Preflare Nonthermal Emission Observed in Microwaves and Hard X-Rays

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ABSTRACT
We present a detailed examination on the nonthermal emissions during the preflare phase of the large X4.8 solar flare which occurred on 2002 July 23. The microwave data obtained with Nobeyama Radioheliograph, at Nobeyama Solar Radio Observatory, NAOJ, and the hard X-ray data taken with *Reuven Ramaty High Energy Solar Spectroscopic Imager* obviously showed nonthermal features. We found a faint ejection associated with the flare in the EUV images taken with the *Transition Region and Coronal Explorer*. Then, we examined the temporal, spatial, and spectroscopic features on the emission sources, and found the loop-top sources during the preflare phase both in hard X-rays and in microwaves.

Key words: Sun: corona — Sun: flares — Sun: particle acceleration

1 INTRODUCTION

Nonthermal emissions from accelerated particles are often observed in hard X-rays (HXRs), γ-rays, and microwaves at the beginning of a solar flare. These nonthermal emissions are associated with strong energy release processes, which characterize the “impulsive phase” of a flare. As Benz & Grigis (2003) reported recently, nonthermal emissions are associated with even a small energy release such as a microflare. However, it has been thought that the particle acceleration works efficiently only in the impulsive phase. On the other hand, in the preflare stage we sometimes find flare-predictive phenomena, such as a gradual enhancement of soft X-ray (SXR) emission, rise of SXR plasmoids and/or Hα filaments, and so on. Even in the preflare stage, some energy release process is probably occurring at a low level, although the energy release is much milder. It has not been widely accepted that nonthermal particles are present in significant numbers prior to the impulsive phase of a flare, rather it has been common to speak of preflare heating implying thermal behavior.

Recently, Holman et al. (2003) examined the HXRs features of the large X4.8 flare which occurred on 2002 July 23, and reported that the nonthermal energy even before the impulsive phase was quite large. The flare showed many spectacular features in HXR and γ-ray wavelengths obtained with the *Reuven Ramaty High Energy Solar Spectroscopic Imager* (*RHESSI*: Lin et al. 2002), and was also observed in microwaves with the Nobeyama Radioheliograph (NoRH: Nakajima et al. 1994) as reported by White et al. (2003). Motivated by the work, we analyzed the flare, and found sufficient emissions both in HXRs and in microwaves that can be candidates for nonthermal emissions during the preflare phase. Especially, this is the first time of imaging observation of the preflare nonthermal emission in microwave. In order to derive information on the energy release in the preflare phase, we examined in detail the features of the emission sources spatially, temporally, and spectroscopically. In this paper we focus on the nonthermal emissions in the preflare phase, from about 23:00 UT, 2002 July 22 to about 00:30 UT, 2002 July 23. We divide the preflare phase into four sub-phases, and examine each phase in more detail.

2 RESULTS

- **Phase I; before the flare**

The first phase corresponds to the time from about 23:30 UT, 2002 July 22 to 00:16 UT, 2002 July 23. We can see a large loop-like bright region in the NoRH image (White et al. 2003). The *GOES* temperature also shows the existence of hot plasma of about 5 MK in this phase. We measured the spectral index α of the emission source, and found that it is about 0 (within from -0.4 to 0.6). Therefore, the optically-thin (free-free) thermal emission is dominant for the source. Moreover, the polarization of the sources is no more than 10 %, which eliminates the possibility of the emission from the gyroresonance near sunspot umbrae. Threfore, we suggest that the large loop-like structure with high temperature, like a sigmoid, exists in this phase.

- **Phase II; preflare phase**

The second phase includes the first flare emissions (from

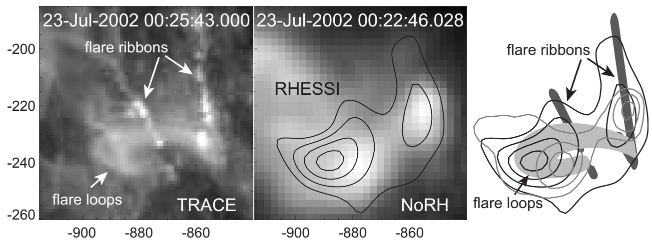

Figure 1. Spatial distribution of the emission sources. The left panel shows EUV image taken with *TRACE* 195 Å. The image in the middle panel and the *gray* counter in the right panel show the NoRH 34 GHz brightness temperature, and the *black* counters in the middle and the right panels are the *RHESSI* 25 - 40 keV intensity. The right panel also shows the positions of the flare ribbons (*dark gray* regions) and the flare loops (*light gray*).

00:16 UT to 00:23 UT). We can see some thermal emission features and also clear signatures of nonthermal emission. The *GOES* temperature rapidly increases from about 4.5 MK at 00:15 UT to above 10 MK at 00:22 UT. At the same time, the *RHESSI* count rate in 12 - 25 keV increases. Such HXR brightenings in lower energy bands, associated with a hotter *GOES* source, are often observed in a preflare phase, and the emissions are thought to be thermal. Holman et al. (2003) performed a spectroscopic analysis of the flare with *RHESSI* data, and reported that the thermal component of the region has high temperature up to 20 - 30 MK.

Figure 1 shows the images of the phase, although the *TRACE* EUV images in the left and the middle panels were taken a few minutes after this phase. In the *TRACE* images, we can see that a large two-ribbon structure brightens from 00:20 UT. We can also see a diffuse loop-like structure that is identified as Fe XXIV emission from 20 MK plasma, as is often observed in *TRACE* 195 Å images during flares. A new microwave source appears above the flare ribbons at (−878, −243) arcsec heliocentric. This site corresponds to the post flare loops, which become visible in the later phase in the *TRACE* images and which connect the flare ribbons. The α index is about −3.0, which implies that this source is emitting nonthermal-gyrosynchrotron radiation. The index is quite small and shows a steep (soft) power-law spectrum. An HXR source also appears at this site, although apparently higher (−890, −240) than the microwave emission source. The HXR source is visible in both 12 - 25 keV and 25 - 40 keV bands. These sources could resemble to the "loop-top" HXR source (Masuda et al. 1994). On the other hand, we can also see footpoint sources which are located on the *TRACE* flare ribbons mentioned above both in the microwave (34 GHz) and in the HXRs (12 - 25, 25 - 40 keV). The energy release probably occurs in the corona, some part of which is deposited at the footpoints to produce the EUV brightenings. The HXR emissions from the flare ribbon are thought to be generated by thick-target emission by nonthermal electrons. This is evidence for the existence of the nonthermal particles in this phase.

- **Phase III; ejection**

Third, we focus on the small microwave burst and the faint EUV ejection which occurred at about 00:23:30 UT. We found that the timing of the EUV ejection corresponds to the nonthermal microwave emission. The combination of ejections and HXR bursts has been often observed in impulsive flares (e.g. Kano 1994). The NoRH 34 GHz source moved northward slightly (−875,−230), and showed a loop like structure. This loop structure corresponds to the most intense post-flare loop which appeared later in the *TRACE* 195 Å images. The HXR *RHESSI* 12 - 25 keV and 25 - 40 keV emissions still appear at the top of the NoRH loop. Although the source positions moved northward as to the 34 GHz emission, they cannot be identified because of limitations of the spatial resolution.

- **Phase IV; impulsive phase**

The fourth phase corresponds to the time after the *TRACE* ejection and before the start of the impulsive phase (from 00:24 UT to 00:27 UT). Roughly speaking, the physical features are the same as in the impulsive phase, as Krucker, Hurford & Lin (2003) reported. The positions of the emission sources do not change so much from the previous phase. The HXR coronal sources ascend slightly as the flare progresses. The 34 GHz emission comes to localize gradually on the upper section of the loop. As a notable result, we can see an HXR loop-top source even in 40 - 60 keV as shown in the bottom left panel of Figure 2. In this phase, the α index increases slightly (becomes harder) to about −1.5.

3 DISCUSSION AND SUMMARY

We examined in detail the nonthermal emissions in the preflare phase, and also examined the relation between the nonthermal emissions and other observed phenomena. We identified a faint EUV ejection in the *TRACE* data which was associated with a nonthermal microwave burst, just before the fast energy release process occurs in the impulsive phase. In the phase before the ejection, we found observational evidence of both thermal and nonthermal emissions in the corona above the flare ribbon structure. Our results suggest that energy release mechanism in the preflare phase of a typical flare may be accompanied by particle acceleration, although it is much milder than that in the impulsive phase and therefore difficult to detect in flares smaller than this event.

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