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HARD X-RAY IMAGING OBSERVATIONS BY YOHKOH OF THE 15 NOVEMBER, 1991 FLARE

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ABSTRACT We present hard X-ray imaging observations by *Yohkoh* of the 15 November, 1991 flare. The pre–impulsive and the impulsive phase observations are summarized as follows: (1) Hard X-ray sources in the precursor (or pre–impulsive) phase appear in a much wider area compared with the impulsive phase sources and they show clear evolution just before the onset of the impulsive phase. This suggests that some global re–structuring of coronal magnetic fields led to the impulsive energy release. (2) In the impulsive phase, at the peaks of the individual spikes of the time profile, the bulk of the hard X-ray emission (above 20 keV) originates from the footpoints of the flaring loop. At the valleys between the spikes, X-rays below 30 keV are emitted from near the loop top, while higher energy ones (above 30 keV) are still emitted from the footpoints. Such behavior of hard X-ray sources can be explained by the partial precipitation model.

INTRODUCTION

X-ray images of solar flares provide us with various information on the flare processes such as preflare energy build-up in the corona (in soft X-rays) and particle acceleration and propagation (in hard X-rays). Due to the increased capabilities of both the Hard X-ray Telescope (HXT; Kosugi et al., 1991) and the Soft X-ray Telescope (SXT; Tsuneta et al., 1991) aboard the *Yohkoh* satellite (Ogawara et al., 1991), X-ray imaging observations of solar flares can now be achieved in unprecedented detail. Hard X-rays from solar flares are produced by bremsstrahlung of energetic electrons colliding with ambient plasma. Therefore, hard X-ray images of solar flares, especially in the impulsive phase, are expected to give us information on how and where hard X-rays are emitted, and further how and where accelerations of electrons take place in flaring magnetic loop(s).

HXT has thus far observed more than 400 solar flares including more than 5 GOES X-class flares. In this paper, we present hard X-ray imaging observations by *Yohkoh* of the 15 November, 1991 flare (X1.5 in GOES X-ray class and 3B in Hα). Figure 1 shows time profiles of the hard X-ray count rates observed with HXT in four energy bands (13.9–22.7, 22.7–32.7, 32.7–52.7, and 52.7– 92.8 keV, respectively). A preliminary description of the hard X-ray observations are given elsewhere (Sakao et al., 1992). Besides the X-ray observations, this flare was also well observed at the Mees Solar Observatory (MSO) in Hawaii. Results

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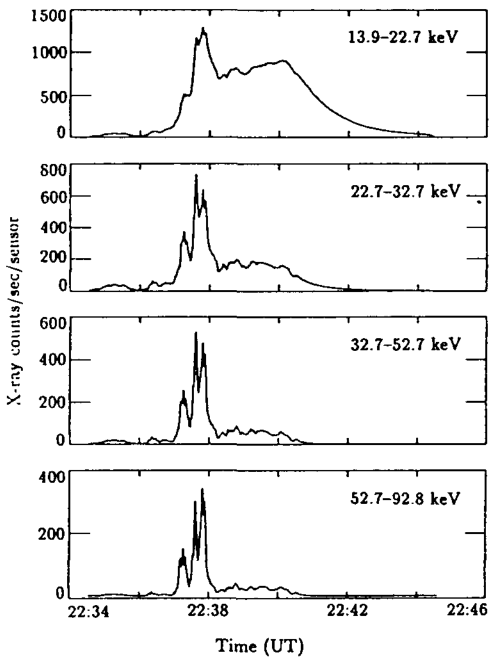


FIGURE I Hard X-ray time profiles of 1991 November 15 flare observed with HXT. Average count rates of the 64 subcollimators of HXT are given (after Sakao et al. 1992).

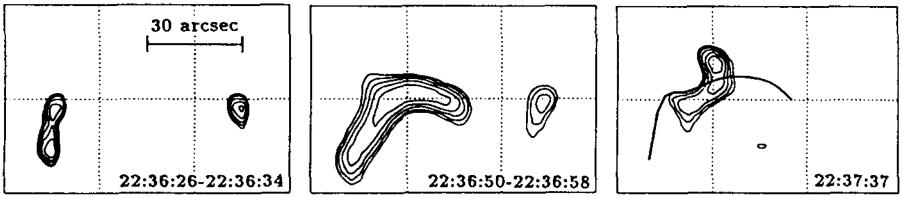
from the Mees observations together with the SXT observations are described in Canfield et al. (1992). A further analysis of this event will be reported in near future (Sakao et al., in preparation).

OBSERVATIONS

As is shown in figure 2, the hard X-ray sources of this flare showed a clear pattern of evolution. To summarize the HXT observations according to the time profile (figure 1), we divided the flare into three phases: (a) *precursor phase* (2234–2237 UT), (b) *impulsive phase* (2237–2238 UT), and (c) *post-impulsive phase* (after 2238 UT). Here we focus on the precursor phase and the impulsive phase observations.

(a) Precursor Phase

A major characteristic of hard X-ray sources in the precursor phase is that they are located in a wide area with a spatial extension greater than 40,000 km (figure 2a,b). This is quite in contrast with the sources in the impulsive phase where the bulk of the hard X-ray emission is concentrated in a compact region (within 20,000 km square; see figure 2c for comparison).



(a) (b) (c)

FIGURE II Hard X-ray images (in 13.9–22.7 keV for (a) and (b), and in 22.7–32.7 keV for (c), respectively) at different timings of this flare. (a) and (b) are the precursor phase images while (c) is the impulsive phase image . Magnetic neutral line observed at MSO is overlaid in the image (c) (after Sakao et al. 1992).

Just before the onset of the impulsive phase, the hard X-ray source in the left hand side in figure 2a showed a continual expansion along the magnetic neutral line (figure 2b).

(b) Impulsive Phase

The impulsive bursts of this flare comprise three separate spikes which are prominent in the energy range above 22.7 keV (figure 1). Figure 3 shows the temporal variation of hard X-ray sources in the energy range 22.7–32.7 keV (top) and 32.7–52.7 keV (bottom). Here P1, P2, and P3 correspond to the peak of each spike, respectively, while V1 and V2 correspond to the valleys between P1∼P2 and P2∼P3 respectively. We note that double sources appeared in 32.7–52.7 keV from P2. These double sources are located on either side of magnetic neutral line. The separation of the double sources got larger with time (∼ 13″ at P2 and ∼ 16″ at 22:38:00). The apparent velocity of the separation increase is ∼100 km/s. In the energy range 22.7–32.7 keV, the hard X-ray sources also showed double source structures at the peaks of spikes (P2 and P3). On the other hand, at the valley V2 and at 22:38:00 single sources appeared which are located on the neutral line. It is interesting to note that, accompanying this structural evolution, the energy spectrum showed the well known solf–hard–soft evolution during the individual spikes.

SUMMARY AND DISCUSSION

The hard X-ray sources in the precursor phase are located quite far (∼20,000 km) from the impulsive phase hard X-ray sources (figure 2). This suggests that some instability which caused activation and/or deformation of surrounding magnetic loops eventually led to the impulsive energy release (see, e.g., Harrison 1986, Kahler et al. 1988).

Since the double sources seen in the impulsive phase are located on either side of the neutral line, we can say that the double sources correspond to the footpoints of a flaring magnetic loop. The behaviour of the double sources dur-

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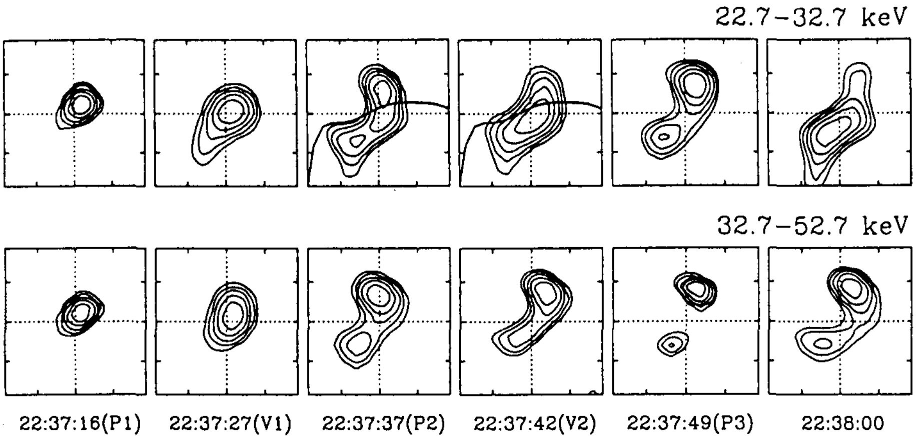

FIGURE III Hard X-ray sources at the peaks and valleys of spikes during the impulsive phase. The size of each map is $37'' \times 37''$. Magnetic neutral lines are shown in P2 and V2 images in the upper row (after Sakao et al. 1992).

ing the impulsive phase can be explained by the partial precipitation model (see, e.g., Melrose and Brown 1976). At the peaks where the acceleration of electrons takes place, accelerated electrons are confined in such a way that higher energy electrons have higher escape probability towards the footpoints, producing double source structure. On the other hand, at the valleys when the acceleration weakens, lower energy electrons which are confined near the loop top have longer lifetime than precipitating higher energy electrons due to the lower plasma density, producing single source structure. The observed soft–hard–soft spectral evolution can also be explained by this model. Furthermore, since the separation of the double sources became larger at an apparent speed $v \sim 100$ km/s, it is suggested that this increase in separation is due to a multiple loop system flaring successively with rising energy release sites. Why only a single source was observed even in 32.7–52.7 keV at P1 is probably due to the fact that the length of the flaring loop was so short that HXT could not resolve the two footpoints, or because the density of ambient plasma was so high that hard X-rays were emitted near the top of the loop.

By analyzing this and other flares in detail, we expect to clearly extract and classify the nature of particle acceleration that takes place during the course of a flare. Such an effort is now being done by our HXT colleagues.

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