Two groups of microwave type U and RS bursts on 15 February 2011

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Abstract

Two groups of microwave type U and reverse-slope (RS) bursts after the soft X-ray (SXR) maximum were observed with the 2.6-3.8 GHz spectrometer of Chinese Solar Broadband Radio Spectrometers (*SBRS*/Huairou) on 15 February 2011. On that day, an X2.2 solar flare occurred in the active region (AR) NOAA 11158. We utilized a shear-driven quadrupolar reconnection (SQR) model to analyze the observed type U and RS bursts and found that the two loops involved are basically in the same spatial scale and have a height difference of about 1300 km. We interpreted these bursts to be a result of a new reconnection process between the two loops.

1. Introduction

Nonthermal radio burst emission was once believed to occur *before* the thermal soft X-ray (SXR) maximum[1, 2]. However, in our observed data, there are some extended nonthermal emissions *after* the SXR maximum, such as the event reported previously by Wang et al. (2001). They suggested that the extended nonthermal radiation was resulted from repeated triggering of a new magnetic reconnection. And the trigger was contributed by both the shear motion of the footpoint and the emerging motion of the small-scale magnetic loop (lower). As well, two groups of type U and reverse-slope (RS) bursts *after* the SXR maximum have been detected on 15 February 2011, which should be caused by the nonthermal emission. They were observed by the 2.6-3.8 GHz spectrometer of Chinese Solar Broadband Radio Spectrometers (*SBRS*/Huairou) during the decay phase of the SXR emission during the X2.2 flare on that day. They are in the time intervals 02:03:00-02:03:35 UT and 02:09:11-02:09:17 UT, respectively.

In this paper, we first presented the observations of the event, then used the shear-driven quadrupolar reconnection (SQR) model to analyze the radiation mechanism of the type U and RS bursts. We found that the magnetic reconnection for this event is triggered by shear motion alone, no emerging motion of the lower magnetic loop found. Finally we summarized in conclusions.

2. Observations

The X2.2 flare on 15 February 2011 occurred in the active region (AR) NOAA 11158. From the SXR emission obtained by *GOES*15 shown as Fig. 1(bottom), the flare started at about 01:46 UT, peaked at 01:56:50 UT, and then decreased monotonically. Morphologically, it was a two-ribbon white-light flare [3].

The *SBRS*/Huairou provide the observational data for solar radio bursts and fine structures at the frequency bands of 2.6-3.8 GHz and 5.2-7.6 GHz. On 15 February 2011, some U and RS bursts were detected after the SXR maximum in the frequency range of 2.6-3.8 GHz with high frequency and temporal resolutions (10 MHz and 8 ms). In Fig. 1 two time profiles at 2.84 GHz and 7.20 GHz were plotted out as examples, in order to present the time-varying tendency of the radio flux in the two frequency bands of 2.6-3.8 GHz and 5.2-7.6 GHz, respectively. It can be seen from the dotted lines in Fig. 1 that after the SXR maximum, the SXR flux and the radio flux in the band of 5.2-7.6 GHz were basically monotonically decreasing, but the radio flux in the band of 2.6-3.8 GHz presented a new increasing, accompanied with complicated fine structures.

We obtained from the 2.6-3.8 GHz radio spectra that the degrees of polarization of group 1 and group 2 were nearly 100% right polarization (RP). As shown in Fig. 2, the top panel is the radio spectra for group 1, the bottom panel for group 2. The horizontal axes of both panels are corresponding to the same time length: 4158 time points chosen, 4158*8 ms = 33264 ms in total. There are four type U bursts and four type RS bursts distinguished clearly from the radio spectra. They are labeled in time

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order. Actually, both of the bursts U2 and U4 can be found to have two successive U-shaped structures respectively (U2(1), U2(2), U4(1) and U4(2)). We extracted the observed characteristic values for the four type U bursts and four type RS bursts in Table 1.

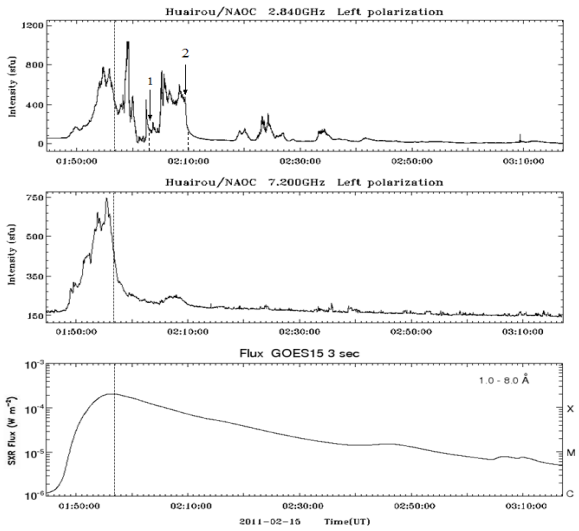

Fig.1 Radio and SXR emissions of the event on 15 February 2011. From top to bottom, the time profiles of the radio emission at 2.84 GHz and 7.20 GHz, and the relevant SXR flux. Between the two vertical dashed lines in the top panel shows an interval during which the type U and RS bursts are found. They are classified into two groups denoted successively as 1 and 2 with two arrows indicating the times when they occurred. The vertical dotted lines in the three panels show the time point of the SXR peak.

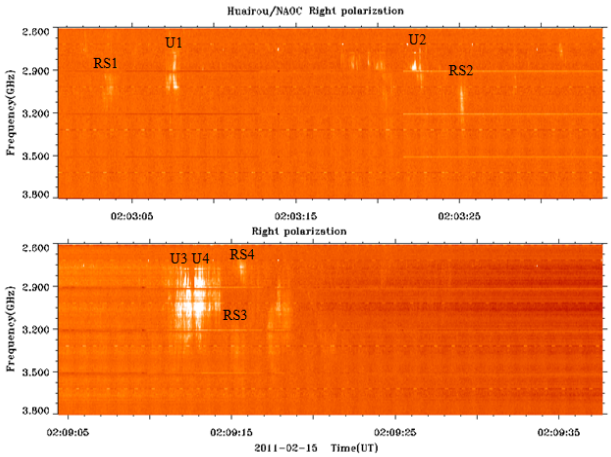

Fig.2 Radio spectra of the two groups of type U and RS bursts shown in RP, both panels in the same time length of about 33 seconds. We have labeled the four type RS bursts and the four type U bursts successively.

According to Table 1, we can obtain the observed characteristics as follows. Firstly, for type U bursts, the value of the mean frequency drift rate of the rising edge is about 1200 MHz/s, and the mean frequency drift rate of the falling edge is about 1600 MHz/s. For type RS bursts, the mean frequency drift rate is about 1600 MHz/s, which is similar to that of the falling edge of type U bursts. Secondly, the mean value of the lowest frequencies of type U bursts is 2765 MHz, while the mean value of the lowest frequencies of type RS bursts is 3035 MHz. The lowest frequencies of the type U bursts are the turnover frequencies of the U-shaped structures. And finally, the mean value of the maximum fluxes of type U bursts is 892 sfu, and the mean value of the maximum fluxes of type RS bursts is 193 sfu. The flux densities of type U bursts are about four times larger than those of type RS bursts.

3. Analysis

3.1 SQR model

We use the SQR model to analyze the radiation mechanism of the observed type U and RS bursts. According to Aschwanden et al. (1999), the SQR model involves two magnetic loops, a large-scale one (higher) and a small-scale one (lower). With the shear motion of the footpoints along the neutral line, the two magnetic loops are getting closer; when close enough, they will undergo a reconnection process. During the process, the two loops exchange the connectivities of opposite magnetic polarities. Finally they become two new disjoint loops. To simplify the model, we consider four magnetic field lines shown as Fig. 3: the two field lines before reconnection are denoted as (L_+, L_-) (large-scale) and (S_+, S_-) (small-scale); the two field lines after reconnection are denoted as (L_+, S_-) (large-scale) and (S_+, L_-) (small-scale). When the footpoints S_- and L_- move along the neutral line, the two magnetic field lines are getting closer until they are into physical contact. A quadrupolar X-type reconnection is thus triggered. The reconnection point, i.e. the X-point, may be near the apex of the small-scale field line (S_+, S_-). The newly configured field lines have reduced curvatures so that the magnetic energy is released [4].

Table.1 The characteristics of the microwave type U and RS bursts on 15 February 2011

Burst type	frequency drift rate of the rising edge (MHz/s)	frequency drift rate of the falling edge (MHz/s)	lowest frequency (MHz)	maximum flux (sfu)
U1	-760	1080	2730	510
U2(1)	-750	880	2760	770
U2(2)	-1560	2290	2760	770
U3	-1280	1490	2780	1100
U4(1)	-1430	2220	2780	1100
U4(2)	-1530	1780	2780	1100
mean value of type U bursts	-1218	1623	2765	892
RS1		1050	2910	170
RS2		1500	3030	300
RS3		1580	3130	170
RS4		2290	3070	130
mean value of type RS bursts		1605	3035	193

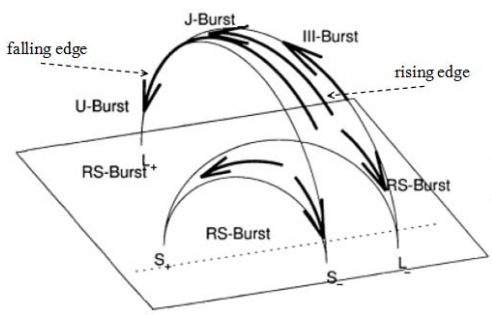

Fig.3 Spatial trajectories of radio bursts in the SQR model [5]. The two arrows in dashed lines are corresponding to the rising edge and falling edge of the type U bursts, respectively.

Near the X-point, the high-energy electron beams generated by the magnetic reconnection will propagate along the field lines in the magnetic loops. They will excite radio emission. Departing from the X-point, upward-propagating electron beams along closed field lines can be detected in the form of type U bursts while downward-propagating electron beams along the field lines can be detected in the form of type RS bursts.

3.2 Theoretic analysis

The spatial scales of the two loops can be compared according to the values of the frequency drift rates: the faster the frequency drifts, the smaller the relevant magnetic loop along which the electrons propagate; the slower the frequency drifts, the larger the relevant magnetic loop. So we can use the mean frequency drift values in Table 1 to compare the spatial scales of the two loops. One can easily

get that the two loops nearly have the same spatial scale. Also for the higher loop, the two sides of the loop corresponding to the rising edge and falling edge have different spatial scales, ratio about 4/3.

The height of the radio source can be estimated by Equation (1) in the assumption that the magnetic field of the active region is a dipole field above the photosphere [5].

$$H = d[(\frac{5.6B_0}{f(\mathrm{MHz})})^{1/3} - 1], \quad (1)$$

where d, the depth of the dipole field, is chosen as 3.5*10^4 km [5], and B_0, the magnetic field strength of the photosphere, can be chosen as 1000 G for this event [6]. By using the mean value of the turnover frequencies of type U bursts of 2765 MHz, and the mean value of the lowest frequencies of type RS bursts of 3035 MHz, we can obtain that the top heights of the two loops are about 9300 km and 8000 km, respectively. The height difference of the tops of the two loops is about 1300 km.

In our case, upward propagating electron beams can be detected by type U bursts, and downward beams by type RS bursts. Generally, the higher the altitude, the lower the magnetic field strength and the thinner the ambient density. So when the accelerated electrons are propagating upwards, it is easier for the emissions to escape. Therefore the flux density of type U burst should be stronger than that of type RS burst. As is shown in Table 1, the flux densities of type U bursts are some four times larger than those of type RS bursts.

4. Conclusions

Three conclusions can be drawn from the present study. Firstly, the two loops involved have basically the same spatial scale. For the higher loop, the one side corresponding to the rising edge is larger in size than the other side corresponding to the falling edge, with ratio 4/3. Secondly, the top height of the loop (higher) corresponding to type U bursts is about 9300 km and the top height of the loop (lower) corresponding to type RS bursts is about 8000 km, about 1300 km in difference. Thirdly, type U bursts have flux densities about four times larger than type RS bursts do.

Considering there is no spatial resolution in spectra observations, our next study will focus on identifying where the sources of these observed type U and RS bursts are.

5. Acknowledgments

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