We present observations of the interactions between the two filament channels of different chiralities and associated dynamics that occurred during 2014 April 18–20. While two flux ropes of different helicity with parallel axial magnetic fields can only undergo a bounce interaction when they are brought together, the observations at first glance show that the heated plasma is moving from one filament channel to the other. The SDO/AIA 171 Å observations and the potential-field source-surface magnetic field extrapolation reveal the presence of a fan-spine magnetic configuration over the filament channels with a null point located above them. Three different events of filament activations, partial eruptions, and associated filament channel interactions have been observed. The activation initiated in one filament channel seems to propagate along the neighboring filament channel. We believe that the activation and partial eruption of the filaments brings the field lines of flux ropes containing them closer to the null point and triggers the magnetic reconnection between them and the fan-spine magnetic configuration. As a result, the hot plasma moves along the outer spine line toward the remote point. Utilizing the present observations, for the first time we have discussed how two different-chirality filament channels can interact and show interrelation.

Key words: magnetic reconnection – Sun: activity – Sun: filaments, prominences – Sun: magnetic fields

Supporting material: animations

1. INTRODUCTION

Solar filaments/prominences are characterized as cool and dense structures that lie above the solar surface in the hot corona (Lobas et al. 2010; Mackay et al. 2010). Filaments exist in the magnetic dips within magnetic configurations known as filament channels or flux ropes (Aulanier et al. 2002; Liu et al. 2012). Filaments and/or associated channels sometimes interact and show interesting dynamics in the chromosphere and low corona (Uralov et al. 2002; Schmieder et al. 2004; Su et al. 2007; Bone et al. 2009; Kumar et al. 2010; Liu et al. 2010; Chandra et al. 2011; Filippov 2011; Li & Ding 2012; Jiang et al. 2013, 2014; Joshi et al. 2014a). During an interaction under specific conditions, these magnetic structures can reconnect and change their footprint connectivity. They can also merge to form one common filament. The first type is known as a “slingshot” reconnection and the second type is “merging” (see paper by Linton et al. 2001; Linton & Antiochos 2005). Additionally, large-scale flux-rope interaction/merging in the outer corona has also been observed in the form of CME–CME interaction and their merging (Gopalswamy et al. 2001; Joshi et al. 2013).

Some observational studies discuss the observational evidence of slingshot magnetic reconnection between filaments (Kumar et al. 2010; Chandra et al. 2011; Filippov 2011; Jiang et al. 2013). Kumar et al. (2010) and Chandra et al. (2011) first reported the interaction, reconnection, and footpoint connectivity change between two nearby filaments using Hα observations on 2003 November 20. Later on, Filippov (2011) reported a few observational cases showing pairs of large filaments joining and exchanging their halves. More recently, Jiang et al. (2013) reported more observational evidence of partial slingshot reconnection during the interaction of two filaments on 2011 December 3.

There are relatively few numerical simulations that have been performed for the slingshot reconnection between flux ropes (Linton et al. 2001; Linton & Antiochos 2005; Török et al. 2011a). Linton et al. (2001) and Linton & Antiochos (2005) presented different types of flux rope interactions using three-dimensional magnetohydrodynamic (MHD) simulations for convection zone conditions. Later on, Török et al. (2011a) simulated the 2003 November 20 filament interaction using a three-dimensional zero β MHD model for coronal conditions and interpreted it in terms of “slingshot” reconnection between two magnetic flux ropes.

The merging of two filament channels after dynamic interactions has also been observed by Schmieder et al. (2004), Bone et al. (2009), Jiang et al. (2014a), and Joshi et al. (2014a). Schmieder et al. (2004) found evidence of a merging of two segments with dextral chiralities to form a long dextral filament. Recently, Jiang et al. (2014) reported the interaction and merging of two sinistral filaments on 2001 December 6, and found that they form a new long magnetic channel. More recently, Joshi et al. (2014a) reported an interesting dynamic event of the merging of two filament channels and formation of a long compound flux rope on 2014 January 1. On the basis of numerical simulations, some authors discussed various conditions necessary for the interaction/merging of filaments. DeVore et al. (2005) and Aulanier et al. (2006) modeled filaments as differentially sheared arcades and found that two filaments occupying a single polarity inversion line (PIL) in a bipolar large-scale magnetic configuration easily merged if
their chiralities were identical and the axial magnetic fields were aligned. This is in accordance with empirical rules for filament interaction found by Martin et al. (1994) and Schmieder et al. (2004). However, in a quadrupolar configuration the situation is more complex and ambiguous (DeVore et al. 2005; Linton 2006; Romano et al. 2011).

Linton et al. (2001) and Linton & Antiocos (2005) numerically analyzed the reconnection of two twisted flux tubes contacting at different angles. The result of interaction depends on the twist handedness of the tubes and the angle between their axial magnetic fields. A pair of oppositely twisted flux tubes shows a bounce interaction if their axial magnetic fields are parallel, and a slingshot reconnection if their axial magnetic fields are anti-parallel or perpendicular. Linton et al. (2001) and Linton & Antiocos (2005) considered isolated flux tubes without a surrounding magnetic field. But flux ropes containing filaments are not isolated flux tubes, they are imbedded into coronal magnetic fields created mostly by photospheric sources and follow basically photospheric PILs. For example, observations of filaments crossing each other at different heights are very rare. Oppositely twisted flux ropes with anti-parallel axial magnetic fields need the presence of an additional PIL between them to be in equilibrium in the coronal magnetic field. Therefore, the slingshot interaction of filaments of different chiralities may be different.

In this paper we present observations of the interaction of two adjacent filament channels of different chirality associated with two adjacent PILs within a fan-spine configuration. This kind of dynamic interaction has not been discussed in detail before. We discuss the filament-channel interaction dynamics, the probable magnetic reconnection at a null point above them, different helical motions, and the apparent exchange of heated plasma between different filament channels. The structure of the paper is as follows: Section 2 deals with the description of the observational data set used in the paper. Morphology and magnetic structure of the filaments are discussed in Section 3. Different events of interactions and associated plasma dynamics are described in Section 4. In Section 5 we present an interpretation of the observed phenomenon in the light of filament flux-rope models and discussion. Main results and conclusions are listed in Section 6.

2. OBSERVATIONS

We used the Big Bear Solar Observatory (BBSO) and the National Solar Observatory (NSO)/Global Oscillation Network Group (GONG) Hα observations for the present study. The BBSO high resolution images are collected from the archive at http://www.bbso.njit.edu/ are used to investigate the chiralities of the filaments. The GONG data are available in the data archive at http://halPHA.nso.edu/archive.html, with full disk images in 6563 Å line. The images have a spatial resolution of 1″ and a cadence of around one minute (Harvey et al. 2011). The GONG Hα observations are used to get the information about the filament activation and partial eruption dynamics. We also used data from the Atmospheric Imaging Assembly (AIA; Lemen et al. 2012) instrument on board the Solar Dynamics Observatory (SDO). It observes the full disk of the Sun in ultra-violet, extreme ultra-violet (EUV), and continuum wavelengths. The minimum cadence for the EUV images is 12 s with a pixel size of 0″.6. We used AIA images in 304, 171, 193, 131, and 94 Å wavelength channels. The line of sight (LOS) photospheric magnetic field data are obtained by the Helioseismic and Magnetic Imager (HMI; Schou et al. 2012), with a spatial resolution of 1″ and a minimum cadence of 45 s. It is also an instrument on board the SDO.

3. MORPHOLOGICAL AND MAGNETIC STRUCTURE OF THE FILAMENTS

Figures 1(a) and (c) represent the BBSO Hα images at ~18:46 UT on 2014 April 15 and ~17:01 UT on 2014 April 16, respectively. Figure 1(b) shows the SDO/AIA 304 Å images at ~18:46 UT on 2014 April 15. These images show the filaments and filament channels about three to four days before the first interaction that starts on 2014 April 18. Two dark filaments, named as the northern filament (NF) and southern filament (SF), are clearly seen in the Hα images (Figures 1(a) and (c)). The extended filament channels of both filaments can be seen in the SDO/AIA 304 Å EUV image (Figure 1(b)). Figure 1(d) shows the SDO/HMI LOS magnetogram at 18:46:19 UT on 2014 April 15. To find out the filament positions and approximate endpoint locations, we tracked the filament spines from the Hα image (see Figure 1(a)) and overplotted them in the LOS magnetogram (Figure 1(d)). The NF/SF axes are shown by the red/orange colors, respectively, in Figure 1(d).

After comparing Hα, EUV 304 Å images, and the LOS magnetogram we determine that the eastern/western ends of both filaments are anchored in a negative/positive polarity, respectively. Both filaments are stretched approximately from the south-east to the northwest along two different PILs. The handedness or chirality of filaments can be determined using high-resolution Hα images, and the position of filament ends relative to the photospheric LOS magnetic fields. Figure 1(d) hints that the eastern ends of both filaments are anchored in negative polarities, while the western ends are rooted in positive polarities. In this case, the axial magnetic field in both filaments is directed from west to east. Accordingly, the NF is sinistral while the SF is dextral because they are separated by positive polarity.

The Hα images in Figures 1(a) and (c) also show that the fine threads within the NF and SF bodies deviated counterclockwise and clockwise from their axes, respectively. The filament barbs are left-bearing/right-bearing for the NF/SF, which corresponds to sinistral chirality of the NF and dextral chirality of the SF (Martin et al. 1994; Martin 1998). Some of the visible barbs are marked with the red arrows in Figures 1(a) and (c).

The magnetic configuration surrounding the filaments can be deduced from the analysis of the SDO/AIA 171 Å images (Figure 2) and the potential-field source-surface (PFSS) magnetic-field extrapolation (Schrijver & De Rosa 2003) (Figure 3). Figures 2(a)–(d) represent the SDO/AIA 171 Å images at 10:48:59 UT on 2014 April 18, and at 00:36:11 UT, 10:28:59 UT, and 17:57:59 UT on 2014 April 19, respectively. To compare the coronal loop structure with a LOS magnetogram we overplot the positive (green) and negative (blue) LOS magnetic field contours on the AIA 171 Å image (Figure 2(a)). We clearly see arcades, connecting the central positive polarity with negative polarities on both sides, above the filaments. We also see long loops that connect the negative polarities to the remote region of positive polarity, near to the western endpoint of the SF. All these images show the fan-spine configuration over the filaments. A null point is expected to be above the
central positive polarity between the filaments. The outer spine field line emanates from the null point but is directed not radially into the outer corona, as it is usually assumed in fan-spine configurations, but deviates to the west and touches the photosphere near the western endpoint of the SF within an area of positive polarity. This configuration is confirmed by the PFSS magnetic field extrapolation (Figure 3). To perform the PFSS extrapolation we used the PFSS software package available in IDL SolarSoftWare. Figure 3(a) shows the full disk magnetogram with extrapolated magnetic field lines, while the zoomed-in region corresponding to the black box is shown in Figure 3(b). The calculated field lines match quite well to the structure of the coronal loops in the SDO/AIA 171 Å images.

The filament channels were approaching each other from April 15–18, as seen in the SDO/AIA 304 Å images in Figure 4. The filament channels manifest themselves as long dark structures. They are quite separate on April 15 (Figure 4(a)), come slowly closer to each other during April
16–17 (Figures 4(b)–(c)), and become very close on April 18 (Figure 4(d)). The closing of the filament channels is marked by the white arrows in all the panels in Figure 4.

4. DYNAMIC INTERACTIONS OF THE FILAMENT CHANNELS

We observed three events of filament channel interactions during 2014 April 18–20. In this section we describe the detailed observations of these interaction dynamics in multi-wavelength channels.

4.1. First Event of Interaction and Associated Dynamics

The sequence of the images showing the first event of interaction are represented in Figure 5. The left panel shows the SDO/AIA 304 Å images ((a)–(d)), while the right panel show the NSO/GONG Hα images ((e)–(h)). In Figure 5(a), the SDO/AIA 304 Å image is overplotted with the SDO/HMI LOS magnetogram contours. Green/blue contours show the positive/negative polarity regions, respectively. In Figure 5(a), we see two nearby filament channels. However, at the same time in the Hα image only the SF is visible (Figure 5(e)). The first event of interaction starts around 20:14 UT on 2014 April 18 with the activation of the middle part of the SF. The initial activation area is shown by the small white circle in Figure 5(a). After the activation, the middle part of the filament partially erupts toward the north. The activated filament is seen in Figure 5(b). Along with the partial eruption we also see the counterclockwise rotation of filament threads around the long filament axis, if we observe it from the east end (see the AIA 304 Å animation associated with Figure 5). This counterclockwise rotation of the threads can be the manifestation of the redistribution of the twist along the flux rope due to its expansion and swelling during the activation (Parker 1974). Negative helicity of a flux rope corresponds to the dextral chirality of a filament in flux-rope models.

The partial failed eruption of the SF seems to trigger a reconnection at the magnetic null that lies above the filament...
channels. It is exhibited by EUV brightenings at several places on either side of both filament channels, simultaneously, with the partial eruption and helical motion. These bright regions are marked by the white circles in Figure 5(c). Such brightenings are believed to appear due to hits of the chromosphere by fast electrons and heated plasma from the region of reconnection. After the partial failed eruption, the heated, as well as cooled, material of the SF moves along the axis toward the eastern and western ends of the filament (directions are shown by the arrows in Figure 5(d)). The two separate filament channels are still observed very close to each other at 20:46:07 UT. Apart from the chromospheric brightenings, no influence of the SF activation on the NF was observed.

The distance–time plot of the hot plasma movement is presented in Figure 6(a). The rough trajectory along which the distance measurements was made is shown by the dashed black line in Figure 5(c). We tracked a bright plasma blob that moves toward the western end of the SF. The east-most point was used as a reference point for the distance measurements. For more accurate results, we repeated the measurements three times, and the standard deviations was used as errors. The linear fit to these data points is used to estimate an average speed. It is evident that the hot plasma moved with the average speed of \( \sim 40 \text{ km s}^{-1} \) between 20:25 and 20:50 UT.

4.2. Second Event of Interaction and Associated Dynamics

Figure 7 represents the selected SDO/AIA 304 Å and NSO/GONG H\(_\alpha\) images, showing the second event of interaction and associated dynamics. The second event of interaction started at \( \sim 15:33 \) UT on 2014 April 19 with a compact brightening near the place of the closest approaching of the filament channels, just between them. Another small brightening appeared on the southern side of the SF. The locations of these compact brightenings are marked by the white circles in Figure 7(a). The activation of the NF started at \( \sim 15:37 \) UT near its eastern end (Figure 7(b)). At the same time we also see a remote brightening (RB) on the west. The location of the RB region is shown in Figure 7(b) with the white circle. Thereafter, the bright features propagate from the eastern end of the NF to its middle part. The pattern of filament bright and dark threads looks like the upper part of a right-handed helix, which is consistent with the sinistral chirality of the NF. What is most surprising is that after reaching the place of the closest approaching of the filament channels the heated plasma propagates, not to the northwest along the axis of the NF channel, but to the west and southwest nearly along the axis of the SF. At first glance one might fancy that the eastern part of the NF and the western part of the SF form a joint magnetic structure, allowing plasma to move easily from the eastern end of the NF to the western end of the SF. However, it is very doubtful if they can form such a structure because their chirality and helicity are opposite. We will discuss the problem in more detail in Section 5.

The signature of the brightening around the magnetic null can also be seen in other AIA channels. Figure 8 shows the SDO/AIA 171, 193, 131, and 94 Å images at \( \sim 15:41 \) UT just after the partial filament eruption. We can see the brightening near the null point, which can be understood due to the magnetic reconnection there. The RB signature is also visible in these channels.

The heated plasma first moves toward the northwest direction with a speed of \( \sim 90 \text{ km s}^{-1} \), and then toward the southwest direction toward the western end of the SF with a speed of \( \sim 140 \text{ km s}^{-1} \). The kinematics of the plasma flows is shown in Figure 6(b). It represents the distance–time profiles of the plasma flows toward the northwest (red curve) and the southwest (green curve). The trajectories along which the northwest directed (white dashed line) and southwest directed (black dashed line) displacement measurements have been performed are shown in Figure 7(d). Two compact bright areas appeared on both sides of the NF near its eastern end closer to Figure 3.

(a) 18-April-2014 00:04:00 UT

(b) 18-April-2014 00:04:00 UT

Figure 3. (a) PFSS magnetic field extrapolation showing a full disk view of the coronal magnetic field structure over the filaments. (b) The zoomed-in view corresponding to the black box shown in the panel (a).
the end of the second event (Figures 7(d), (g), and (h)). They can be considered as the compact ribbons formed by the partial eruption of the NF and the associated flare. The overplotted $SDO/AIA$ 171 Å image at around $\sim 16:21$ UT shows the loop like structures joining the two bright ribbons and can be considered as the post-flare loops (Figure 7(d)).

4.3. Third Event of Interaction and Associated Dynamics

The third event has many similar features to the second event of interaction. Figure 9 show the interaction dynamics in the $SDO/AIA$ 304 Å and NSO/GONO H$\alpha$ observations. It starts at $\sim 00:14$ UT on 2014 April 20 with brightenings near the place of the closest approach of the filament channels and the southern side of the SF. Immediately after that, at $\sim 00:15$ UT we observe an activation and failed eruption of the eastern part of the NF with the formation of two bright ribbons on both sides of it. These ribbons can be formed as a result of reconnection between the legs of surrounding arcades during the partial eruption of the NF inside the northern arcades of the fan-spine structure. Soon after the activation an RB appears near the western end of the SF at nearly the same place as in the second event (Figures 9(b), (e) and (f)). We also observed the brightening at the magnetic null point just after the partial eruption of the NF in all the EUV channels (Figures 9(b) and 10). Figure 10 represents the $SDO/AIA$ 171, 193, 131, and 94 Å images at $\sim 00:18$ UT on 2014 April 20 also showing the brightening at the null. This brightening is due to some magnetic reconnection at the null point. The outer spine lines
Figure 5. SDO/AIA 304 Å (left column) and the NSO/GONG Hα (right column) images showing the first event of the interaction/reconnection. The northern filament channel (NFC) and southern filament channel (SFC) are shown in panel (a). The green and blue contours in panel (a) are the SDO/HMI magnetic field contours for positive and negative polarity, respectively. The contour levels are ±50, ±100, ±200, ±300, ±400, and ±500 Gauss. (An animation of this figure is available.)
and the RB can be seen in the hotter AIA channels (Figures 10(c) and (d)).

Heated plasma in the eastern part of the NF forms a wide, bright helical structure with intensive internal motions. Some part of the hot plasma moves from the middle of the NF to the northwest along its axis to the western end, while a fraction of the bright material moves to the western end of the SF along the curved path, in nearly the same way as in the second event. Different directions of plasma flows are shown by the arrows in Figure 9(c).

Several long threads shift as a whole from the northern side of the NF channel to the southern side. This movement corresponds to the clockwise rotation of a right-hand helix around its axis, as seen from the east, if the threads belong to its upper part and reveals the untwisting of the helix. The eastern part of the helix looks more twisted, with threads more transversal to the axis. At the ending phase of the event there are many blobs moving along the threads to the eastern end of the NF. Their rotation (counterclockwise) is opposite to the rotation of the whole threads in the middle part of the helix because they presumably move along the upper part of the right-hand helix to its eastern end.

The distance–time profiles of these plasma motions are represented in Figure 11. Figure 11(a) shows the results for plasma moving to the northwest along the NF channel. We measured the profiles along two different trajectories shown by white dashed lines in Figure 9(d). Heated plasma moves with average speeds of \(-110\) and \(-160\) km s\(^{-1}\) along trajectories one and two, respectively. Figure 11(b) represents the profiles of plasma motion along the SF channel toward its western end. Since plasma moves along the curved path, we measured two profiles along straight lines, one for the northward motion and another for the southwestward motion. The speeds are \(-90\) and \(-45\) km s\(^{-1}\), respectively.

5. INTERPRETATION AND DISCUSSION

Two filaments gradually approach each other in their middle parts during their passage through the solar disk on 2014 April. We specify chiralities of the filament to be opposite. The NF fine structure definitely reveals the sinistral chirality, which is in accordance with the general hemispheric rule for the southern hemisphere. The chirality of the SF is evidently dextral for many reasons despite the violation of the hemispheric rule (see Section 3 and Figure 1 for more details). During several episodes from April 18–20, the filaments show an activation and formation of a temporal structure that joins them into a united system. It looks puzzling because usually filaments with parallel axial magnetic fields and opposite chirality do not merge or reconnect with the formation of a new stable or two different filaments from their halves.

In our interpretation of these observations we follow the flux-rope model (e.g., Canou & Amari 2010; Guo et al. 2010; Joshi et al. 2014b; Filippov et al. 2015) of filaments, considering filament plasma accumulated in lower parts of helical flux tubes. Dextral filaments are contained within the left-handed helices, while sinistral filaments fill the right-handed ones. In our case, the axial magnetic fields of the two flux ropes are parallel but the azimuthal fields have a different sense of rotation. Therefore, when these two flux ropes come
Figure 7. SDO/AIA 304 Å (left column) and the NSO/GONG H\(\alpha\) (right column) images showing the second event of the interaction/reconnection. The inset image over panel (d) is the SDO/AIA 171 Å image at \(\sim 16:21\) UT on 2014 April 19, showing the post flare loops joining the two compact bright ribbons. Remote brightening regions are shown by white circles in panels (b), (g), and (h). The green and blue contours in panel (a) are the SDO/HMI magnetic field contours for positive and negative polarity, respectively. The contour levels are \(\pm 50, \pm 100, \pm 200, \pm 300, \pm 400,\) and \(\pm 500\) Gauss. (An animation of this figure is available.)
close together side-by-side, both their axial and azimuthal field components have the same directions and cannot reconnect.

Two flux ropes of similar helicity either show a merging or slingshot reconnection during their interaction (Linton et al. 2001; Török et al. 2011a). However, two flux ropes of different helicity with parallel axial magnetic fields can only undergo a bounce interaction (Linton et al. 2001) when they are brought together. They repulse from each other and cannot reconnect and form the joint structure. In our case, it is clear that the SF/NF have dextral/sinistral chiralities, respectively, with parallel axial magnetic fields. Therefore, the associated flux ropes should have different signs of twist, which is the condition for the bounce interaction.

We believe that, although the events look like the interaction of two filament channels, the most important interaction occurs between a flux rope and the surrounding coronal magnetic field of special structure. We clearly observe a fan-spine configuration over the filament loops, with a presumed null point above them (see Figure 2). The PFSS magnetic field extrapolation confirms the existence of the fan-spine magnetic configuration (see Figure 3).

The initial magnetic field line distribution and subsequent plasma dynamics are shown in the schematic representation in Figure 12. The coronal structure is similar to a “pseudostreamer” (Wang et al. 2007; Rachmeler et al. 2014) with two flux ropes at the base. The left column represents the 3D disk view (Figure 12(a)), while the right column shows the projected view of selected 3D field lines (Figure 12(g)). However, in contrast to the “pseudostreamer” the outer spine field line emanating from the null point is not directed radially into the outer corona, but deviates to the west and touches the photosphere near to the endpoint of the SF within an area of positive polarity (see Figures 2 and 3). In the projection on the disk the outer spine field line runs nearly parallel to the SF axis, so the plasma motion along the spine can easily be mixed up with the motion along the SF axis. We believe it is most probable in the observations of the filament interaction in our case.

In the first event the case looks simple, i.e., reconnection between the inner green and the outer blue line (Figures 12(b), (h) and 5). However, in the second and third case the scenario is a little complex. There are no anti-parallel field lines belonging to flux ropes that contain the SF and NF. But if each of the flux ropes approaches the null point, its azimuthal field can reconnect with the outer field lines of the opposite lobe, i.e., circular field lines of the red flux rope can reconnect with
Figure 9. The SDO/AIA 304 Å (left column) and the NSO/GONG Hα (right column) images showing the third event of the interaction/reconnection. The inset image over panel (d) is SDO/AIA 171 Å image at ∼00:40 UT on 2014 April 20, showing the post flare loops joining the two compact bright ribbons (panels (g) and (h)). Remote brightening regions are shown by the white circles in panels (b), (e), and (f). The green and blue contours in panel (a) are the SDO/HMI magnetic field contours for positive and negative polarity, respectively. The contour levels are ±50, ±100, ±200, ±300, ±400, and ±500 Gauss.

(An animation of this figure is available.)
the outer green line. This case seems to take place in the second (Figures 12(c), (i), and 7) and third (Figures 12(e), (k), and 9) events of the filament interaction. The locations of the reconnections are shown by pink stars in Figure 12. Due to the projected view of 3D field lines in a 2D plane, the reconnected field lines appear as a single line in the panels (j) and (l) of Figure 12. But actually it represents the two different sets of field lines as shown in the 3D view (Figures 12(d) and (f)).

After the reconnection some amount of the heated plasma previously confined within the flux rope is able to propagate along the field lines of the surrounding magnetic configuration. In particular, it can move along the spine, and this motion mimics the movement along the SF axis. Penetration of the flux-rope plasma into the outer structure can be illustrated by a simple 2D model.

Let us consider the coronal magnetic field with fan-spine structure as a sum of a vertical homogeneous magnetic field, $B_0$, and a vertical 2D dipole located at $x = 0$, $z = z_d$ with the dipole moment, $M$. If $y$ is the axis of translational symmetry, $x$ is the horizontal axis, and $z$ is the vertical axis with the origin at the photospheric level, the external field is described by a $y$-component of vector potential $A$

$$A_y = B_0 x + \frac{M_x}{x^2 + (z - z_d)^2}. \quad (1)$$

We put into this field a flux rope in the simplest form of a straight linear current along the $y$-axis. According to the boundary condition for the coronal current $I$ on the photosphere, its vector potential can be written as (van Tend & Kuperus 1978; Molodenskii & Filippov 1987; Filippov et al. 2001)

$$A_y = \frac{I}{c} \left[ \ln((x - x_0)^2 + (z + z_0)^2) - \ln((x - x_0)^2 + (z - z_0)^2) \right], \quad (2)$$

where $x_0$ and $z_0$ are the coordinates of the coronal current. Neglecting the weight of the flux rope, its equilibrium position $(x_0, z_0)$ is defined by the equations:

$$B_0 - M \frac{x_0^2 - (z_0 - z_d)^2}{(x_0^2 + (z_0 - z_d)^2)^2} = 0, \quad (3)$$
\[
\frac{I}{cz_0} - M \frac{2x_0(z_0 - z_d)}{(x_0^2 + (z_0 - z_d)^2)^2} = 0. \tag{4}
\]

Figure 13 (left) shows the field lines described by Equations (1) and (2) for dimensionless parameters \(B_0 = 1, M = -4, z_d = -1\), and the value of \(I/c\) being close to the critical value of the current \(I_c\) over which a stable equilibrium is impossible (Molodenskii & Filippov 1987; Filippov et al. 2001). Spaces between several magnetic surfaces, \(A_i = \text{const.}\) are shadowed by different tints. Figure 13 (right) shows the same magnetic surfaces for the slightly increased value of \(I_c\). The magnetic flux, \(\Phi\), conservation between the current and the photosphere is taken into account in the form

\[
\Phi = Mx_0\left(\frac{1}{x_0^2 + (z_0 - z_d)^2} - \frac{1}{x_0^2 + z_d^2}\right) + \frac{I}{c} \ln \frac{2z_0}{r_0} = \text{const}, \tag{5}
\]

where \(r_0 = 0.01\) is the radius of a flux tube with a nearly homogeneous current density, which should be taken into account to avoid divergency.

When the equilibrium position becomes higher, some of the previously closed field lines reconnect with open field lines at the null point. Plasma (possibly previously heated) confined between some closed magnetic surfaces is able to propagate along the open field lines into the upper corona and to the photosphere. We expect such a scenario to happen in the present case of filament interactions during 2014 April 18–20.

The first event and reconnection on April 18 was initiated by the activation and partial eruption of the SF that bring the inner green field lines toward the null point and trigger the reconnection (Figures 12(b) and (b)). The observed brightenings (shown by the chartreuse color) near the foot points of the fan lines on both sides of the filaments is strong evidence of the null point reconnection (Figure 5(c)). The accelerated electrons move after the reconnection toward the foot points of the fan lines and produce brightenings there. In the second event on April 19 the activation and partial eruption of the NF bring its field lines to the magnetic null, and trigger reconnection (Figures 12(c) and (i)). The brightening at the foot points of the fan lines was also observed in this event. Some part of the heated NF plasma travels along the outer spine over the SF toward the western footpoint (Figures 12(d) and (j)). The third event on April 20 is quite similar to the second one with a partial eruption of the NF again, but there is additional flow of the heated NF plasma along the axis of the NF toward the western end (along the white arrows in Figure 9(c)).

Apparent brightening near the null point has also been observed just after the partial eruption in both the second and third cases, which provides a signature of magnetic reconnection (see Figures 8 and 10). In SDO/AIA images the filaments and filament channels, arcades, and loops look the same after the second event. However, we believe that there should be some changes in the magnetic configuration, as shown in panel (j) of Figure 12. The flux rope with helical field lines (black color) and the outer green spine lines reconnect (Figures 12(c) and (d)) and create a new domain between a few new
Figure 12. Schematic representation of the change in the magnetic configuration and the reconnection scenario in the 3D disk view (left column) and projected view of 3D field lines in a 2D plane (right column). The northern (NF) and southern (SF) filaments are shown by the red and orange colors, respectively. Reconnection regions are marked by the pink star, while the reconnected field lines are shown by the dotted black lines. The blue overlying arcades over the NF in panels (c)–(f) are not in the plane of reconnection.
reconnected lines joining the two systems (shown by dotted black lines in Figures 12(d) and (j). We believe that a similar reconnection is occurring during the third event (Figures 12(e) and (k)). The activation of the filaments can be understood by some photospheric magnetic changes. Looking at the magnetic field evolution in this region, we note flux cancellation close to the eastern end of the SF, emerging flux close to the middle and the western end of the SF, along with the expending motions (see the SDO/HMI animation attached with Figure 1). These motions could create shear and canceling flux and be the trigger of the activation of the filaments. The SF remains stable after the first event. From this we could guess that the twist of the SF flux rope became less, and the overlying arcades have more potential. On the other hand, the NF being overlaid arcades by less and more sheared arcades can rise and reach the null point.

The most interesting aspect of these events is the geometry of the spine line of the coronal fan-spine structure. In projection on the solar disk, the spine line runs nearly parallel to the SF axis, or close to it. The remote point, where the outer spine line is anchored in the photosphere, is located near the western end of the SF. It leads to the wrong impression that plasma from filament channels with different chiralities within a large-scale coronal fan-spine magnetic structure have not been observed before, although fan-spine configurations have been discussed in the case of solar eruptions in “pseudostreamers” (Wang et al. 2007; Török et al. 2011b; Rachmeler et al. 2014; Yang et al. 2015), jets (Filippov et al. 2009, 2015; Pariat et al. 2009), and flares (Wang et al. 2014; Joshi et al. 2015).

Observations of filament interactions and merging are crucial for better understanding of reconnection between large-scale coronal flux ropes. It also provides the information on the interaction the flux ropes have with the overlying magnetic configurations. These magnetic structures are responsible for different types of eruptions. High-resolution observations

6. CONCLUSIONS

In this paper, we discuss the observations of the interactions between two nearby filament channels of different chirality with parallel axial magnetic fields. We found a key role of the interaction of partially erupting filaments and associated flux ropes with the overlying fan-spine magnetic structure. On the basis of the analysis of coronal EUV images and magnetic field calculations, we come the following main results:

1. SDO/AIA EUV observations show a close connection between the two nearby filament channels during three episodes of activation and interaction of the filaments with different chiralities on 2014 April 18, 19, and 20, respectively.
2. The observations as well as the PFSS calculations clearly show the existence of a fan-spine magnetic configuration over the two filaments.
3. Although the events look like interaction of two filament channels, the most important interaction occurs between the flux ropes containing the filaments and the surrounding coronal magnetic field of special structure. The activations and partial eruptions of the filaments are believed to be responsible for the reconnection between their magnetic field lines with the coronal field at the magnetic null that lies above them.

Figure 13. 2D model of the flux-rope magnetic field reconnection at the null point. Black lines represent the magnetic field lines, while the different tints of the blue color show the confined plasma.
provide important inputs for the MHD modeling of flux-rope interactions and reconnections, which are needed to understand the physics of flux-rope dynamics more clearly.

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