YOHKOH HXT/SXT OBSERVATIONS OF A TWO-LOOP INTERACTION SOLAR FLARE ON 9 DECEMBER 1992

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Abstract

Observations with the Soft X-ray and Hard X-ray Telescopes aboard *Yohkoh* of a simple solar flare on 9 December, 1992 at ~10:40 UT are discussed. Soft X-ray images reveal an appearance of a secondary loop, located ~7 arcsec to the east of and almost parallel to the original loop, about ten minutes prior to the flare, and their merging just before the onset of the hard X-ray flare. Hence this flare provides a chance to examine the solar flare caused by the two-loop interaction mechanism. It is found (i) that the loop- top portion near the interaction region brightens in the 14-23 keV hard X- rays in the early stage of the flare, and (ii) that the 23-33 keV hard X-ray emission originates dominantly from two compact sources at the two ends of the merging loop. These observations suggest that high-energy electrons are produced at the interaction site near the loop top, and that they precipitate towards the footpoints along the loop.

1. Introduction

The two-loop interaction hypothesis for explaining the solar flare energy release has been repeatedly proposed by many authors (e.g., Gold and Hoyle 1960; Tajima *et al.* 1987; Sakai and de Jager 1991; Chargeishvili *et al.* 1993; Zhao *et al.* 1993). One of the most crucial tests to this hypothesis may be provided by simultaneous soft X-ray and hard X-ray imaging observations, because the former gives us the magnetic loop configuration that may vividly show the two-loop interaction while the latter observes the behavior of energetic electrons accelerated and confined in it.

In this paper, we present observations of a simple flare with the Soft X-ray Telescope (SXT) and the Hard X-ray Telescope (HXT) aboard *Yohkoh.* This flare is remarkable in that two loops, which later merge into one, are clearly seen in the preflare stage. Thus this flare may provide a chance to examine the validity of the two-loop interaction model, and further to put constraint upon how particles are accelerated in it.

2. Observations and Results

A *GOES* C2.7 class solar flare occurred on 9 December 1992 at ~10:40 UT near the east limb (~E60) in active region NOAA 7363. The evolution of this active region before the flare was monitored with SXT at a cadence of typically once every minute for each of the analysis filters. Soft X-ray images from preflare to onset of the flare are shown in figure 1. While only one loop is seen before ~10:31 UT (fig. 1a), a second loop appeared ~7 arcsec to the east of the first about ten minutes prior to the flare onset, as clearly seen in the 10:38:39 UT image (fig. 1b). The two loops were approximately parallel to each other, and almost equally bright at this instance. Then the two loops seem to have collided or interacted with each other in the 10:40:49 UT image (fig. 1c). The interaction region is located near the top (or more rigorously slightly south of the apex) of the two loops. Finally a remarkable brightening occurred at the two footpoints of the merging loop in the 10:41:53 UT image (fig. 1d). The temperature T of the interaction region is derived from the ~10:41 UT data to be ~5 $\times 10^6$ K.

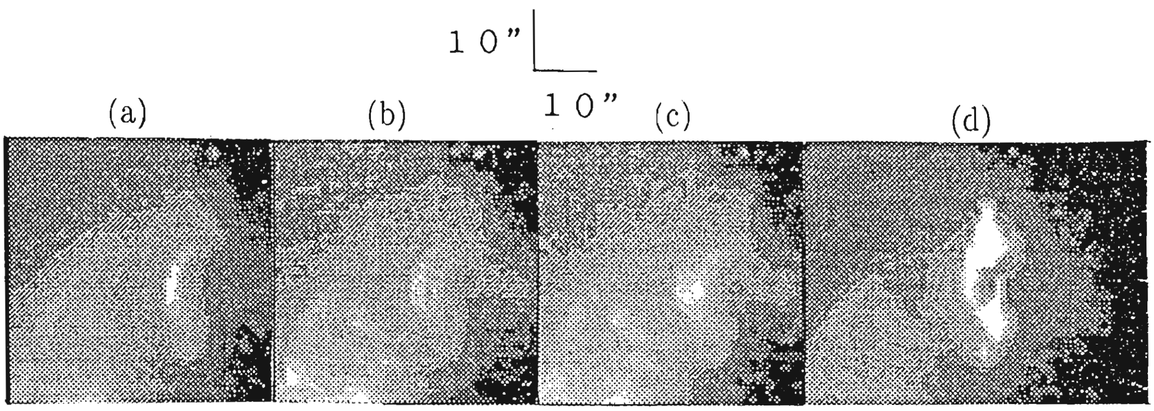

Fig. 1. Soft X-ray images of the 9 December, 1992 flare at (a) 10:28:17 UT, (b) 10:38:39 UT, (c) 10:40:49 UT (~2 min prior to the hard X-ray onset), and (d) 10:41:53 UT. These images were taken with *Yohkoh* SXT through the thin-aluminum filter. arcsec. Solar north is up and east is to the left.

The hard X-ray time profiles in the HXT L- (14 – 23 keV) and M1- (23 – 33 keV) bands are shown in figure 2. The M1-band data are available only after 10:42:47 UT. Figure 3 and figure 4 (b)(c) show HXT images during the flare in the two energy bands. Note that this flare is weak so that relatively long accumulation of photon counts is necessary for synthesizing images. No higher-energy images are synthesized. Even though some spurious features do exist in the synthesized images due to low signal-to-noise ratio, we can derive the following: (i) The L-band source is elongated throughout the flare, suggestive of tracing the magnetic loop. (ii) Still we see an evolutional change in this energy range. In the preflare phase (A), the brightest region tends to be located at the central portion, probably at the loop top. At the first peak of the impulsive phase (B), the brightest region shifts northwards, and at the second peak (C) the whole loop is equally bright. The loop top becomes the brightest again in the gradual phase (after C). (iii) On the other hand, in the M1-band, the hard X-ray emission originates dominantly from two compact sources, separated from each other by ~30 arcsec or 22000 km.

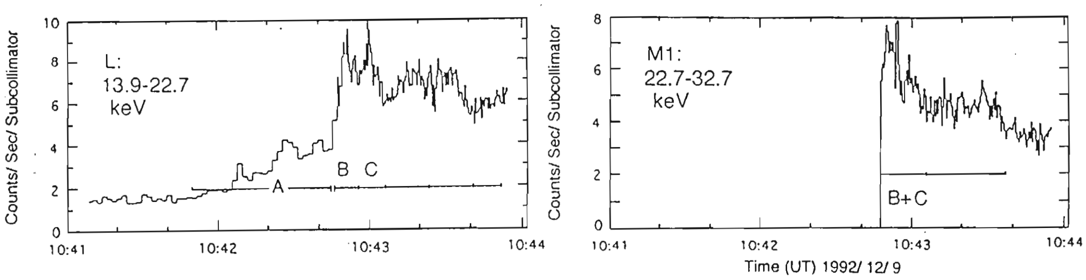

Fig. 2. Hard X-ray time profiles of the 9 December, 1992 flare in the HXT L- (13.9 – 22.7 keV) and M1- (22.7 – 32.7 keV) energy bands. The temporal resolution is 2 s (L-band alone) and 0.5 s (L- and M1- bands) before and after 10:42:47 UT, respectively. No M1-band data are available before this time. The labels A to C give the time intervals during which photon counts are accumulated for synthesizing snapshot images shown in figure 3.

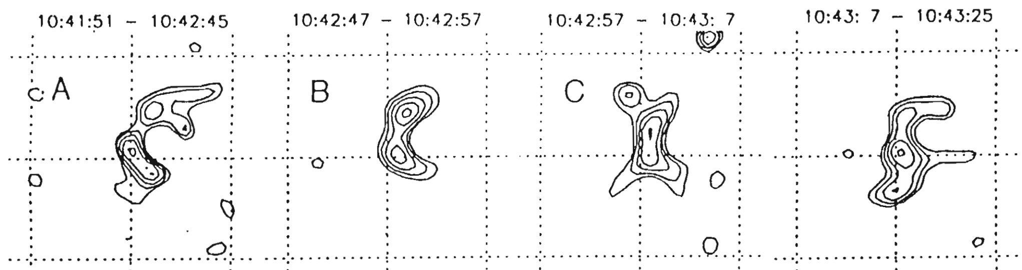

Fig. 3. Hard X-ray snapshot images of the 9 December, 1992 flare in the HXT L1- band. The data accumulation interval is given at the top of each map (see also fig. 2). Contours are 10.0, 17.3, 30.0, 52.0, and 90.0% of the peak brightness for each map. Each map covers 63 × 63 arcsec. Solar north is up and east is to the left.

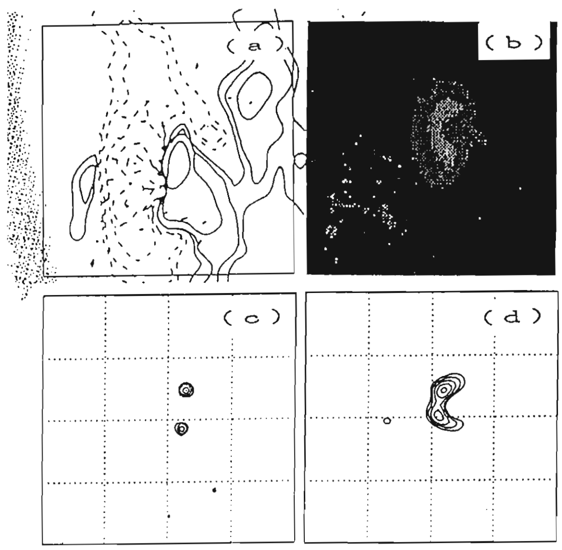

Fig. 4. Comparison of images for the 9 December, 1992 flare. (a) Magnetogram at 03:52:16 – 05:08:46 UT. Contour levels are ±18, 36, 91, 182, 370 and 1030 gauss (solid = plus, dotted = minus), taken from *Solar Vector Magnetograms 1992*, Okayama Astrophysical Observatory / National Astronomical Observatory. (b) SXT image taken through the thin Al filter at 10:43:03 UT. (c) HXT M1-band image at 10:42:47 – 10:43:7 UT. (d) HXT L-band image at 10:42:47 – 10:42:57 UT. The image orientation (solar north up, east to the left) and size (63 × 63 arcsec) are common for the four images. The accuracy of the alignment is within a few arcsec.

To confirm that the two sources seen in the M1-band represent the two ends of a magnetic loop, we compare SXT and HXT images with a magnetogram taken at the Okayama Observatory in figure 4. It is found that the two sources are located at the opposite sides of a magnetic neutral line. Hence, it is not unreasonable if we take the sources as the two footpoints of a magnetic loop (or loops).

3. Discussion

The SXT images taken during the preflare and onset stages of the flare (fig. 1) suggest that the two-loop interaction really occurs and triggers the flare energy release. In particular, the images after 10:40:49 UT (fig. 1c) show a single loop, suggestive that the two loops have coalesced or merged into one. Note that this coalescence takes place about 2 minutes prior to the onset of hard X-rays (cf. fig. 2).

As seen in figure 1b, the two loops that coalesce several minutes later are parallel to each other. Thus, according to the classification scheme proposed by Sakai and Koide (1992), this event exhibits a two-loop interaction flare of I- type.

If this is the case, the short timescale of the interaction process could be understood by the Alfvén transit time, τ_A, of the interacting loops. Since τ_A is estimated to be $\sim$10 s from our observations, the observed interaction timescale, $\sim$2 min, is $\sim 10\ \tau_A$. Note that such a short timescale is explained only by the explosive reconnection model (Sakai and Ohsawa 1987), but not by the steadily-driven reconnection model (e.g., Petscheck 1964).

The HXT image at the early phase of the hard X-ray emission (fig. 3; A) suggests that hard X-rays are first emitted from the interaction region. Most probably, electrons are energized here, and then stream down along the magnetic loop(s) into the footpoints, resulting in the hard X-ray emission from the whole loop (in the L-band) or from the double footpoint sources (in the M1-band) during the impulsive phase (fig. 3; B and C). Unfortunately the spatial resolution of HXT ($\sim$5") is not high enough to conclude whether the hard X-rays are emitted from a single pair or two pairs of footpoints, which may be crucial to discuss whether the two loops have completely merged into one loop or not. Later on in the gradual phase (after C), energy impulsively released flows downwards into the footpoints, "evaporates" dense, chromospheric material up to the corona, and thus creates a hot plasma near the loop top, which is seen as the bright source in the HXT L-band images, as well as in SXT images.

A more detailed description of this flare, both observational and theoretical, will be published elsewhere in the near future.

References

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