Hinode-3: The 3rd Hinode Science Meeting
ASP Conference Series, Vol. 454
T. Sekii, T. Watanabe, and T. Sakurai eds.

Survey of Accelerated Particles in a Solar Active Region Using Hinode/XRT and Ground-Based Type-I Radio Burst Observations

Kazumasa Iwai,[1] Hiroaki Misawa,[1] Fuminori Tsuchiya,[1] Akira Morioka,[1] Satoshi Masuda,[2] and Yoshizumi Miyoshi[2]

[1]*Planetary Plasma and Atmospheric Research Center, Tohoku University*

[2]*Solar-Terrestrial Environment Laboratory, Nagoya University*

Abstract. The relationships between solar radio type-I bursts and soft X-ray activities were investigated using Hinode/XRT and a ground-based radio telescope belonging to Tohoku University. Although a type-I burst is thought to be generated by high energy non-thermal electrons in the solar corona, the counterpart of this radio burst in X-rays or EUV have yet to be identified. In this study, we found some small scale soft X-ray activities on the XRT images around the onset time of the type-I burst when 10 percent of the soft X-ray flux enhancement around the onset time of the radio burst is defined as a burst-related activity. However, the causal relationship between the observed soft X-ray activities and the onset of the type-I burst are unclear, and more simultaneous observations of radio bursts and X-rays are needed to investigate the coronal counterpart of the type-I burst.

1. Introduction

Type-I is one of the solar radio phenomena that has been frequently observed in the metric range. It has generally been believed that non-thermal electrons generated through some physical process are trapped in a closed magnetic field and generate Langmuir waves. Then, the Langmuir waves are converted into O-mode radio waves and finally observed as type-I (Benz & Wentzel 1981). The flux density of type-I is weak compared to other solar radio bursts (Elgaroy 1977), and therefore, it is believed that the emission is caused by some small scale particle acceleration processes in the solar corona. However, the acceleration processes of the non-thermal electrons are not yet fully understood. One of the major reasons is a lack of coronal phenomena that are associated with the appearance of a type-I burst (Krucker et al. 1995). Bentley et al. (2000) and Wilson (2005) tried to detect the coronal counterpart of a type-I burst using magnetograms and EUV images. However, not enough information was collected in these studies to find a definite correlation between them.

Some non-thermal electrons can reach the chromosphere and could enhance soft X-ray or EUV flux through chromospheric evaporation (Aschwanden 2006). The X-ray Telescope (XRT) onboard the Hinode spacecraft has the highest spatial resolution in the soft X-ray wavelength range and it is an efficient tool for investigating small scale solar soft X-ray phenomena. Thus, we investigated the relationships between type-I observed by using ground-based radio telescope and soft X-ray activities observed by the Hinode spacecraft for this study.

2. Observations

Iitate Planetary Radio Telescope (IPRT) was used to observe type-I. The IPRT is a ground-based radio telescope developed by Tohoku University (Misawa et al. 2003; Tsuchiya et al. 2009). The physical aperture of IPRT is 1023 square meters, so it realize very high-sensitivity observations. The solar radio observation system in IPRT allows for continuous spectral observations of the Sun within a frequency range of 230 to 400 MHz. The time and frequency resolutions are 270 ms and 1 MHz, respectively. The minimum detectable sensitivity of this system is better than 1 Solar Flux Unit in the meter wavelength range. An IPRT observation was carried out from December 2006 to January 2007.

The data from the X-ray Telescope (XRT) onboard the Hinode spacecraft are used to identify the solar soft X-ray phenomena associated with radio bursts. During the IPRT observation period, XRT mainly observed the active region NOAA 10933, which was expected to be a source region of radio bursts. XRT observed the active region using only an Al-Poly filter at an exposure time of 0.1-0.5 s. The images were recorded every 60 s during the observation time. IPRT and XRT made simultaneous observations for 1-3 hours a day.

3. Results

During the observation period, type-I bursts started to be observed when the active region NOAA 10933 appeared in the eastern limb. The burst activity was highest when that active region passed the central meridian. The radio burst ceased when the active region went down into the western limb. These results indicate that type-I bursts emitted from this active region. Figure 1 (c) shows the radio dynamic spectrum observed by using IPRT on January 11. A clear onset of type-I bursts was observed at 1:40 and 3:13 UT. Figure 1 (a) shows the full disc image of the Sun observed by using XRT on the same day. The active region NOAA 10933 is located around the eastern limb (surrounded by a blue box). The region inside the blue box is divided into a 16×16 pixel square area. Then, the light curves of each area are obtained. We define a burst-related activity as 10 percent of a soft X-ray flux enhancement within 10 minutes of the onset of radio bursts. Figures 1 (b1) and (b2) show the soft X-ray images of the active region when the type-I onsets were observed. The regions which showed burst-related activity are shown by the red squares. Figures 1 (d1) - (d7) show the light curves of some of the selected regions that showed the burst-related activity.

At the first onset (01:40 UT), there were two areas that showed burst-related activity. If non-thermal electrons, which excite radio bursts, cause the soft X-ray enhancement, the soft X-ray enhancement should start almost simultaneously with or after the radio bursts. The X-ray flux in the (d1) region is, however, concluded not to relate to the radio burst since it was enhanced before the radio burst onset. The X-ray flux in the (d2) region was detected as a burst-related activity in this analysis, but it is difficult to find significant activity from the noise of the light curve. In the second onset (03:13 UT), there were several areas that showed burst-related activity. In some areas, for example in (d4) or (d5), X-ray enhanced almost simultaneously with the onset of the radio burst although there remains some ambiguity in distinguishing burst-related activity from accidental coincidences.

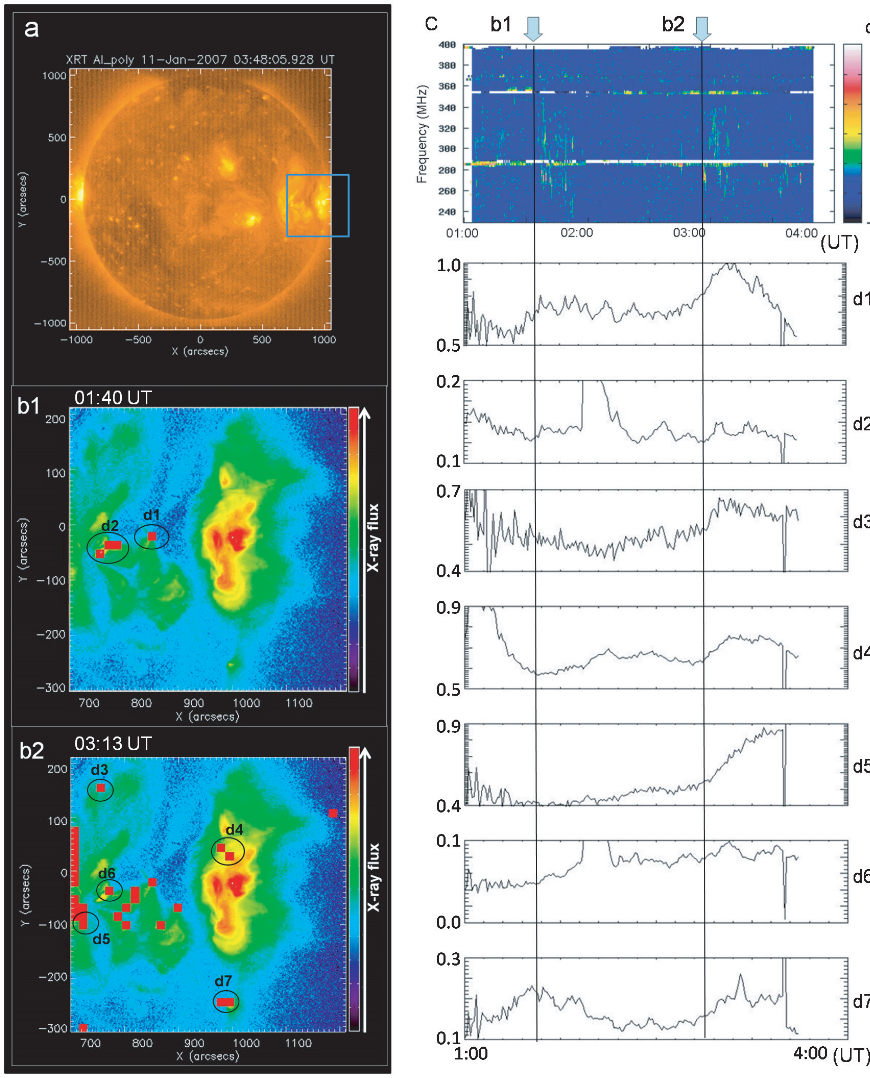

Figure 1. (a) Full disc image of the Sun observed by XRT on January 11. (b1-b2) Soft X-ray images around the NOAA 10933 region at radio burst onset times. (c) Radio dynamic spectrum observed by IPRT on January 11. (d1- d7) Light curves of areas showing burst-related activity. The intensities of these light curves are individually normalized, so absolute values have no meaning.

4. Summary and Discussion

We investigated the relationships between solar radio type-I bursts and soft X-ray activities. We found some small scale soft X-ray activities around the onset of the type-I burst although some ambiguity still remains for concluding that there are cause-and-effect relationships between them. Simultaneous observations of radio and X-ray were too short to analyze the onsets of the radio burst in detail in this study. In addition, the following two points should also be discussed.

First, there is the possibility that high energy particles didn't reach the chromosphere. If high energy particles propagate only into the interplanetary space, they could excite radio bursts without the presence of soft X-ray emission. Note that type-I is correlated with a micro type-III storm, suggesting that high energy particles propagate to the interplanetary space (Bougeret, Fainberg, & Stone 1984). XRT can be used to observe the temperature distribution of the corona using two filters, and a change in the temperature distribution may occur in the particle acceleration region regardless of the accelerated direction of the particles. Unfortunately, temperature information is not available from the data set of this study.

Second, during the observation period, type-I bursts were observed at around 230-300 MHz, which is almost the lower limit of the observational frequency range of IPRT. In fact, type-I is usually emitted more frequently around 100-200 MHz (Elgaroy 1977). It might be suggested that the frequencies of type-I bursts are too low to be detected by using IPRT.

As future work, more simultaneous observations of radio and soft X-ray are required. Our Hinode observation proposal (HOP129) will start soon. The time variation in the temperature distribution will be available in this observation. The radio observation system in IPRT has also recently been improved. This system enables us to observe lower frequencies than the previous system. The collaboration of these facilities will provide useful data to investigate the coronal counterpart phenomena of a type-I burst.

Acknowledgments. Hinode is a Japanese mission developed and launched by ISAS/JAXA, with NAOJ as domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and NSC (Norway). This work was carried out by the joint research program of the Solar-Terrestrial Environment Laboratory, Nagoya University. This work was supported by JSPS Research Fellowships for Young Scientists.

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