HARD X-RAY IMAGING OF A SOLAR GRADUAL HARD X-RAY BURST ON APRIL 1, 1981

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Abstract. An intense solar X-ray burst occurred on April 1, 1981. X-ray images of this gradual hard X-ray burst were observed with the hard X-ray telescope aboard the Hinotori satellite for the initial ten minutes of rise and maximum phases of the burst. The hard X-ray images (13–29 keV) look like a large loop without considerable time variation of an elongated main source during the whole observation period. The main X-ray source seems to lie along a ridge of a long coronal arcade \(2 \times 10^4\) km above a neutral line, while a tongue-like sub-source may be another large coronal loop although the whole structure of the X-ray source looks like a large semi-circular loop. Both nonthermal and hot thermal \((3–4 \times 10^7\) K) electrons are contributing to the source image. The ratio of these components changed in a wide range from 2.3 to 0.4 during the observation, while the image was rather steady. It suggests that both heating and accelerations of electrons are occurring simultaneously in a common source. Energetic electrons of 15–30 keV would be collisionally trapped in the coronal magnetic loops with density of the order of \(10^{11}\) cm\(^{-3}\).

1. Introduction

Study of the source structure and its time variation of hard X-ray bursts are important in understanding energy release and subsequent energy transport in flares.

The hard X-ray imaging observations made so far with the HXIS aboard the SMM and the SXT aboard the Hinotori have revealed a lot of variety in the hard X-ray sources. One-to-one relation cannot be seen between the source image and type of burst, but the source image would be governed mostly by the length and the density of the coronal loop in which energetic electrons are produced (Takakura, 1984a).

The burst of the present report is one of the most intense bursts observed with the Hinotori and may fall into the same category as the bursts on April 27, 1981 (Takakura et al., 1983) and May 13 (Tsuneta et al., 1984), i.e., high coronal extended source for gradual hard burst.

The gradual hard burst is about the same as ‘extended burst’ named by Hoyng et al. (1976). It is characterized by a long duration, high intensity and hard power-law spectrum which becomes harder with time on the average. Such a type of burst was not observed with the HXIS: All hard X-ray bursts observed with the HXIS (except one) are short and weak impulsive bursts, the spectrum of which generally becomes softer in the later phase.

One-directional observations for the associated radio bursts were made at 35 GHz

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(Kawabata et al., 1982) and 17 GHz (Nakajima, 1983), showing a coincidence with the X-ray source.


2. Observational Results

An X-ray flare classified as X2.3 on the GOES satellite scale was recorded with the hard X-ray monitor spectrometer (HXM) aboard the Hinotori from 01:27 UT to 02:01 UT as shown in Figure 1. The long burst consisted of three major peaks, but the imaging observation was limited to a period between about 01:29 and 01:37 UT, up to near the end of the first major peak. The X-ray spectrum derived from channel 2 (40–50 keV) and higher energies fits better to a power law with a spectral index $\gamma$ (in photons/energy) which decreases with time on the average from 6.7 at 01h30m, 3.7 at 01h35m and still gradually to 3.2 at 01h54m. At the valleys in the time profile, as time marks 4 and 6, $\gamma$ is greater by about 0.5 compared with that at the peaks. In the channel 1 (17–40 keV), a hot thermal component seems to be superposed, since the time profile of this channel alone is more gradual and also the counting rate is much greater than that expected from an extrapolation of the power-low spectrum fitted at higher energies. A ratio between the excess counts (hot thermal component) and the extrapolation counts (power-law component) is about 1.4 at time mark 2 and 0.25 at time mark 5. Thermal emission with $(1.5 \sim 1.9) \times 10^7$ K and maximum EM of $4 \times 10^{49}$ cm$^{-3}$ was observed (Moriyama et al., 1982), which is too small to account for the excess counts in the channel 1. On the other hand, the Fe xxvi line was not detected with the soft X-ray spectrometer SOX aboard the Hinotori indicating that the emission measure for the hot thermal component was less than $10^{48.5}$ cm$^{-3}$. If we take the emission measure of $10^{48.5}$ cm$^{-3}$ or less, $T \gtrsim 3.5 \times 10^7$ K is required for the hot thermal component to account for the excess counts in the channel 1. In this estimate, rather low energy resolution of Na i detector is taken into account, by which photons below the lower discrimination energy (17 keV) partly contribute to channel 1.

A 4N Hz flare was observed at the Yunnan Observatory in China at the solar coordinates about S 42, W 52. Three intensity maxima were observed at 01:36, 01:46, and 01:53 UT corresponding to the three peaks in X-ray time profile. As shown in Figure 2, a loop system was formed as soon as the flare started. Most of the loops changed quickly, and a loop in the northern part became bright and thick forming a main loop from north to west. Microwave type IV burst starting from about 01:30 UT with a spectral peak near 10 GHz with 4400 sfu ($10^{-22}$ Wm$^{-2}$ Hz$^{-1}$) was observed at 35 GHz (Nagoya), 17 GHz (Nobeyama), and 9.4 GHz to 1 GHz at Toyokawa. This great burst was preceded by a precursor starting from 01:07 UT. A meterwave type IV burst with a moderate intensity was observed from 01:36 to 02:10 UT at Nobeyama.

Some of hard X-ray images obtained with SXT-2 in an effective energy range of about 13–29 (12–24) keV are shown in Figure 3. The range in the brackets is for the earlier