A Flare of 1992 Aug. 17 23:58 UT

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Abstract

A flare of GOES X-ray class C4.3 was observed in NOAA 7260 on 1992 Aug. 17 at 23:58 UT. All the instruments on board Yohkoh made high time and spatial resolution observations. The soft X-ray time profile in the 3 – 15 keV energy range obtained by Soft X-ray Spectrometer (SXS) shows double peaks around Aug. 18, 00:00 and 00:05 UT. Images of Soft X-ray Telescope (SXT) show that four discrete points brighten in a straight line from northeast to southwest around Aug. 17 23:58 UT, which are also bright in Hard X-ray Telescope (HXT) images. We name these four points in SXT images as Points 1, 2, 3 and 4 from the northeast of the sun. Four points observed by SXT can be considered as the foot points of magnetic flux tubes. Moreover HXT contour images show that another hard X-ray source exists between Point 3 and Point 4. The logarithmic-scale SXT images indicate the existence of two loops connecting Point 1 with Point 4, and Point 2 with Point 3. Overlaid SXT images on the vector magnetogram obtained by the Solar Flare Telescope (National Astronomical Observatory of Japan) reveal that a magnetic neutral line runs between the second and third points. With the electron temperature and emission measure obtained by the SXT filter ratio method, the RTV scaling law (Rosner, Tucker, and Vaiana 1978) implies the connections of Point 1 with Point 4 and of Point 2 with Point 3 in the flare decay phase. The time profiles of electron temperature derived from the Bragg Crystal Spectrometer (BCS) also have double peaks. Simultaneous brightenings of two loops which connect Points 1 and 4, and Points 2 and 3, and a reasonable agreement with the simulation results suggest a possibility of collision of the two parallel current loop.

1 Introduction

Yohkoh satellite (Ogawara et al. 1991) observed a flare of 1992 Aug. 17 23:58 UT from its rise phase to decay phase. It was an impulsive C4.3 flare in GOES 1 – 8 Å intensity scale and showed a double peak feature in soft X-ray energy ranges. Yohkoh had four instruments on board, which were Hard X-ray Telescope (HXT) (Kosugi et al. 1992), Soft X-ray Telescope (SXT) (Tsuneta et al. 1992), Wide Band Spectrometer (WBS) (Yoshimori et al. 1992) and Bragg Crystal Spectrometer (BCS) (Culhane et al. 1992). X-ray images were obtained with high spatial resolutions (2.5 arcsec for SXT and 5 arcsec for HXT) and high time resolutions (2.0 sec for SXT and 0.5 sec for HXT).

This flare was also observed by the magnetograph of Solar Flare Telescope at NAOJ, Mitaka (Ichimoto et al. 1991). Yohkoh images were overlaid on magnetograms of Solar Flare Telescope with an 2 to 5 arcsec accuracy, as the both imaging X-ray telescopes have the coaligned optical aspect instruments.

The 1980 Jun 7 flare had a feature of quasi-periodicity in X-ray and gamma-ray light curves (Chupp 1983; Forrest and Chupp 1983; Nakajima et al. 1983; Kiplinger et al. 1983). The 1982 November 26 flare also showed quasi-periodic oscillations in the light curve of the 17 GHz interferometer at Nobeyama Solar Radio Observatory, Japan and of the Hard X-ray Burst Spectrometer (HXRBS) on Solar Maximum Mission (SMM). These flares are interpreted as those excited by quasi-periodical collisions of two current loops, which then coalesce after several collisions (Sakai and Ohsawa 1987). The magnetic reconnection during the two parallel current loop coalescence can be classified into six categories from a viewpoint of the MHD theory (Sakai and Koide 1992), which are identified in vectormagnetograms with a moderate spatial resolution of 2.5 – 5 arcsec.

In this paper, we investigate the possibility of the interaction of two parallel loops, which may have caused this flare.

2 Overview of the flare of Aug. 17 23:58 UT

The 1992 Aug. 17 23:58 UT flare has two peaks in the time profile of Soft X-ray Spectrometer (SXS) at Aug. 18 00:00 UT and at 00:05 UT, and the time interval between their two peaks is about 5 minutes. SXT observations show four bright points at the flare onset of Aug. 17 23:58 UT (Fig. 1). We name these four points as Points 1, 2, 3, 4 from the northeast of the sun. A loop appears, which connects Point 2 and Point 3 around Aug. 18 00:00 UT. At Aug. 18 00:05 UT, a loop originating from Point 1 increases its brightness to the direction of the southeast and gradually becomes spatially extended (Fig. 1). Four bright points in the HXT image, which is processed by the maximum entropy method (MEM), correspond to Points 1, 2, 3 and 4 in the SXT image of Aug. 17 23:58:46 UT, while another hard X-ray source exists between Point 3 and Point 4 (Fig. 2). Overlaying the four points in the SXT image on the magnetogram of Solar Flare Telescope reveals that a magnetic neutral line runs between Point 2 and Point 3, and that Point 1 and Point 2 have N-polarity, and Point 3 and Point 4 have S-polarity (Fig. 3). The time profiles of electron temperature derived from soft X-ray emission lines in BCS also show two peaks at about Aug. 18 00:00 UT and 00:05 UT.

By overlaying a SXT image taken before the flare onset, it is obvious that Point 2 and Point 3 are continuously bright features well before the flare starts. During the flare, a loop-like structure appears, connecting Points 2 and 3. Because these two points show opposite polarities, this structure can be considered as a real coronal magnetic loop. Another faint loop-like structure emanated from Point 4 can be recognized in the logarithmic-scale SXT images. Points 1 and 4 also show opposite polarities in the magnetogram.

3 RTV model

Temperatures and emission measures of these four points are derived by the SXT filter ratio method (Hara et al. 1992). SXT images with the filters of Be (119 μm) and Al (12 μm) are used. Figure 4 shows a scatter diagram of emission measure vs electron temperature for different observed instants. Temperatures and emission measures are obtained from the 9 (3 × 3) pixel areas centered at the four points in the SXT image. Point 1 and Point 4, and Point 2 and Point 3 in the decay phase of the flare occupy similar locations in Figure 4. The emission measures of Points 1 or 4 and Points 2 or 3 are noted as EM_{14} and EM_{23}, respectively. It is interesting to note that the slopes of EM_{23} and EM_{14} against temperature in Fig. 4 are very close to 4. A simple coronal loop model of Rosner, Tucker and Vaiana (1978), hereafter RTV, is adopted in this paper. If a constant heat input per unit volume along the loop is assumed, the following equation is derived,

$$T = 1.4 \times 10^3 (pl)^{\frac{1}{3}} \tag{1}$$

where T , p and l are the maximum temperature at the loop top, the constant loop pressure in the loop and the semi-loop length, respectively. If it is supposed that the width of a loop is nearly constant along the loop, and the unique relationship for the coronal temperature distribution in the loop to the maximum temperature at the loop top is assumed, the following relation can be derived,

$$T^4 \propto EM \cdot L \tag{2}$$

where T , EM and L are the temperature and the emission measure of the above 9 pixel areas of the coronal loop and the distance of the loop foot points, respectively. If a circular shape of the loop is assumed, the distance of the loop foot points can be substituted in Equation (2). Therefore, the RTV model explains the observed slope of EM vs T during the flare decay phase, despite of its assumption of the steady state (constant heating rate with time). From Equation (2), the relation,

$$\frac{EM_{23}}{EM_{14}} = \frac{L_{14}}{L_{23}} \tag{3}$$

is obtained, where L_{14} and L_{23} are the foot point distances of the loops 1 – 4 and 2 – 3. Applying the least square method to the data in the decay phase, the ratio of EM_{23} / EM_{14} at the same temperature is 2.75. The distance ratio, L_{14} (4.96×10^9 cm) / L_{23} (1.76×10^9 cm) derived from the SXT image on Aug. 17 23:58:46 UT (Fig. 1) is 2.82. Therefore, the emission measure ratio is almost identical to the loop length ratio. Thus, this correspondence indicates the coronal loop connections of Point 1 to Point 4 and Point 2 to Point 3.

The magnetic energy can be derived from the magnetogram of Solar Flare Telescope. Photospheric magnetic field strength at the four foot points is nearly $B = 10^2$ Gauss. It is supposed in the SXT images that the magnetic field strength in the corona is not so different from that in the photosphere, as the width of the loops is nearly constant in the corona. The radius of the loop is obtained as $r = 3.37 \times 10^8$ cm, which is common for the both loops. In case of the circular shaped loop, the volumes of the loops 2 – 3 and 1 – 4 are $V_{23}\,(loop\ 2-3) = 9.86 \times 10^{26}\mathrm{cm}^3$ and $V_{14}\,(loop\ 1-4) = 2.78 \times 10^{27}\mathrm{cm}^3$, respectively, and the total volume of the two loops is estimated to be $V = 3.77 \times 10^{27}\mathrm{cm}^3$. Therefore, the total magnetic energy of two loops is $\left(\frac{B^2}{8\pi}\right) V \sim 10^{30}$ ergs. Using the electron temperature (log T_e =6.95) and emission measure (log EM =49.05) at Aug. 18 00:05 UT, which are derived from the SXT filter ratio method, the total thermal energy is estimated to be $3k\sqrt{\frac{EM}{V}} \times T_e \sim 10^{29}$ ergs. As a result, the magnetic field strength in the loops is found to be capable of providing the whole energy for heating the soft X-ray thermal plasma of the flare.

4 Discussion

Based on these observations, a bold hypothetical scenario of this flare is the following : At Aug. 17 23:58 UT, the first collision of two loops occurred. The non-thermal electrons were accelerated and hit the chromosphere. Four foot points of the two loops brightened in both SXT and HXT images. HXT observed a hard X-ray source (22.7 keV – 32.7 keV) as well between Point 3 and Point 4. Twist of magnetic field lines around Point 1, the foot point of the loop 1 – 4 in SXT images, became loose as the flare went on. Around Aug. 18 00:05 UT, the second collision of the two loops took place, and the EM of Point 1 increased rapidly, while no rapid increase of the intensity of the loop connecting Point 2 to Point 3 was observed, because the chromospheric evaporation in the loop 2 – 3 was suppressed by high electron density due to the evaporated material already filled in the loop. On the other hand, the magnetic configuration at Point 1 was changed so that the accelerated electron easily hit the chromosphere. At Aug. 18 00:05 UT, electron densities of the loops, n_{23} (loop 2 – 3) and n_{14} (loop 1 – 4), were estimated to $n_{23} = \sqrt{\frac{EM23}{V23}} = 3.01 \times 10^{10}\mathrm{cm}^{-3}$ and $n_{14} = \sqrt{\frac{EM14}{V14}} = 9.51 \times 10^{9}\mathrm{cm}^{-3}$, where log EM_{23} =47.95 (average of Point 2 and Point 3), log EM_{14} =47.40 (average of Point 1 and Point 4).

Theoretical simulations based on the collision of two parallel loops (I-type) (Chargeishvili et al. 1992; Zhao et al. 1993) support this view of the flare. The time interval between the collisions of two current loops is $3\tau_a$, where τ_a is Alfven wave transit time. The length of the interaction region of the two loops is estimated to 1.5×10^9 cm in the SXT image. If the ratio of the magnetic field along each loop to the azimuthal field is assumed to be 10, with electron density of $10^{10}\mathrm{cm}^{-3}$ derived from SXT and with the field along the loop is 100 Gauss from the magnetograph observation, then the Alfven transit time is estimated to be 68 s and the collision time interval is 3.4 min, which gives a consistent time scale for the observed collision recurrence.

It is noted that the highest electron temperature (log T_e =7.15) is obtained in the area between Point 3 and Point 4 in SXT images (Fig. 4). An additional hard X-ray source (22.7 keV – 32.7 keV) seen in the HXT image is located in the same region at Aug. 17 23:55:44. Zhao et al. (1993) shows that particles can be accelerated to about 30 keV within a second in the magnetic reconnection region and the thermal plasma of 10^8 K can be produced in two-parallel-loop collisions with reasonable ranges of parameters. These facts imply that the region between Point 3 and Point 4 may be the interaction region of the two loop collision.

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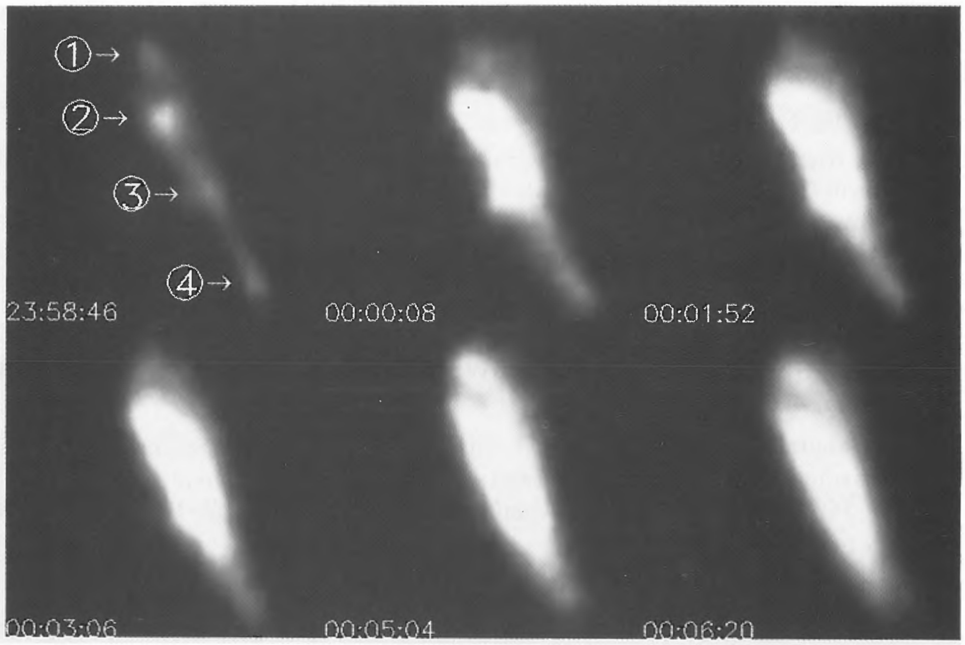

Figure 1: Time sequence of SXT images with the filter of Be 119 μm during a flare of 1992 Aug. 17 23:58 UT.

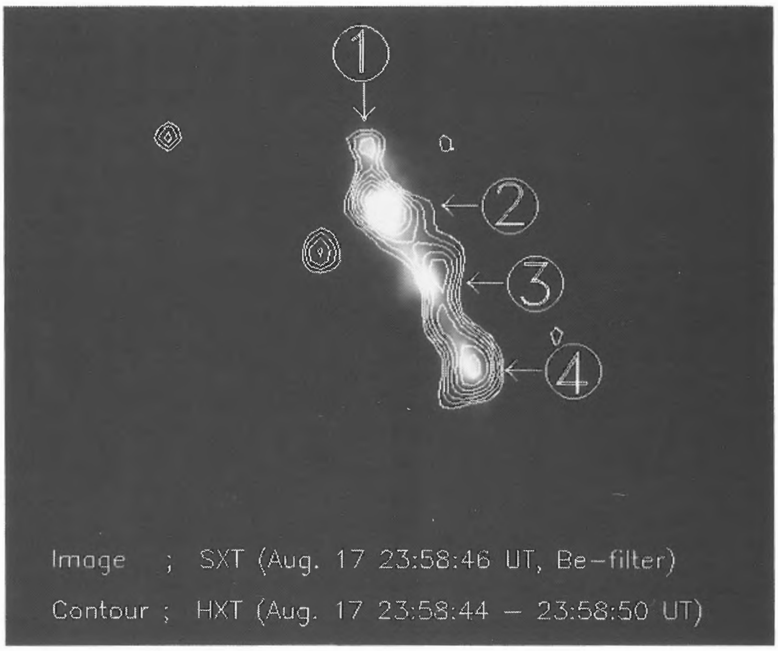

Figure 2: HXT Low channel (13.9 keV – 22.7 keV) image contour overlaid on SXT image. The HXT image is integrated and synthesized during Aug. 17 23:58:44 UT to 23:58:50 UT. The SXT image is obtained on Aug. 17 23:58:46 UT, with the filter of Be 119 μm.

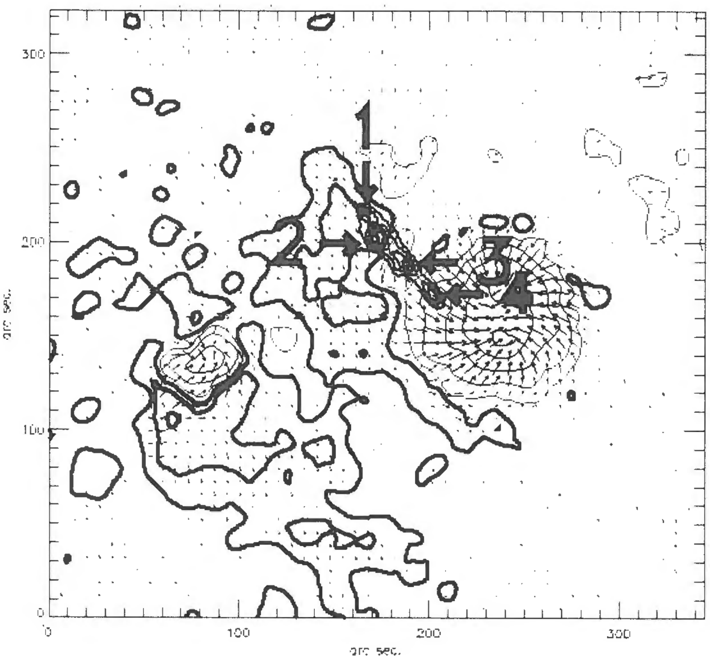

Fig. 3. A magnetogram at the post flare phase, at Aug. 18 01:50:15 – 01:51:21 UT, obtained by the Solar Flare Telescope at Mitaka. The SXT image of Aug. 17 23:58:46 UT is superposed as contours on the magnetogram. Contours in the magnetogram show the magnetic field strengths of ±50, 200, 500, 1000, 1500 Gauss.

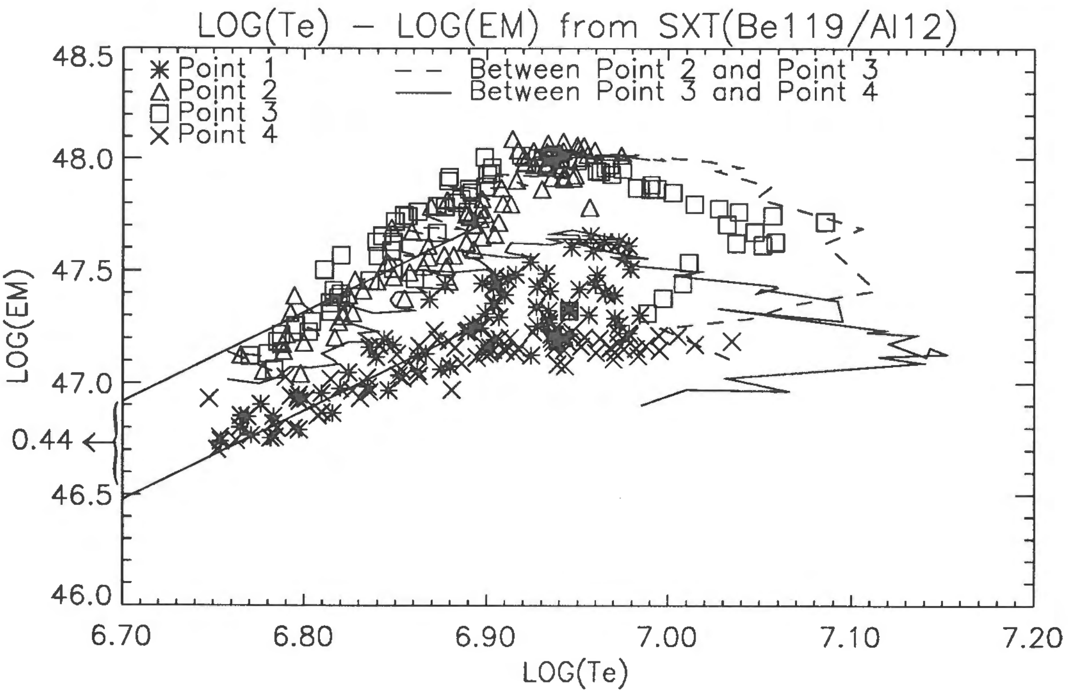

Fig. 4. The scatter diagram of emission measure vs electron temperature derived from the SXT filter ratio method with the filters of Be 119 μm and thick Al 12 μm. The emission measure ratio of the loop 2 – 3 to the loop 1 – 4 at the same temperature is log(2.75)=0.44.