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Flare Onset Observed with *Hinode* in the 2006 December 13 Flare

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Abstract. We present a detailed examination of the preflare phenomena of the X3.4 flare that occurred on 2006 December 13. This flare was associated with a faint arc-shaped ejection, which is thought to be an MHD fast-mode shock wave, seen in the soft X-ray images taken with the *Hinode* X-Ray Telescope (XRT), just at the start of the impulsive phase of the flare. Even before the ejection, we found many preflare features, such as an S-shaped brightening (sigmoid) with XRT, chromospheric brightening at the footpoints of the sigmoid loops with the Solar Optical Telescope (SOT), a faint X-ray eruption with XRT, and so on. The EUV Imaging Spectrometer (EIS) also observed the flare, and therefore, enabled us to examine the spectroscopic features. We discuss these phenomena and the energy release prosses.

1. Flare Obserview

The intense solar flare, which was X3.4 on the GOES scale, occurred on 2006 December 13, in the NOAA active region 10930 (S06°, W22°). Figure 1 shows the light curves of the flare in soft X-rays taken by GOES and in microwaves taken by Nobeyama Radio Polarimeters (NoRP). This flare is one of the largest flares observed with *Hinode*, and therefore, has been extensively studied.

The intense gyrosynchrotron emission from nonthermal electrons observed in microwaves becomes dominant after 02:22 UT, that is, the impulsive phase of the flare started at the time. As we reported in the previous paper Asai et al. (2008), we found a blueshifted phenomenon with the EUV Imaging Spectrometer (EIS) on board *Hinode* just at the beginning of the impulsive phase of the flare. The blueshifted phenomenon was further associated with a faint arc-shaped ejection seen in the soft X-ray images observed with the X-Ray Telescope (XRT) of *Hinode*. This ejection is thought to be an MHD fast-mode shock wave. On the other hand, the start time of the flare is recored as 02:14 UT in the GOES X-ray intensity (see Fig. 1), and we observed many preflare and/or flare onset

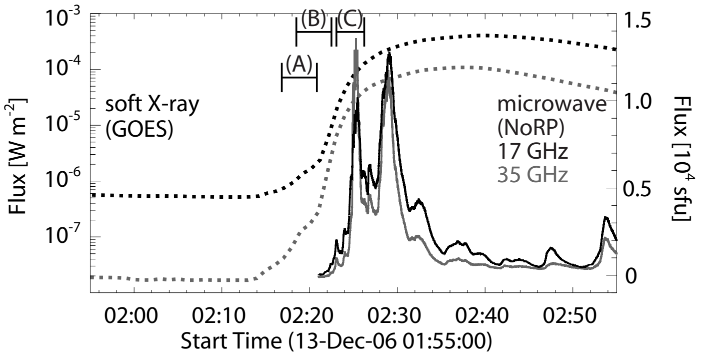


Figure 1. Lightcurves of the 2006 December 13 flare. Soft X-ray fluxes obtained by GOES are shown with the dotted lines, and microwave fluxes observed at 17 GHz (*black*) and 35 GHz (*gray*) by NoRP are shown with the solid lines.

phenomena even before the start of the impulsive phase. In this paper, we focus on such preflare phenomena.

First, from 02:16 to 02:20 UT (time range A in Fig. 1), we can identify an inverse S-shaped X-ray brightening (sigmoid) in the XRT (the middle panel of Fig. 2). In the chromospheric Ca II line image taken with SOT shows brightenings at both ends of the sigmoid loop (the left panel of Fig. 2). These features, such as positions and structure, are stable during the time range, and no notable changes are seen.

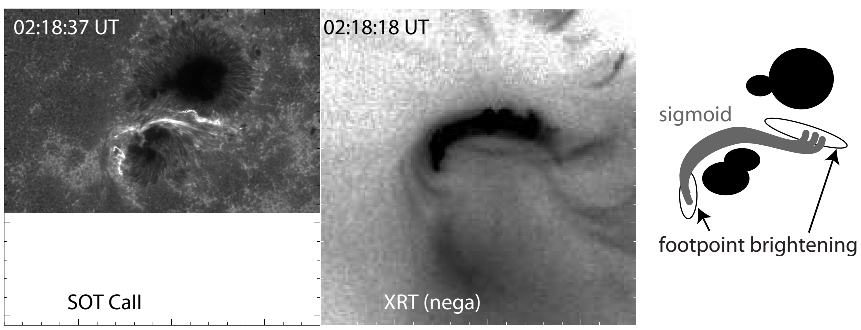


Figure 2. Chromospheric and coronal features of the preflare stage of the flare. Solar north is up and west is to the right. *Left*: Ca II line image taken with *Hinode* SOT. *Middle*: Soft X-ray image (negative image) obtained by *Hinode* XRT. *Right*: Diagram showing the geometrical features of the flare. The Ca II brightenings are connected with the X-ray sigmoid loop.

Second, from 02:18 to 02:22 UT (time range B in Fig. 1), a faint ejection is seen to rise up from the (pre-)flaring region. The ejection is slightly accelerated from about 40 km/s to about 100 km/s, and becomes unclear after 02:22 UT. On the other hand, just after the ejection, from 02:23 to 02:26 UT (time range C), we can identify the faint arc-shaped X-ray ejection, or X-ray wave, as mentioned above. The X-ray wave starts to appear at about 100″ far from the flare core

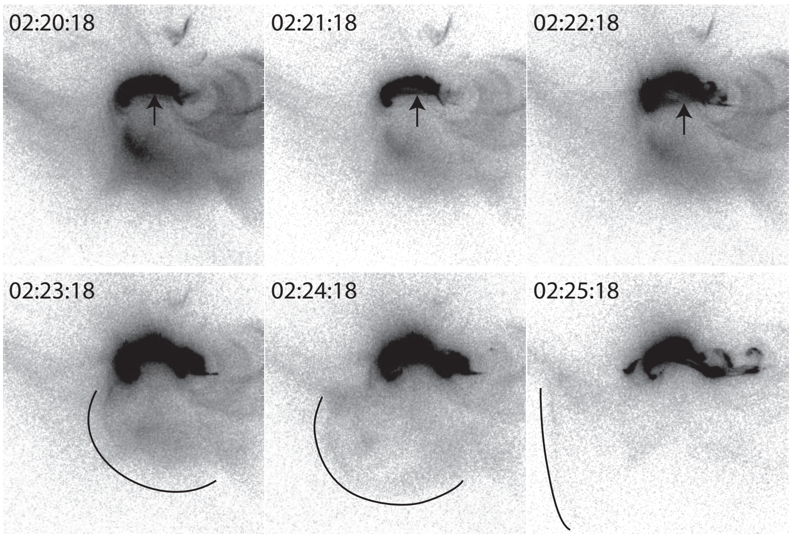
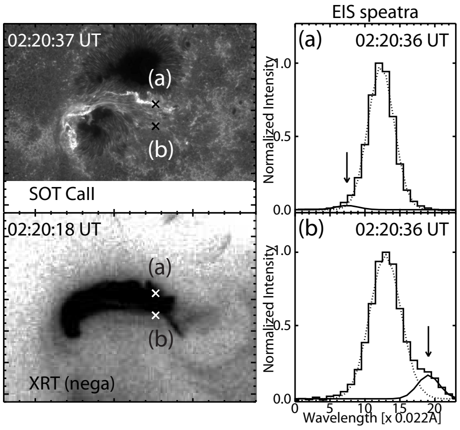


Figure 3. Evolution of the flare in soft X-ray. Soft X-ray images are obtained with XRT (negative images). Solar north is up and west is to the right.

region. We present the evolution of the flare in soft X-rays observed by XRT in Figure 3. The faint ejection and the X-ray wave are seen in the top and the bottom rows, respectively. The faint ejection is pointed with the arrows. The evolution of the X-ray wave is also guided with the solid lines.

2. EIS Observations

These preflare and/or flare onset phenomena were also observed with EIS. Therefore, we can examine their spectroscopic features. Figure 4 shows the spectra of the Fe XV line (284.2 Å; 2.5 MK) at the footpoint (top panels; point a) and the top (bottom panels; point b) of the soft X-ray sigmoid loop. We can see an EUV blueshifted component at the chromospheric brightening region beside the main component. We fitted the spectra with two gaussian functions. The Doppler velocity, which is determined by the displacement between the blueshifted and the main component, is about 110 km/s, which is slightly smaller than the sound speed. The same blueshifted features are also seen in the Fe XVI (274.2 Å; 1.6 MK) and Ca XVII (192.8 Å; 6.3 MK), and the Doppler velocities change according to the line-forming temperatures. These temperature-depending and subsonic blueshifted component is possibly the evaporation flow of the chromospheric plasma. However, the Doppler velocity of about 100 – 200 km/s is quite faster than those reported before (e.g. Milligan & Dennis 2009), and detailed examinations are required before the conclusion. If it is really the chromospheric evaporation, this means that a certain energy release mechanism (i.e. magnetic reconnection) occurs even in the preflare phase, and that the X-ray emitting sigmoid is filled by such evaporated plasma.



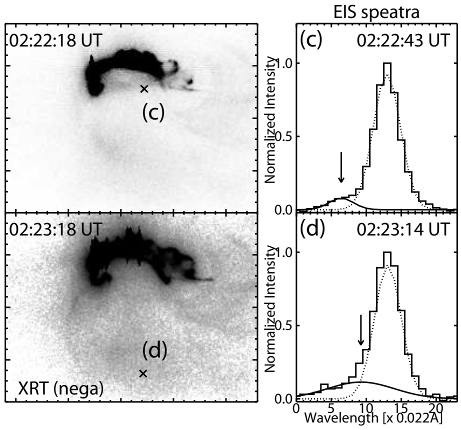


Figure 4. EIS spectra (*right*) of the footpoint (a) and the top (b) of the X-ray sigmoid. The arrows show the peaks of the blueshifted components. The left panels show the positions in the SOT Ca II and the XRT X-ray images.

Figure 5. EIS spectra (*right*) of the faint ejection (c) and the X-ray wave (d). The arrows show the peaks of the blueshifted components. The left panels show the studied positions in the XRT X-ray images.

On the other hand, the loop top part of the X-ray sigmoid (point b) shows redshifted component with the Doppler velocity of about 150 km/s. This is seen steady during the preflare phase and was also reported by Imada et al. (2009). This redshifted component could be shrinking magnetic loop, while we cannot discard the possibility that is plasma flow inside the magnetic loops.

As shown in Figure 5, we also examined the spectroscopic features of the faint ejection (top rows; point c) and the X-ray wave (bottom rows; point d). Again we fitted the spectra with two gaussian functions. Although we can see blueshifted components both for the points, the features are much different. The faint ejection shows the blueshifted component with the Doppler velocity of about 150 km/s, which is comparable or slightly faster than the traveling velocity ($\sim$100 km/s). The blueshifted component of the X-ray wave, however, shows the very wide spectra, and the Doppler velocity of the X-ray wave is smaller ($\sim$100 km/s, see Asai et al. 2008, for more detail). Therefore, the faint ejection is not the same phenomenon as the X-ray wave, although the disappearance of it (02:22 UT) is right followed by the start of the X-ray wave. Instead, the faint ejection may be the ejection that derives the MHD shock wave.

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).

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