A COMPARISON OF HARD X-RAY, SOFT X-RAY, AND MICROWAVE SOURCES IN SOLAR FLARES

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Abstract

Hard X-ray, soft X-ray, and microwave images of about 20 solar flares that occurred in NOAA 7270 are compared for investigating where electrons are energized and emit hard X-rays. We find the following: (i) Usually hard X-ray sources appear inside a soft X-ray flaring loop or loops. The hard X-ray emission tends to originate from the two ends of the soft X-ray loop in the impulsive phase (double footpoint sources), and later the double sources evolve into a single source located near the loop top (loop-top gradual source). (ii) In a few cases, another impulsive hard X-ray source with comparable intensity with the double footpoint sources appears at a site remote from the footpoint sources. This source shows only weak brightening in soft X-rays but is bright in microwaves.

1. Introduction

Solar flares are complicated phenomena in which magnetic energy is suddenly converted into other forms via acceleration of particles, heating of high-temperature plasma, and/or mass motion. The problems to be solved are: What magnetic configuration is unstable to initiate the energy conversion? Where and how does the primary energy release take place? How efficiently are particles accelerated?

We challenge these problems by comparing hard X-ray images taken with the Hard X-ray Telescope (HXT; Kosugi *et al.* 1991) on board *Yohkoh* with soft X-ray images taken with the Soft X-ray Telescope (SXT; Tsuneta *et al.* 1991) on the same satellite. Since hard X-rays are believed to be emitted from energetic electrons, and since soft X-ray images well reflect the magnetic field configuration in a flaring region, we expect some useful information can be derived from this comparison. For this study, we arbitrarily take as examples about 20

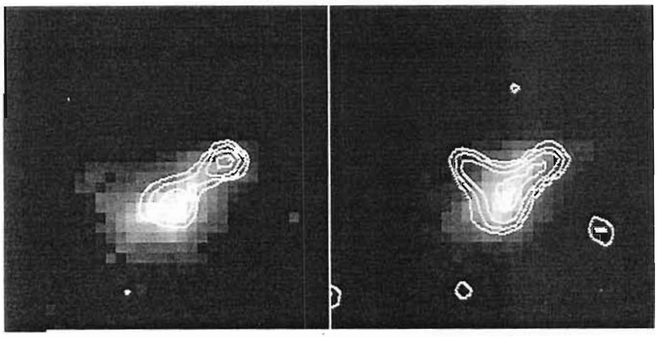

Fig. 1. Hard X-ray (23 - 33 keV; in contours) *versus* soft X-ray (Be filter; in grey scale) images for the 1992 September 6 flare at 09:02 UT. At the largest spike (left; at 09:03:30 UT) a double-source structure is clearly seen in hard X-rays, while at a later spike (right; at 09:04:36 UT) the part in between the double sources becomes growing. Each map covers 1.3 × 1.3 arcmin. The solar north is to the top, west to the right.

flares that occurred in NOAA 7270 and were well observed by *Yohkoh* (Yaji 1994; Kurokawa *et al.* 1994). When available, we also make use of microwave images taken with the Nobeyama Radioheliograph. Because of the brevity of this paper, observations of only two flares are presented in detail.

2. Observations

2.1. 1992 September 6 Flare at 09:02 UT

In the majority of flares, soft X-ray images reveal one or more flaring loops. The hard X-ray emission above ~ 20 keV originates mainly from two sources located near the both ends of the soft X-ray flaring loop(s) (double footpoint sources; e.g., Sakao *et al.* 1992, 1994; Sakao 1994; Masuda 1994a,b).

As is shown in figure 1, this flare is a typical example of such cases. This flare commenced at 09:02 UT at S11W38. At 09:03:30 UT when the strongest spike was recorded in the hard X-ray time history, we see a clear double-source structure in the HXT image (figure 1, left). The two sources are located near the two ends of an elongated soft X-ray brightening. At 09:04:36 UT when the last spike occurred, though the double-source structure is still visible, the intermediate part in between the two sources increases its intensity (figure 1, right). Later in the gradual phase, this part becomes the brightest area.

Judging from magnetograms taken with the Flare Telescope at Mitaka (courtesy K. Ichimoto), the double hard X-ray sources are located at the both sides of the magnetic neutral line. Hence we are confident that the elongated soft X-ray brightening represents a flaring magnetic loop or loops connecting regions of opposite polarities.

2.2. 1992 September 6 Flare at 01:56 UT

In a few cases, we observe another hard X-ray source at a remote site where soft X-rays brighten only weakly.

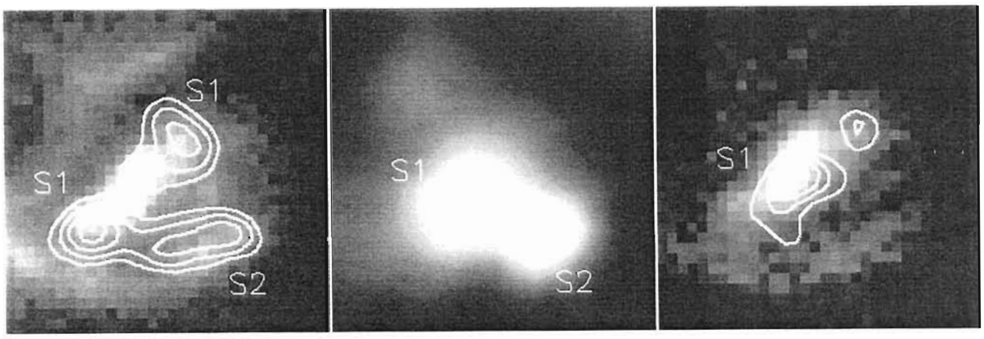

Fig. 2. The 1992 September 6 flare at 01:56 UT. Overlay of hard X-ray (14 - 23 keV; in contours) and soft X-ray (Be filter; in grey scale) images in the impulsive phase at 01:58:06 UT (left). A microwave image at 17 GHz in the impulsive phase at 01:58:11 UT (middle). Same as the left panel but for the gradual phase at 01:59:21 UT (right). Each map covers 1.3 × 1.3 arcmin. The solar north is to the top, west to the right.

A typical example of this source was observed in the 1992 September 6 flare at 01:56 UT. As shown in figure 2 (left), the hard X-ray flare shows three separate sources in the impulsive phase . A soft X-ray flaring loop connects the south-east and the northern hard X-ray sources, while only weak soft X-ray excess brightness is seen at the south-west hard X-ray source . Towards the gradual phase the first two hard X-ray sources merge into a single source located at the brightest portion of the soft X-ray loop (figure 2, right). Again the two sources are located at regions of opposite magnetic polarities. Thus with no doubt the two sources are a pair of footpoint sources discussed in the previous subsection.

Let us call the first two sources S1 (including the soft X-ray loop connecting the two) and the south-west source S2. As shown in the middle panel of figure 2, both S1 and S2 brighten in microwaves at 17 GHz. Temporal behavior seen in the hard X-ray (14 - 23 keV), soft X-ray (Be filter), and microwave (17 GHz) ranges are plotted in figure 3 separately for S1 and S2. It is clear from this figure that S2 shows only impulsive behavior both in hard X-rays and in microwaves. On the other hand, S1 seems to comprise two components: one is impulsive and the other gradual. The former corresponds to the footpoint sources, seen only in hard X-rays, while the latter corresponds to the loop-top source seen in all of the three emission ranges. Thus only the S2 source is peculiar in that it lacks the gradual phase.

This result is confirmed by a temperature analysis of SXT images; the temperatures for S1 and S2 are 1.2×10^7 K and 0.7×10^7 K, respectively. The S2 temperature is anomalously low for flaring plasmas.

In short, we find in this flare an anomalous hard X-ray and microwave source at a site from where no intense soft X-ray emission originates. The lack of thermal component implies that there is no energy release inside nor intense energy inflow to this source. It is suggested that only nonthermal electrons precipitate into this source from the primary energy release site. A similar source has been reported by Masuda *et al.* (1994) in the 1991 October 24 flare.

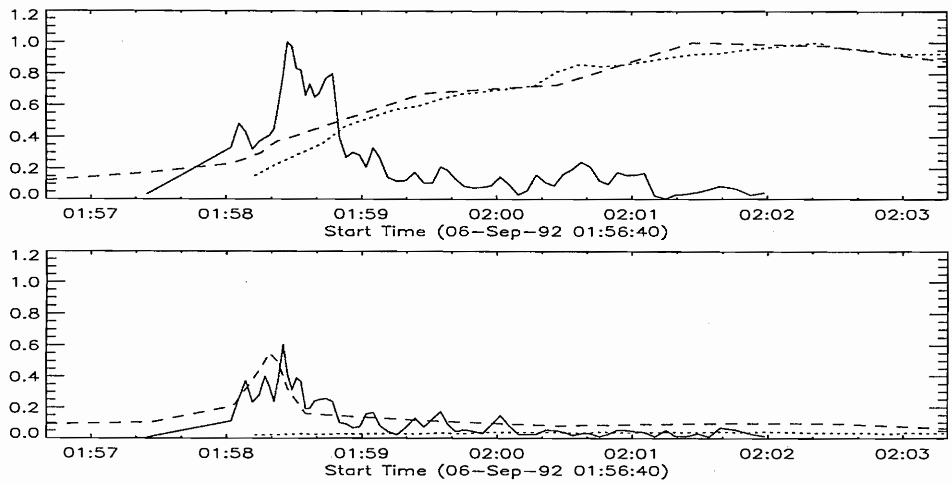

Fig. 3. Temporal behavior of the S1 (top) and S2 (bottom) sources. Fluxes in hard X-rays (14 - 23 keV), microwaves (17GHz), and soft X-rays (Be filter) are denoted by solid lines, dashed lines, and dotted lines, respectively. Note that the hard X-ray flux for S1 only includes contributions from the two footpoint sources. The hard X-ray time profile for the loop-top part of S1 (not shown) resembles those of soft X-rays and microwaves.

3. Summary

We have compared hard X-ray, soft X-ray, and microwave images of about 20 solar flares that occurred in NOAA 7270. We find that bright hard X-ray sources usually appear inside a bright soft X-ray loop or loops. In the impulsive phase the hard X-ray emission tends to originate at the two footpoints of the loop(s). The two sources later merge into a single source near the loop top. In addition, we find an anomalous hard X-ray and microwave source at a site from where no intense soft X-ray emission originates. This type of sources appear only rarely. A further study need be made to clarify the origin of this type of sources.

References

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