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X-ray Plasma Ejection Associated with Hα Filament Eruption

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Abstract

The 1993 May 14 flare was associated with both an X-ray plasma ejection and an eruption of an active region filament. The flare proceeded through two stages. In the first stage the X-ray plasma ejection, Hα filament eruption, and a chain of point-like Hα brightenings occurred. In the second stage, an Hα two-ribbon flare and X-ray arcade structure were seen in Hα and soft X-ray images, respectively. The X-ray plasma ejection and the eruptive Hα filament in the first stage started to rise before the main peak of the hard X-ray emission. The ejected X-ray plasma was a loop-like feature that started to rise with a speed of $\sim$270 km s^{-1} from below and temporally after the Hα filament eruption. The ejected X-ray loop appeared to be decelerated when it approached the Hα filament, and then rose with the eruptive filament at an apparent velocity of $\sim$ 100 km s^{-1}. The temperature of the ejected loop was 9.5$\pm$2.3 MK. The mass of the ejected X-ray loop and of the pre-eruption Hα filament were estimated to be $\sim 10^{14}$ g and $\leq 10^{15}$ g, respectively. Even if all the material of the pre-eruption filament was ejected, the total kinetic energy ($\leq 1.5 \times 10^{29}$ erg) of both the ejected X-ray loop and the eruptive Hα filament was smaller than the thermal energy content of the flare loops ($\sim 1.3 \times 10^{30}$ erg). This result implies that the energy involved in the ejected material was not the energy source of the flare, although they were closely related each other. The rising motion of the ejected X-ray loop was, presumably, one of the causes triggering the flare.

1. Introduction

A compact impulsive hard X-ray source is discovered above a soft X-ray flare loop in some impulsive flares with Yohkoh observations (Masuda et al. 1994). Shibata et al (1995) found that X-ray emitting plasma moves upward at about 50 – 400 km s^{-1} above the soft X-ray loop and the above-the-loop-top HXR source. These discoveries indicate that the impulsive flares occur through a magnetic reconnection which takes place in the vertical current sheet above flare loops. The X-ray plasmoid is a loop structure which is consistent with a three dimensional view of a plasma ejection in the reconnection model (Ohyama and Shibata 1997, 1998).

Ohyama and Shibata (1997, 1998) derived the physical conditions of the X-ray ejecta in the 1993 November 11 and 1992 October 5 events. The temperature of the ejected plasma was about 10 MK and its electron density was 10^{10} cm^{-3}, which was an order of magnitude larger than that of the typical active-region corona. They found that the kinetic energy of the ejecta was smaller than the thermal energy content of the flare loop. This result is not consistent with the assumption in some reconnection models that an ejected plasma stretches the overlying magnetic fields to form a current sheet and hence leads to magnetic reconnection. However, the flares which they analyzed were associated with only X-ray plasma ejection. If a flare is associated with both an X-ray plasma ejection and Hα filament eruption, does such a flare support the hypothesis or not? In this paper we analyze the 1993 May 14 flare, which was associated with both an X-ray plasma ejection and an Hα filament eruption. We investigate the spatial relationship between the X-ray ejecta and eruptive Hα filament, and compare the total kinetic energy of the ejected material (X-ray plasma and eruptive Hα filament) with the thermal energy content of the flare loops.

2. 1993 May 14 M4.4 Flare

An M4.4 class flare occurred on 1993 May 14 7500 at N20W48. The time profile of GOES X-ray flux shows two peaks in this event; a first peak at about 22:07, and a second (maximum) peak, corresponding to M4.4, at 22:53 UT. The first stage was a short duration event, while the second stage was a long duration event. Figure 1 shows the evolution of the flare observed in Hα. An Hα filament eruption occurred at the first stage, and Hα brightenings were composed of a chain of point-like features, and propagated both north-eastwards and south-westwards with time (21:57:46 – 22:02:47 UT). Then in the second stage a two-ribbon flare was clearly seen (22:48:17 and 23:00:59 UT). X-ray images show X-ray plasma ejections in the first stage and X-ray arcade structure in the second stage.

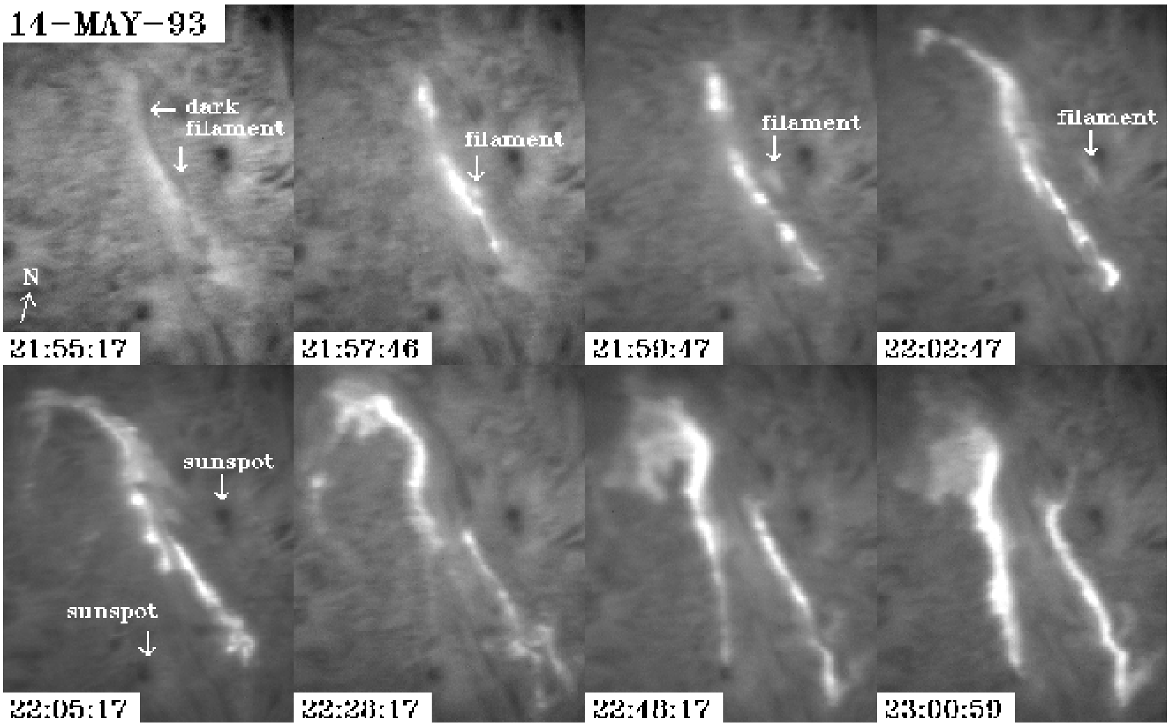

Fig. 1.. Development of the flare on 1993 May 14. The dark filament before its eruption is shown in 21:55:17 UT image. The eruptive filament is indicated by the arrows.

3. Relation Between X-ray Plasma and an Hα Filament

Both the Hα filament eruption and the X-ray plasma ejection occurred in the first stage. We are very interested in the spatial relation between the two. Figure 2 shows the Hα image at 22:02:47 UT coaligned with the SXT PFI image at 22:02:49 UT. The apparent features of the flare in the Hα and soft X-ray images were similar. The X-ray structures in the early phase of the filament eruption appeared nearly parallel to the pre-eruption filament, and the result is consistent with the *Skylab* observations (Kahler 1981). The ejected X-ray loop was situated near the eruptive filament, though we do not know their positions along the direction of the line-of-sight. To be ejected, the X-ray ejecta and eruptive Hα filament must be in the current sheet. If the X-ray plasma were in another current sheet, the Hα brightenings (ribbons) corresponding to other current sheet should be observed in the 22:02:47 UT image. However, only two ribbons were observed. Hence we think that the X-ray ejecta and eruptive Hα filament were in a same current sheet.

Figure 3 shows the apparent displacement of the eruptive filament and ejected X-ray loop without considering the projection effect. The Hα filament moved at $\sim$ 20 km s^{-1} ($\sim$ 30 km s^{-1} if we consider the projection effect assuming the ejecta moved radially) before the peak of the hard X-ray emission and was accelerated to $\sim$ 100 km s^{-1} (150 km s^{-1}). On the other hand, the X-ray loop was ejected at $\sim$ 270 km s^{-1} (400 km s^{-1}) after the filament eruption, and was decelerated to $\sim$ 100 km s^{-1} (150 km s^{-1}). Unfortunately, we cannot determine the location where the X-ray loop was launched, because the ejected loop was apparently hidden by the flaring loops in the early phase.

We suggest from these results that the X-ray loop was ejected from a region below and temporally after the filament eruption (Figure 4). Suppose that magnetic reconnection may have occurred in a vertical current sheet between the eruptive filament and the flare loops ($t = t_1$). Since the eruptive Hα filament continued to rise, the current sheet may have lengthened further with the rise of the filament ($t = t_2$). Suppose also that an impulsive magnetic reconnection occurred once again somewhere in the current sheet ($t = t_3$). Since the material within the plasmoid which was formed by the recent magnetic reconnection would not include cool material such as the Hα filament and would be heated through slow shocks or by the reconnection jet, it could be observed in soft X-rays. The loop shape of the ejected material is consistent with a three-dimensional view of a plasma ejection (i.e., plasmoid) in the reconnection model (e.g., Shibata et al. 1995) and with other X-ray plasma ejections (Ohyama and Shibata 1997, 1998).

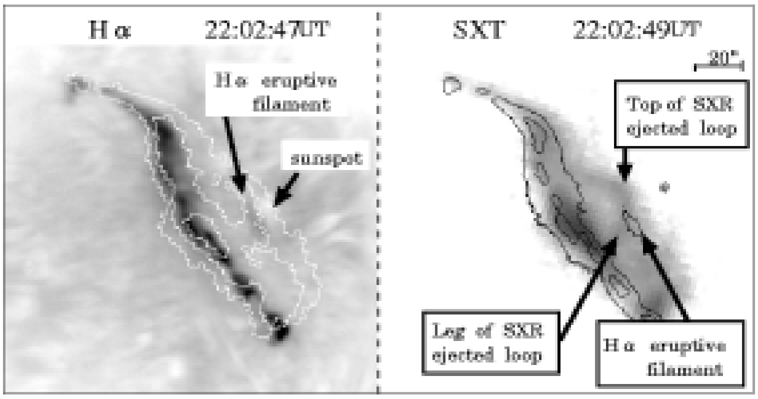

Fig. 2.. Coalignment images between SXT and Hα images. (Left) Contours of the SXT image overlaid on the Hα image. (Right) Contours of the Hα image overlaid on the SXT image.

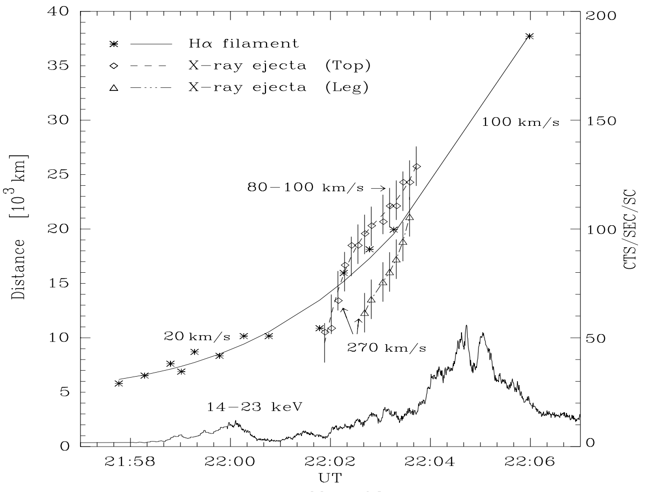

Fig. 3.. The apparent displacement of the ejected X-ray loop and Hα eruptive filament for the 1993 May 14 flare. The bottom curve shows the counting rates from the 14−23 keV channel of HXT. Asterisks indicate the height of the eruptive filament. Diamonds and triangles indicate the top and leg of the ejected X-ray loop. The smooth curve of the eruptive filament is drawn from constant acceleration fits. The position of the leg of the ejected X-ray loop corresponds to that of the eruptive filament, if the ejected loop rose along nearly the same trajectory as the eruptive filament. The values of the velocity are the apparent velocity.

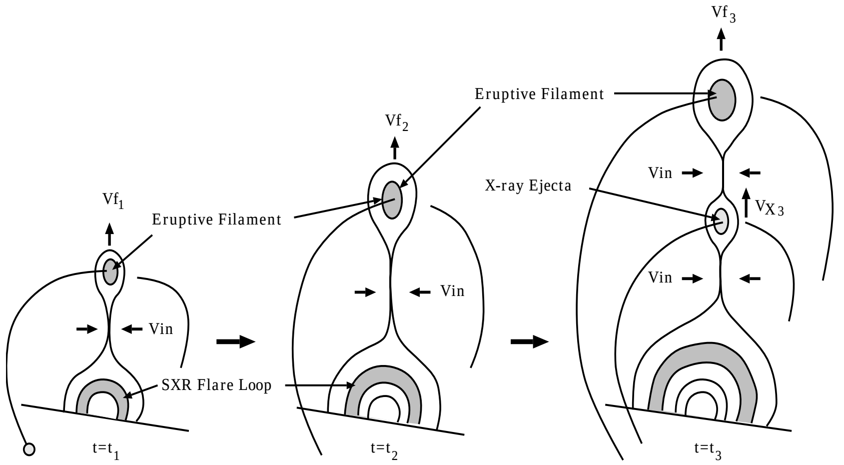

Fig. 4.. Schematic picture of the magnetic reconnection model for the 1993 May 14 flare. This is an extension of the CSHKP reconnection model. $V_{\rm f}$ and $V_{\rm X}$ is the velocity of the eruptive filament and the ejected X-ray loop, respectively. $V_{\rm in}$ is the inflow speed to the reconnection point.

Table 1.. Physical parameters of X-ray Ejecta and Eruptive H Filament

Physical Parameters	X-ray Ejecta	Eruptive Hα Filament
Temperature [MK]	7 – 12	1
Mass [g]	$\sim 10^{14}$	$\leq 10^{15}$
Kinetic Energy [erg]	$5{\times}10^{28}$ – 10^{29}	$\leq 5{\times}10^{28}$

(Thermal Energy Content of the flare loops $\sim 10^{30}$ [erg])

4. Ejected Plasma (Plasmoid) and Magnetic Reconnection

Ohyama and Shibata (1997, 1998) found that the kinetic energy of the ejecta was smaller than the thermal energy content of the flare loop. This result is not consistent with the assumption in some reconnection models that an ejected plasma stretches the overlying magnetic fields to form a current sheet and hence leads to magnetic reconnection. However, the 1993 May 14 flare was associated with not only the X-ray plasma ejection but also the Hα filament eruption, and hence we have to compare the total kinetic energy of both ejections with the thermal energy content of the flare loop. We derived the physical parameters of X-ray ejecta and eruptive Hα filament (Table 1). The kinetic energy of X-ray ejecta and Hα filament were $\sim 10^{29}$ and $\leq 5{\times}10^{28}$ erg, respectively. The thermal energy content of the flare loops was $\sim 10^{30}$ erg. The total kinetic energy of the plasmoid was an order of magnitude smaller than the thermal energy content of the flare loops. This result suggests that the energy involved in the ejected material was not the source of energy for the flare, although they were closely related.

References

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