Patch-like
4	15:13:36.1	15:13:36.4	1128–1236	2210–2250	1.96	Weak emission
5	15:13:36.7	15:13:37.4	997–1278	2050[a]–2250	—	
6	15:14:32.8	15:14:33.3	973–1297	2050[a]–2250	—	Inverted "U" type + core
7	15:14:35.6	15:14:36.1	870–1100	2050[a]–2192	—	Weak patch
8	15:14:36.4	15:14:36.6	1048–1114	2118–2199	2.02	Weak quasi-circular patch
9	15:14:36.8	15:14:37.4	1034–1114	2118–2207	2.05	Weak patch RS $df/dt \sim 160$ MHz/s
10	15:14:42.8	15:14:43.7	988–1100	2061–2191	2.09	"V" type (two $\neq df/dt$)
11	15:14:43.9	15:14:44.2	1006–1119	2071–2191	2.06	Very weak patch
12	15:14:47.0	15:14:47.4	988–1067	2070–2140	2.10	Patch
13	15:14:47.7	15:14:48.2	1020–1128	2092–2210	2.05	Patch
14	15:14:48.7	15:14:50.3	983–1105	2070–2250	2.11	Split pair
15	15:14:52.9	15:14:53.3	1034–1114	2080–2192	2.01	Drop patch (irregular)
16	15:14:54.4	15:14:54.7	1067–1152	2090–2199	1.96	Irregular patch
17	15:14:56.0	15:14:56.6	1081–1184	2160–2250	2.00	Irregular patch
18	15:14:57.9	15:14:58.5	983–1184	2065–2250	2.10	Patch
19	15:15:42.0	15:15:42.3	964–1016	2050[a]–2090	—	RS type III-like burst
20	15:15:53.7	15:15:54.2	959–1072	2050[a]–2160	—	RS type III-like burst
21	15:16:02.4	15:16:02.8	800[a]–1062	2050[a]–2220	—	RS type III-like burst
22	15:16:04.6	15:16:05.1	880–1006	2050[a]–2071	—	RS type III-like burst
23	15:16:06.4	15:16:06.9	880–983	2050[a]–2062	—	RS type III-like burst

[a] Initial frequency is out of the range of the observations.

Table 2
Details of harmonically related decimetric fine structures Nos. 2, 6, 10, and 14

No.	Range (MHz)	Fc (MHz)	Δf (MHz)	Flux (s.f.u.)	df/dt (MHz/s)
2					
BSRS	2106–2250X	2182	144	314	$\sim$+250
OSRS	978–1208	1093	230	240	−750
Ratio		2.00	0.63	1.31	
6					
BSRS	2058–2250X	2130	192	445	–
OSRS	978–1297	1138	319	348	−1500
Ratio		1.87	0.60	1.28	
10					
BSRS	2050X–2134	2078	84	334	–
OSRS	800X–1062	931	262	171	−1280
Ratio		2.32	0.32	1.95	
14					
BSRS	2098–2114/2126–2138	2106/2130	16/12	329/309	
OSRS	1025–1114/1212–1241	1070/1226	89/29		
Ratio		1.97/1.74			

4.4. Split pair structures (∼15:14:48 UT) (Fig. 2d)

A group of narrow band fine structures showing intense core with a split in the frequency spectrum.

5. Results

The frequency ratios of the harmonically related fine structures, split pairs and decimetric type III bursts ranged from 1.76 to 2.29, whereas ratios of their fluxes varied from 1.28 to 3.57 except in one case where the ratio is found to be ∼0.98.

From the starting frequencies of the fine structures, in the range of 800–1100 MHz, the height ($h_{\min}$) where the electron beam becomes unstable was estimated, using a density model for the solar atmosphere suggested by Aschwanden and Benz (1995). The minimum altitude above the photosphere ($h_{\min}$) where the beam of energetic electrons becomes unstable is given by (Kane et al., 1982)

$$h_{\min} = h_0 + 1.5 \times 10^4 \alpha\tau (T_e/10^6\ \mathrm{K})^{1/2}\ \mathrm{km},$$

where h_0 is the height of the acceleration site above photosphere, α is the exponent for the electron velocity spectrum,

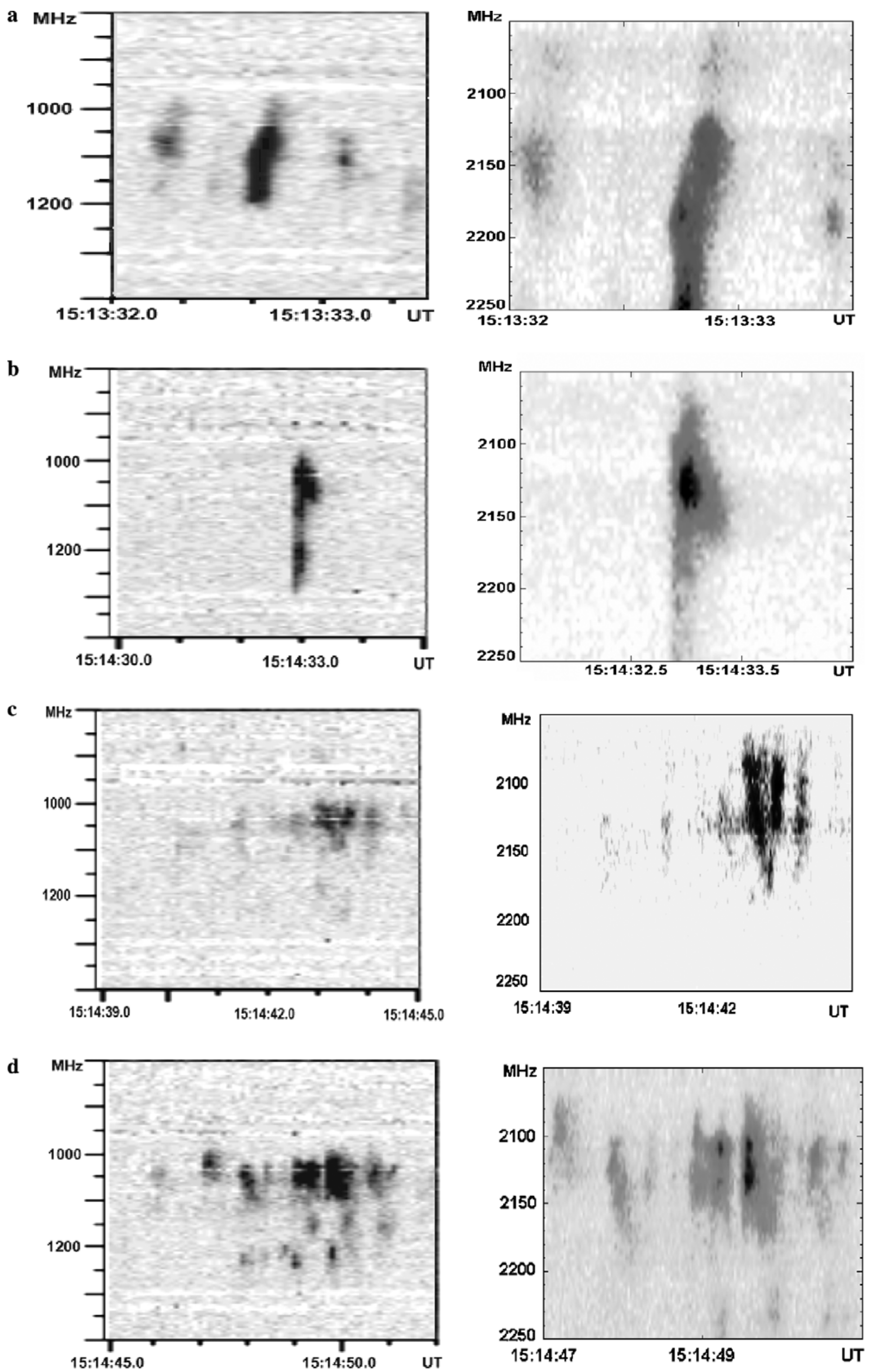

Fig. 2. Detailed dynamic spectra of harmonically related fine structures observed on August 22nd, 2001, simultaneously by OSRS (left-side) and by BSRS (right-side): (a) bi-directional structure (~15:13:33 UT); (b) inverted U-type burst (~15:14:32 UT); (c) "V" shape structures (~15:16:02 UT); (d) split pair structures (~15:14:48 UT).

τ is the characteristic time for acceleration and T_e is the coronal temperature. For the decimetric range we can assume $\alpha\tau \sim 1$ and $T_e \sim 10^6$ K. Then the height above the photosphere for the acceleration site is found to be $\leqslant 10^4$ km.

6. Discussions

We assume beam plasma interaction for generation of the fundamental and the harmonically related bursts. The knowledge of the starting frequency of the fine structure enables us to estimate the height of the acceleration region. The values obtained are $\leqslant 10^4$ km above the photosphere. Early estimates based on different measurements such as the direct detection in X-ray of the signature of accelerated particles (Masuda et al., 1994), stereoscopic multi-spacecraft measurements (Kane et al., 1982), time of flight measurements (Aschwanden et al., 1996), bi-directional electron beam (Aschwanden et al., 1995; Melendez, 1998) and correlated analysis of radio and X-ray emissions (Fernandes et al., 1998) indicated a very wide range of the height of the acceleration source ($\sim$0.5–5 $\times 10^4$ km). The values obtained in this work are comparable with the previous estimations. The observed lower flux values of the fundamental component can be understood due to its more intense absorption. The surprising reproduction of the fine structure of the fundamental at the harmonic is a definite pointer to the role of coherent plasma processes such as the wave–wave interactions in general and four wave interaction processes in particular as suggested by Melrose (1983). Details of the possible mechanisms of generation of these bursts with more observations will be reported elsewhere.

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