

A RAPID CHANGE IN MAGNETIC CONNECTIVITY OBSERVED BEFORE FILAMENT ERUPTION AND ITS ASSOCIATED FLARE

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ABSTRACT

To gain insight to the cause of filament eruptions and flares on the Sun, we observed a filament that erupted in active region NOAA 8597. The observations consisted of $H\alpha$ filtergrams at three wavelengths (line center and $\pm 0.5 \text{ \AA}$) and line-of-sight magnetograms. All were taken on 1999 June 24 at Big Bear Solar Observatory. We found from the time sequence of $H\alpha$ images that the filament eruption was preceded by a rapid change in connectivity in a bundle of filament threads. The thread bundle was initially sharply curved near its one end of the filament and suddenly flipped and then became straight in the new orientation. The flipped segment of the thread bundle swept over a $100'' \times 50''$ area on the solar surface in about half an hour. At the latter stage of the connectivity change, we observed a downward draining of material along the thread bundle that had a transverse component of 50 km s^{-1} . After that, the filament body split into two parallel parts, one part erupted while the other part remained, and the two-ribbon flare occurred. We also found canceling magnetic features in the vicinity of the initial location of the thread end, which displayed a flux decrease during the $H\alpha$ connectivity change. Our results show clear and direct evidence that magnetic reconnection takes place in the low atmosphere *prior to* eruption. This preeruption reconnection seems to be very different from a posteruption coronal reconnection, which is believed to lead to a two-ribbon flare.

Subject headings: Sun: filaments — Sun: flares — Sun: magnetic fields

1. INTRODUCTION

Prominences, or equivalently filaments, are dense clouds of material that are suspended by a magnetic field above the solar surface typically for days or weeks. Prominences may suddenly erupt because of unknown reasons, often being associated with flares (Moore 1988; Martens & Kuin 1989) and coronal mass ejections (e.g., Smith, Hildner, & Kuin 1992; Filippov 1996).

Observations have indicated that a filament eruption may be closely related to changes in the magnetic field structure in and around the filament body. Rust et al. (1994) suggested a few possible candidates that provoke an unstable field configuration for an active region, i.e., sunspot motions, which produce magnetic shear, flux emergence, and flux cancellation. Raadu et al. (1988) regarded activities of pores as a common triggering mechanism of filament destabilization. Heyvaerts, Priest, & Rust (1977) and Simon et al. (1984) suggested that filament eruption and flaring are induced by different phases of emerging flux and the subsequent reconnection processes. Later, it was suggested that eruptive flares could be triggered by the interaction of one flux region with another (Priest 1992), which would show up as a canceling magnetic feature (CMF). The roles of CMFs were studied by Wang & Shi (1993). They measured the transverse field from vector magnetograms and determined topological connectivities of field lines. As a result, they found that the emergence of new flux and its driven flux cancellation are elementary processes that make filaments unstable. Recently, Kotrč et al. (1998) presented evidence of magnetic reconnection in prominence eruption based on enhanced $H\alpha$ images and Doppler mass motions. Pevtsov, Canfield, & Zirin (1996) reported the signature of reconnection before filament eruption in soft X-ray images. These are indirect ob-

servational evidences that magnetic reconnection may be important for filament eruptions.

In this Letter, we report a rapid connectivity change in threads of a filament that took place prior to the filament eruption. We interpret this as direct evidence for preeruption magnetic reconnection. We also report CMFs that appear to be associated with the connectivity change.

2. OBSERVATIONS AND RESULTS

On 1999 June 24, we observed an active region filament that was located in the east-north part (E408'', N361'') of the solar disk. High-cadence $H\alpha$ images at line center and two off-band wavelengths ($\pm 0.5 \text{ \AA}$) and line-of-sight magnetograms were taken at Big Bear Solar Observatory. We used the 65 cm vacuum reflector for $H\alpha -0.5 \text{ \AA}$, the 25 cm refractor for $H\alpha 0.5 \text{ \AA}$, and the $H\alpha$ full-disk telescope for the center line. The cadence of each observation was about 1 minute, and the duration of the observation was 8 hr, running from 16:00 to 24:00 UT.

In Figure 1, we show a set of selected $H\alpha 0.5 \text{ \AA}$ images that reveals a change in filament connectivity. The field of view is $215'' \times 215''$. The active region (NOAA 8597) was composed of two main sunspots of positive polarity and several small spots to the south of the field of view. The filament lay along the polarity inversion line, separating the positive polarity of the main sunspots and the negative polarity of nearby plage. Initially, filament threads were connected to the left sunspot and were highly curved (Fig. 1a). The left end of the filament threads expanded and became darker around 17:40 UT (Fig. 1b). Then, the curved expanding threads underwent explosive flipping (Figs. 1b–1d). This change took about

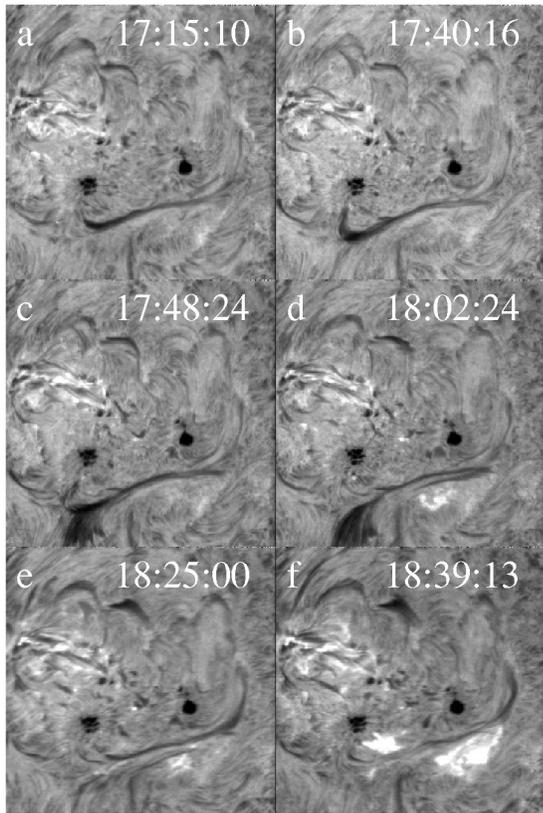


FIG. 1.—Related subset of the time sequence of $H\alpha$ images at 0.5 \AA

30 minutes, and the flipped threads swept out a $100'' \times 50''$ area on the solar surface. As a consequence of the change, the threads became straightened.

We observed transverse mass motion of about 50 km s^{-1} along these straightened threads. Our comparison of $H\alpha$ line center and the two off-band images show that the mass motion had a significant downward velocity component, too. Therefore, there seems to be downward draining of material along the threads. We also found $H\alpha$ brightenings at line center and at -0.5 \AA near the end of the straightened threads, which indicate that the threads became rooted at a new position.

Interestingly, we found that some threads remained in their

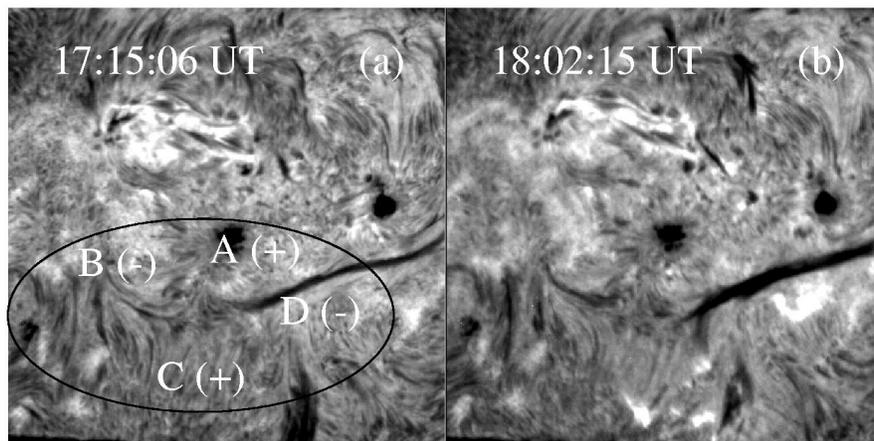


FIG. 2.— $H\alpha -0.5 \text{ \AA}$ images (a) before and (b) after the connectivity change. In the area within the ellipse, there exists a fibril structure that shows an X-shaped magnetic topology.

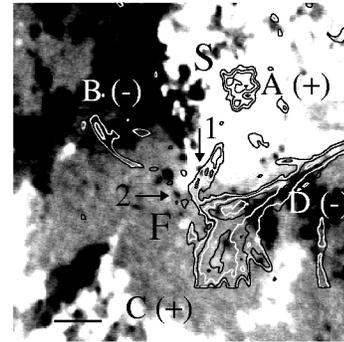


FIG. 3.—Line-of-sight magnetogram taken at 17:47:55 UT. The brightest and darkest patches correspond to the flux density levels equal to or higher than $\pm 50 \text{ G}$, respectively. CMFs are indicated by arrows. Contours represent the intensity levels of the $H\alpha + 0.5 \text{ \AA}$ image taken at 17:48:05 UT. The locations of the filament and nearby sunspot is labeled "F" and "S," respectively. The horizontal bar corresponds to $20''$.

original position without undergoing the connectivity change. This resulted in the splitting of the filament body into two parallel parts (Figs. 1c–1e). Only the part that underwent the connectivity change erupted, and a two-ribbon flare followed. The other part of the filament body was seen at the same position even after the flare (Fig. 1f). Partial filament eruptions were previously reported by Tang (1986) for various active region cases.

Figure 2 shows the alignment of fibrils in the region where connectivity change took place. It clearly displays an X-shaped structure. The filament was connecting regions A and D initially (Fig. 2a), but after the change, a part of it came to connect regions C and D (Fig. 2b). Note that the polarity is the same in regions A and C.

We have examined magnetogram data and found two CMFs near the curved end of the filament that appear to be associated with the filament connectivity (see Fig. 3). The CMFs are inside the X-shaped structure defined by the four regions A–D. CMF 1 consists of a negative flux island and the surrounding positive flux. The amount of the negative flux increased from zero at 16:00 UT up to $3 \times 10^{18} \text{ Mx}$ at 17:30 UT. Then, the flux decreased to $1 \times 10^{18} \text{ Mx}$ in the next half-hour when the connectivity change proceeded. The rate of the flux cancellation is estimated to be $4 \times 10^{18} \text{ Mx hr}^{-1}$. On the other hand, the

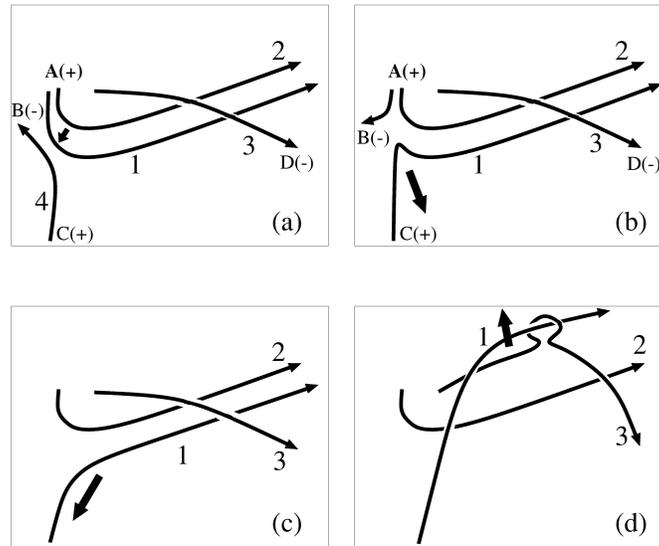


FIG. 4.—Schematic drawings of the filament evolution. (a) The initial expansion of the filament threads toward the center of the X-type configuration. (b) The filament flipping as a result of the chromospheric reconnection inside the X-type configuration. (c) The filament splitting with down-draining material. (d) The layer eruption of the filament and the subsequent coronal reconnection. Field lines 1 and 2 represent the filament, field line 3 the coronal arcade, and field line 4 the loop that interacted with the filament. The arrows indicate mass motions either along or perpendicular to the field lines.

major step of flux cancellation in CMF 2 occurred from 16:24 to 16:54 UT, preceding the $H\alpha$ connectivity change. The rate of flux cancellation in this CMF is $8 \times 10^{18} \text{ Mx hr}^{-1}$.

The observed initial increase of the negative flux at CMF 1 is mysterious. If it was due to the flux emergence, there should be a growing positive pole that is the partner of the negative flux patch. But we could not find any obvious candidate for the growing positive pole. Perhaps the observed flux variation reflects a sudden change of inclination of predominantly horizontal magnetic fields that is combined with the off-disk center effect of geometrical projection. This interpretation is, however, not realistic either, since the negative flux patch is round whereas a local portion of horizontal magnetic fields is expected to be elongated. Moreover, the off-disk center effect is not big enough. So, we regard the observed initial increase of flux at CMF 1 as an instrumental effect, that is, a result of the unveiling of the negative flux patch that had been hidden by the large amount of polarized stray light originating from the surrounding area of strong fields of positive polarity. In any case, the two CMFs we found may indicate liberation of magnetic energy, which provides some disturbance to curved filament threads.

3. DISCUSSION

The observational findings are as follows: (1) One end of the filament threads underwent a rapid connectivity change preceding the filament eruption. (2) A downward draining mass motion was observed along the newly connected threads. (3) The connectivity change occurred inside an X-shaped magnetic topology in association with CMFs. (4) After the connectivity change, the filament erupted partially, and an associated two-ribbon flare followed.

These results are direct evidence that magnetic reconnection took place before the filament eruption and the associated flare. Magnetic reconnection is defined as the change of magnetic field line connectivity and thus is what we observed in the filament before eruption. The observed filament showed a rapid flipping of threads inside an X-shaped magnetic field config-

uration. This kind of a rapid magnetic flipping has been theoretically expected in magnetic reconnection occurring in a three-dimensional space (Priest & Forbes 1992; Priest & Démoulin 1995). It is likely that the observed CMFs may be closely related to the initial expansion of the curved filament threads that led to the preeruption reconnection inside the X-type configuration. Our results are also compatible with numerous previous studies that indicated the importance of CMFs in disturbing filaments (Martin & Livi 1992; Wang, Shi, & Martin 1996; Jiang & Wang 2000).

The reconnection evidenced by our observations is distinguished from that which is supposed to lead to two-ribbon flare (e.g., Kopp & Pneuman 1976). What we observed is a preeruption reconnection, whereas a flare is thought to be an outcome of a posteruption reconnection. This strongly suggests that the preeruption reconnection may induce the filament eruption and the subsequent flaring. We conjecture that the downward-draining filament material, which is along the newly connected field lines, may have made the reconnected threads lighten and move upward, thus being partly responsible for the eruption. On the other hand, the posteruption reconnection is regarded as being the result of the filament eruption. The preeruption reconnection is distinct from the posteruption reconnection in the thermodynamical properties, too. The preeruption reconnection seems to have occurred at a cool temperature, $T \approx 10^4 \text{ K}$, as the connectivity change was well observed in $H\alpha$, whereas the posteruption reconnection in charge of flares is supposed to occur at very hot temperatures, $T \approx 10^7 \text{ K}$ (e.g., Tsuneta 1996).

Figure 4 summarizes our observations and interpretations. The initial magnetic configuration is represented in Figure 4a by the four sets of field lines labeled 1–4. Note that field lines 1, 2, and 3 connect the two regions A and D and field line 4 connects the other two regions, B and C. The apex of the curved portion of filament thread 1 expands toward the center of the X-type configuration, possibly as a result of some disturbance relevant to the observed CMFs. Figure 4b shows that the first reconnection occurs between field lines 1 and 4 at the center

of the X-type configuration, resulting in the flipping of the filament threads seen in H α . Next, the filament splits into two parts, 1 and 2 (Fig. 4c). Part 1 erupts, and as a consequence a coronal magnetic reconnection occurs in the coronal arcade 3 (Fig. 4d). The coronal reconnection is observed as the two-ribbon flare. Therefore, our observations demonstrate quite vividly that reconnection events occurring in the lower atmosphere trigger reconnection events in the upper atmosphere.

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