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Nonradial eruption of a kinking filament observed from STEREO

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ABSTRACT

On 5 April 2008, a filament at the periphery of an active region was observed by the Extreme Ultraviolet Imager telescope aboard the *STEREO*-A spacecraft, which showed up as a prominence eruption in the field-of-view from *STEREO*-B. The filament at *STEREO*-A 304 Å was first lengthened toward a region with weak overlying magnetic field so evolved as a large-scale one consisting of bright and dark threads twisting with each other, and then the portion below the weak field underwent an eruption. Meanwhile, the corresponding *STEREO*-B 304 Å prominence threads exhibited a kinking structure and tilting motion, with its center deflecting from the radial direction. By using three-dimension (3D) reconstruction technology, we obtain the 3D topology for the kinked prominence when its apex arrived at 1.4 radii, from which a clockwise rotation of about 90° is found in the course of the eruption. By comparing the 3D structure with the magnetic-field configuration computed by using the Potential-Field Source-Surface (PFSS) model, it is suggested that the filament erupted against the rather weaker than stronger overlying magnetic field, which make it appear to tilt toward one side.

1. Introduction

Solar prominence is striking extended emission structures over the solar limb in chromospheric spectral lines, which consist of relatively cold chromospheric material and protrude high into the million degree solar corona. When viewed on the solar disk, these structures form sinuous absorption features, known as filaments. Since there is no physical distinction between them, the terms of filament and prominence can be used interchangeably. They are always located along the magnetic polarity inversion lines (PILs) that separate opposite-polarity magnetic field regions in the photosphere. It is believed that the filament magnetic fields are twisted and there is a one-to-one correspondence between their magnetic helicity and chirality (Martin et al., 1994). Based on the chirality, filaments are classified as sinistral and dextral ones, in which the axis fields always point to the left and right for an observer in the positive-polarity side, respectively. Some authors have made use of a twisted flux rope to match the initiation process of filament eruptions, which exhibits a writhing motion when kink instability happens after the flux-rope twist exceeds a critical value (e.g., Hood and Priest, 1979; Kliem et al., 2004). The writhe, which can be thought of as the rotation causing the helicity of the flux rope axis itself when a flux rope experiences a kinking motion, is converted from the twist of the field required by the magnetic helicity conservation. Moreover, by studying the crossing topology of bright and dark threads consisting of the filament observed at EUV, Chae, 2000 suggested that the interwinding threads follow the local helical field lines inside filaments. Rust and LaBonte, 2005 further provided observational evidence of that the helicity signs of kinked filaments indeed match the signs of twist structures inferred from the crossing threads of pre-eruption filaments.

Recent observations of kinking in a number of filament eruptions, including full (Williams et al., 2005), partial (Gibson and Fan, 2006), and failed (Ji et al., 2003) eruptions, suggested that interaction between an eruptive filament and its magnetic environment plays an important role in deciding whether it can evolve as a coronal mass ejection (CME; for full or partial eruption) or is confined (for failed eruption). Simulations of Török and Kliem, 2005 showed that the kink instability could trigger a full eruption if its overlying magnetic field decreases fast with height. By studying the magnetic field overlying eruptive filaments using a Potential-Field Source-Surface (PFSS) model, Liu, 2008 suggested that the field strength at low altitude might be another factor in deciding whether or not a full eruption would take place. More recently, Jiang et al., 2009 studied interaction between an eruptive filament and its overlying helmet streamer, and found that the streamer arcade can act on the erupting filament, laterally deflected and channeled its motion.

A kinking filament has been known as a characteristic three-dimension (3D) structure, but it was mainly inferred by

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observations from one view in the early year (e.g., Green et al., 2007; Liu et al., 2007). Since a suit of optical telescopes, by the name of Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI; Howard et al., 2008) on board both Ahead and Behind of the twin *Solar Terrestrial Relations Observatory* (*STEREO* A and B) spacecrafts, can provide simultaneous images from two different views, the 3D shape of a filament can be inferred by using data from the Extreme UltraViolet Image (EUVI; Wuelser et al., 2004) included in SECCHI. Different kinds of 3D filament structures have been reported. For example, a kinking prominence exhibited a writhing motion of about 120° in its eruptive phase (Thompson et al., 2009), and a large quiescent polar crown prominence was also seen to undergo substantial rotation of at least 90° as it rose (Thompson, 2010). The event reported by Bemporad, 2009 showed that a prominence expanded mainly parallel to the plane of the sky, and Liewer et al., 2009 presented that a filament erupted in an asymmetric, whip-like fashion.

In the paper, we study a filament eruption observed by the twin *STEREO* spacecrafts on 5 April 2008. The eruptive filament exhibited twist structures in its activation phase, showed a kinked shape as it rose, and then erupted to tilt toward one side. In order to account for such nonradial motion, we also compare the 3D shape of the filament at two moments with the magnetic field topology extrapolated by using a PFSS model.

2. Observations and data analysis

2.1. Instrumentations and data

Our primary data source is provided by the EUVI telescopes aboard the twin *STEREO* spacecrafts with a separation angle of 48° on 5 April 2008. EUVI's 2048 × 2048 pixel detectors have a field-of-view (FOV) out to about 1.5 solar radii, and observations are made in four spectral channels, of which wavelengths are 171, 195, 284, and 304 Å, respectively. The standard SECCHI synoptic program running provide simultaneous observations from the twin spacecrafts at a ten-minute cadence for 304 Å and a 20-min cadence for 284 Å. Began at 18:00 UT on 5 April 2008, however, EUVI 304/284 Å images were obtained at a rate of one every 2.5/5 min for our event. To identify the associated CME, observations from Inner Coronagraphs (COR1; Thompson et al., 2010) included in SECCHI are also used. Having a FOV from 1.5 to 4 solar radii, COR1 images were available at a 5-min cadence for our event. Finally, full-disk H_α line-center images with a pixel resolution of $2''.29$ and a three-minute cadence from the Mauna Loa Solar Observatory (MLSO; MacQueen et al., 1998) and line-of-sight magnetograms from the Michelson Doppler Imager (MDI; Scherrer et al., 1995) aboard the *Solar and Heliospheric Observatory* (*SOHO*) are also examined.

2.2. Evolution of the filament observed from the two views

The eruptive filament located at the periphery of a decaying active region (AR), NOAA AR 10989 in the southern hemisphere. The EUVI observations presented in Fig. 1 show the general appearance of the filament observed from different views by the two *STEREO* spacecrafts at 15:36 UT just prior to its disturbance. In *STEREO*-A images, the whole body of the filament was on the solar disk and along northwest–southeast direction, whereas only its eastern part was seen in the western limb but the other part was already behind the limb from the view of *STEREO*-B. The overlay of the *STEREO*-A images with the contours from a corresponding MDI magnetogram indicates that the northern end of the filament was rooted in a negative-polarity region. Consistent with the preferential hemisphere pattern of filament chirality (Zirker et al., 1997; Martin, 1998), therefore, we identify the filament as a sinistral one.

The filament eruption was preceded by a distinct activation phase, which can be seen from the *STEREO*-A EUVI 304 and 171 Å images presented in Fig. 2. First, a brightening around the filament's northern endpoint was observed at 171 Å (see the inserts in panels a1–a2 of Fig. 2), then its northern half part was covered by a bright thread (see panel a3 of Fig. 2), and eventually the filament seen on panel a4 of Fig. 2 became a longer one with its southern end having shifted to further south relative to that at 15:36 UT. Noted that by 18:51 UT the filament has consisted of a bright and a dark thread, which was outlined with red and green line, respectively on panels a4 of Fig. 2. The bright thread seemed to be a fountain of material spilling onto the disk from the northern endpoint of the filament (Gilbert et al., 2001), and cover the northern segment of and pass under the southern segment of the dark thread, and thus the sign of the mutual helicity of the two threads can be inferred to be positive (i.e., right-helicity) from their geometry of crossing as the cartoon on panel a4 of Fig. 2 shown (Chae, 2000). Compatible with the sinistral chirality of the filament, such activation makes us infer that the filament had a right-handed magnetic field based on the assumptions made by Chae, 2000 that the mutual helicity of the two threads has the same sign as that of a filament.

Panels b1–b4 of Fig. 2 show the MLSO H_α image that has been geometrically transformed to the view of *STEREO*-A, in which the filament also exhibited consistent evolution that appeared to be elongated toward the south. The green curve outlining the 15:36 UT 304 Å filament seen from panel a1 just overlapped the H_α filament on panel b1 of Fig. 2, but had different location with that on panel b2 of Fig. 2, suggesting that the filament has been elevated during this time. A similar example of the filament activation has been reported by Liewer et al., 2009, who found that the hotter material seemed to be originated from the end of the filament made the filament extend to greater height. Thus, like the pattern of the zipping-like asymmetric filament eruption discussed by Liu et al., 2009, the elevating motion of the northern segment of the filament may make the filament rise and expand toward its invisible end, which is not loaded enough mass before the activation phase, and then make the filament appear to elongate toward the south. Comparing the overlay of the outlines of the two 304 Å threads, moreover, we find that the disappearing segment of H_α filament on panel b4 just overlapped the 304 Å bright thread at the segment covering the 304 Å dark thread. It thus seems that the hotter material implied by the bright thread makes the H_α line shift out of the filter band, so that the filament seen from H_α image appeared to split up into two separates (Liewer et al., 2009; Bone et al., 2009).

After about 19:46 UT, the filament started to undergo a drastic eruption. This is shown in *STEREO*-A EUVI 284 and 304 Å, and *STEREO*-B EUVI 304 Å and COR1 observations in Fig. 3 (Also see the movie 1 showing the EUVI 304 Å data from both spacecrafts' views, which is available as a QuickTime video in the Electronic version of the Journal). To aid matching, the outline of the 304 Å filament at 15:36 UT before its activation phase is also plotted as green curve on panel a1. It is noted that, in 284 Å images, there were bright arches covering the northwest segment of the filament spine, but two dark thin threads (marked by yellow and cyan arrows, respectively on panels a1–a2 of Fig. 3) instead of loop-like feature appeared around its southeast segment in the course of the eruption. By 20:16 UT, we see that on panel a3 of Fig. 3 the above one (marked by the cyan arrow) of the two dark threads seen in 284 Å has disappeared but the below one still remains (marked by the yellow arrow). In 304 Å difference images, such eruption can be clearly discernible. These difference images are derived by subtracting a same background image from the image at a given time in each case, in which the background image is obtained by