EVIDENCE FOR MIXED HELICITY IN ERUPTING FILAMENTS

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ABSTRACT

Erupting filaments are sometimes observed to undergo a rotation about the vertical direction as they rise. This rotation of the filament axis is generally interpreted as a conversion of twist into writhe in a kink-unstable magnetic flux rope. Consistent with this interpretation, the rotation is usually found to be clockwise (as viewed from above) if the post-eruption arcade has right-handed helicity, but counterclockwise if it has left-handed helicity. Here, we describe two non-active-region filament events recorded with the Extreme-Ultraviolet Imaging Telescope on the Solar and Heliospheric Observatory in which the sense of rotation appears to be opposite to that expected from the helicity of the post-event arcade. Based on these observations, we suggest that the rotation of the filament axis is, in general, determined by the net helicity of the erupting system, and that the axially aligned core of the filament can have the opposite helicity sign to the surrounding field. In most cases, the surrounding field provides the main contribution to the net helicity. In the events reported here, however, the helicity associated with the filament “barbs” is opposite in sign to and dominates that of the overlying arcade.

Key words: Sun: corona – Sun: coronal mass ejections (CMEs) – Sun: filaments – Sun: magnetic fields – Sun: prominences – Sun: UV radiation

1. INTRODUCTION

Hanle effect measurements (Bommier et al. 1994) have shown that quiescent (non-active-region) filaments have “inverse” magnetic polarity, meaning that their transverse field component is opposite in sign to that of the coronal loops crossing high over the photospheric neutral line. The usual interpretation of this result is that the filament material is supported in the dipped or concave-upward portions of a twisted flux rope (see, e.g., van Ballegooijen & Martens 1989; Rust & Kumar 1994; Low 1996; Aulanier & Démoulin 1998; Amari et al. 1999; Lites 2005; Gibson & Fan 2006). For this topology, it is natural to assume that one sign of helicity prevails throughout the flux rope and its overlying arcade.

In an alternative scenario, the filament is regarded as a sheared arcade whose intermediate legs or “barbs” are rooted in minority polarity on the “wrong” side of the neutral line (Martin 1998). In that case, the helicity of the filament itself would be opposite in sign to that of the overlying coronal loops, contrary to most theoretical models. Possible support for this picture comes from the observation of continual flows along the spines and up and down the barbs of filaments (Zirker et al. 1998; Wang 1999; Kucera et al. 2003; Lin et al. 2003, 2005); such flows, which may be driven by chromospheric reconnection (Litvinenko & Martin 1999; Martin et al. 2008), seem to obviate the need for static support within magnetic dips, one of the principal arguments in favor of a flux rope geometry.

Statistically (and independently of the flux rope/sheared arcade question), it is found that filaments in the northern (southern) hemisphere are predominantly “dextral” (“sinistral”), meaning that their axial fields point to the right (left) when viewed from the positive-polarity side of the photospheric neutral line (Martin 1998; Pevtsov et al. 2003; Yeates et al. 2007; Yeates & Mackay 2009). Dextral (sinistral) filaments have right-bearing (left-bearing) barbs but underlie arcades with left-handed (right-handed) helicity. The helicity sign of the overlying arcade can be inferred from the skew of the arcade loops relative to the polarity inversion line (PIL).

Although the magnetic topology of a stable filament/prominence remains a subject of debate, it is almost universally accepted that an erupting filament and its surrounding field have the structure of a twisted flux rope. In a three-dimensional system, the pinching-off of pairs of stretched, opposite-polarity field lines beneath the rising filament will necessarily give rise to a flux rope; reconnections may occur among the legs/barbs of the filament, between the legs and the overlying arcade, and among the highly distended arcade field lines themselves. As the bright post-eruption arcade expands outward from the PIL, the orientation of the reconnected loops (seen projected against the photosphere) will appear to rotate clockwise (counterclockwise) if the arcade has right-handed (left-handed) helicity; this apparent rotation is due to the tendency for the loops rooted farther from the PIL to cross it more nearly at right angles.

The axes of the erupting filaments themselves are sometimes observed to rotate about the vertical direction. As viewed from above, this rotation is again usually clockwise if the post-event arcade has right-handed helicity, and counterclockwise if it has left-handed helicity (for examples, see Rust & LaBonte 2005; Green et al. 2007; Wang et al. 2009). The sense of rotation is consistent with the conversion of field-line twist into writhe (three-dimensional twisting of the axis itself), as predicted by MHD simulations of kink-unstable flux ropes (Linton et al. 1999; Kliem et al. 2004; Török & Kliem 2005) and sheared arcades that have been converted into erupting flux ropes via reconnection (Lynch et al. 2009). It is reasonable to assume that the net helicity of the erupting structure is the sum of the helicity of the original filament and that of the surrounding field with which it has become entrained by reconnection (see Berger 1998). If the barb system and the overlying coronal field have opposite helicity signs, as suggested by Martin (1998), then in most events the main contribution to the helicity of the erupting
structure must come from the surrounding field (compare also the discussion of Ruzmaikin et al. 2003). However, the question arises as to whether the rotation ever occurs in the direction opposite to that implied by the helicity of the overlying arcade, thereby providing stronger support for the barb picture of Martin.

Here, we describe two events observed with the Extreme-Ultraviolet Imaging Telescope (EIT; Delaboudinière et al. 1995) on the Solar and Heliospheric Observatory (SOHO), in which the erupting quiescent filament appeared to rotate counterclockwise but the post-eruption arcade had right-handed helicity.

2. EVENT OF 1999 SEPTEMBER 20

The sequence of Fe xii 19.5 nm images in Figure 1 shows the eruption of a southern-hemisphere filament on 1999 September 20. The dark filament in fact represents the western half of a longer structure that occupies a circular filament channel. The axis of the erupting feature undergoes a continual counterclockwise rotation between \( \sim 03:00 \) and \( \sim 05:00 \) UT. In order to exhibit this rotation more clearly, we have traced the filament spine at successive times and superposed these traces in Figure 2, after shifting them in longitude to correct for the average photospheric rotation. We note that the observed motions cannot be interpreted simply as a straightening of the initially highly curved filament as it rises, which would require both the northern and southern portions of the filament to move eastward; instead, the northern section moves eastward but the southern section moves westward, consistent with a counterclockwise rotation of the filament axis. Subsequently (after 04:48 UT), the rotation "overshoots" near both the northern and southern ends of the erupting filament, which thus kinks into a forward-S shape. As shown in Figure 1, the post-event arcade with its double row of footpoint brightenings begins to form after \( \sim 04:36 \) UT. In addition, in the images recorded between 04:36 and 05:12 UT, EUV brightenings (circled in Figure 1) may be seen at the far endpoints of the erupting filament; these brightenings occur as the filament threads, anchored well outside the filament channel itself, are jerked upward into a vertical orientation (see Wang et al. 2009). From the slant of the post-eruption loops in the image taken at 06:00 UT, and from the apparent clockwise rotation of the loop orientation between 06:00 and 07:13 UT, we conclude that the overlying arcade has right-handed helicity.
even though the filament rotates counterclockwise. The first post-eruption loops (observed at 06:00 UT) are located near the original pivot point of the filament rotation, where the traces approximately intersect in Figure 2, suggesting that the instability and rapid upward motion of the filament were initiated in this region.

Figure 3 shows the distribution of photospheric magnetic flux underlying the erupting filament. Here, we compare a Michelson Doppler Imager (MDI) line-of-sight magnetogram taken at 04:48 UT with the difference between the 19.5 nm images recorded at 04:48 and 04:36 UT. The magnetogram, saturated at ±50 G, represents a five-minute average of higher cadence data. The circular filament channel evidently encloses a positive-polarity region. Since the northern (southern) end of the erupting filament is rooted in negative-polarity (positive-polarity) network flux, the axial field points to the left so that the filament is sinistral.

As indicated by the He II 30.4 nm images in the left column of Figure 5, the filament re-forms immediately after the eruption; however, its northern end now bends westward rather than eastward (see also the Hα image in Figure 4, the bottom panel). The MDI magnetograms in the right column of Figure 5 suggest that this change in the shape of the filament, as well as the eruption itself, may have been associated with the emergence of a small magnetic bipole to the west of the original filament.

The eruption is shown in more detail in the sequence of Fe XII 19.5 nm running-difference images in Figure 8. The post-event arcade begins to form at 15:00 UT, with the appearance of a compact bundle of highly sheared loops that are almost aligned with the filament channel. From the MDI magnetogram (the fourth panel of Figure 8), we conclude that the western end of this narrow bundle of reconnected loops lies on the negative-polarity side of the photospheric neutral line, implying right-handed helicity. That the overlying arcade is indeed right-handed is confirmed by the subsequently forming loops (see the bottom panel of Figure 8), which are rooted farther from the PIL and are shifted clockwise relative to the earlier loops.

Hα images recorded at BBSO on September 27 show that the preeruption filament had left-bearing barbs (see Figure 9), consistent with sinistral chirality.

3. EVENT OF 2001 SEPTEMBER 28

The sequence of EIT He II 30.4 nm images in Figure 6, taken at six-hourly intervals, shows the disappearance of a high-latitude filament in the southern hemisphere on 2001 September 28. In the frame recorded at 13:19 UT, during the eruption itself, the axis of the filament shows a pronounced counterclockwise rotation relative to its preeruption orientation. This kinking into a forward-S shape is seen even more clearly in Figure 7, where we have superposed four successive traces of the filament spine taken between 19:19 UT on September 27 and 13:19 UT on September 28, after removing the effect of the photospheric differential rotation.

In association with this filament event, the Large Angle and Spectrometric Coronagraph (LASCO) on SOHO observed a faint halo coronal mass ejection (CME) with an average speed of 600 km s⁻¹.

See http://soi.stanford.edu.
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4. DISCUSSION

Filaments are conventionally regarded as cool material supported inside the dips of a helical flux rope of a given “handedness.” If the flux rope becomes unstable, its axis rotates about the direction of ascent, with the rotation being clockwise (counterclockwise) if the flux rope has right-handed (left-handed) helicity. Although observations of filament eruptions have tended to support this picture, we have here described two events in which the filament rotated in the opposite sense to that implied by the handedness of the surrounding arcade. Both of these quiescent filaments were located in the southern hemisphere and had left-bearing barbs; their axes rotated counterclockwise, even though the post-event arcades were clearly right-handed. By helicity conservation (Berger 1984), the source regions must have had mixed helicity, since the left-handed writhe acquired through the counterclockwise rotation could only have originated in negative helicity embodied as twist or shear in the preeruption field.

If the filament barbs are concave-downward features, as advocated by Martin (1998), their helicity sign or handedness would be opposite to that of the overlying coronal loops. The direction of rotation of the erupting structure would then depend on whether the barbs or the overlying arcade provides the main contribution to the net helicity. From a preliminary survey of the entire EIT database for solar cycle 23, we were able to determine unambiguously the direction of rotation of an erupting filament in only ~10 events. Presumably because of the relatively low cadence of the EIT observations, all of these events involved non-active-region filaments, of which only the two discussed here rotated in the “wrong” sense. In the active region events examined by Rust & LaBonte (2005) and Green et al. (2007), the acquired writhe of the erupting filament and the helicity observed in the surrounding field were always of the same sign. Thus, if the barbs and the surrounding field have opposite helicity signs, then the helicity of the overlying arcade must dominate in most eruptions, particularly those occurring in active regions. That the exceptions found here involve quiescent
Figure 6. Sequence of EIT He\textsc{ii} 30.4 nm images taken at six-hourly intervals showing the disappearance of a southern-hemisphere filament on 2001 September 28. The filament axis has clearly undergone a counterclockwise twist at 13:19 UT, in the midst of the eruption itself. The 1040' × 520'' field of view is centered at (5°E, 32°S).

Figure 7. Successive traces of the filament spine in Figure 6 are shown superposed, after correcting for the longitudinal displacement (relative to 13:19 UT, 2001 September 28) due to the photospheric differential rotation. Orange: 19:19 UT (September 27). Blue: 01:19 UT (September 28). Green: 07:19 UT (September 28). Red: 13:19 UT (September 28). Field of view is the same as in Figure 6. At 13:19 UT, the western end of the filament splits into two branches; the southern branch is indicated by dashed lines.

Figure 8. Closer look at the 2001 September 28 filament eruption (same field of view as in Figure 6). Top three panels: Fe\textsc{xii} 19.5 nm running-difference images taken at 13:13, 13:49, and 15:00 UT. Fourth panel: MDI line-of-sight magnetogram recorded at 15:00 UT (five-minute average of higher cadence data). Bottom panel: 19.5 nm running-difference image taken at 15:48 UT, where the post-event arcade is seen to have right-handed helicity. The first compact bundle of reconnected loops, appearing at 15:00 UT, is highly sheared and almost aligned with the filament channel; its westernmost end (circled) lies on the negative-polarity side of the PIL, again indicating right-handed helicity.

Filaments might be due to the fact that the latter are more likely to have well-developed barb systems than active region filaments. As suggested by Wang (2001), barbs form when flux elements that have become connected to the overlying axial field diffuse across the filament channel and undergo flux cancellation on the other side.

That the helicity tends to be concentrated in the surrounding field rather than in the filament itself is consistent with recent...
models of active region fields, in which a flux rope is inserted into a potential configuration and the system is allowed to relax, including the effect of a helicity-conserving magnetic diffusion (Bobra et al. 2008; Su et al. 2009). The observed Hα filament and surrounding coronal-loop structure are best fit with a highly sheared but weakly twisted flux rope held down by the overlying arcade; as in a hollow solenoid, the electric currents and magnetic helicity are concentrated in a semicylindrical shell around the outer edge of the flux rope, not within its interior, where the field lines are essentially straight and not much current flows. Moreover, for stability, the amount of axial flux must be small compared with the total flux that holds down the filament. Thus, it is not surprising that it is the helicity of the surrounding field that usually determines the direction of rotation of an erupting active region filament.

The event of 1999 September 20 provides support for the hypothesis that some filament eruptions are triggered by the emergence of flux near the filament channel (see, e.g., Bruzek 1952; Feynman & Martin 1995; Wang & Sheeley 1999). In this particular case, the eruption was accompanied by a reconfiguration of both the underlying photospheric neutral line and the shape of the filament itself. Sheeley et al. (1975) described a rather similar event in which the eastward hook of an Hα filament disappeared and was replaced by a westward hook that pointed toward a region of newly emerging flux (the sense in which the filament axis rotated during the eruption is unknown).

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