Observation of a Reversal of Breakout Reconnection Preceding a Jet: Evidence of Oscillatory Magnetic Reconnection?

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Abstract

Recent studies have revealed that solar jets involving minifilament eruptions may be initiated under the well-known magnetic-breakout mechanism. Before or just at the onset of those jets, there should be a current sheet, where breakout magnetic reconnection takes place, between open fields and the outside of the jet-base arcade carrying a minifilament in its core. In this paper we present a jet produced by the eruption of two minifilaments lying at the jet base. A current sheet is detected near the jet base before the onset of the eruption, suggesting the magnetic-breakout mechanism. However, we further find that the current sheet undergoes a transition. The current sheet first shortens to zero in length, but then lengthens toward an orthogonal direction relative to its initial orientation. The change of the current sheet gives rise to a reversal of the breakout reconnection, as the inflow and outflow regions before the transition become the outflow and inflow regions after the transition, respectively. We therefore propose that this observation provides evidence for the so-called oscillatory reconnection that is defined by a series of reconnection reversals but not yet proven to exist in the real plasma environment of the solar atmosphere.

Key words: Sun: activity – Sun: chromosphere – Sun: corona – Sun: filaments, prominences

1. Introduction

Solar jets are transient, collimated plasma ejections that escape away from the low solar atmosphere along open or far-reaching magnetic fields. They have been observed to be ubiquitous across the Sun surface and studied extensively over the past several decades (see the recent reviews of Innes et al. 2016; Raouafi et al. 2016). Theoretically, it is widely accepted that jets are produced by magnetic reconnection at a magnetic-null region between a closed field and surrounding open field (e.g., Shibata et al. 1992; Yokoyama & Shibata 1995; Archontis et al. 2005; Jiang et al. 2007; Chen et al. 2008; Pariat et al. 2015, 2016; Ni et al. 2017). The magnetic null is susceptible to collapse to form a current sheet where bursty reconnection can take place (Antiochos 1990; Priest & Forbes 2000). Observationally, the magnetic configuration with a magnetic-null point prior to a jet has been inferred from the specific fan-spine shapes of jet emissions in the corona, the circular flare ribbons in the chromosphere at jet base, and the so-called embedded bipolar fields in the photosphere (Wang & Liu 2012; Zhang et al. 2012; Li et al. 2017; McCauley et al. 2017). However, the current sheet between the closed field and open field has rarely been observed directly at the onset of a jet.

Recent observations have revealed that solar jets are accompanied by minifilament (Wang et al. 2000) eruptions in the manner of large coronal mass ejections (CMEs) by large-scale filament eruptions (Shen et al. 2012, 2017; Li et al. 2015; Sterling et al. 2015, 2016; Hong et al. 2016, 2017; Panesar et al. 2016, 2017, 2018; Zhang & Zhang 2017; Moore et al. 2018). Sterling et al. (2015) randomly select 20 polar jets that are recorded in coronal images of X-ray and extreme ultraviolet (EUV) wavelengths simultaneously. They find that for each example an EUV minifilament erupted upward from the pre-jet base, producing an X-ray jet above the base and leaving a flare-like brightening near the base. Using the joint observations from the New Vacuum Solar Telescope (NVST; Liu et al. 2014) and the Solar Dynamics Observatory (SDO; Pesnell et al. 2012), Hong et al. (2016) report in detail how a standard jet seen in EUV wavelength is initiated by a minifilament eruption detected at the Hα emission line. The erupting minifilament forced the external closed field enveloping itself to reconnect with the long coronal loops nearby. As a result, a jet along the loops was produced by that external reconnection. The external reconnection for the jet production corresponds to the well-known breakout reconnection for CMEs involving large filament eruptions (Antiochos 1998; Antiochos et al. 1999; Shen et al. 2012; Chen et al. 2016). Very recently, Moore et al. (2018) found that 6 of 15 polar X-ray jets they studied are plausibly initiated due to the breakout reconnection in each minifilament eruption. If the data have enough resolution and the viewpoint is proper, a current sheet, the site for breakout reconnection, should be seen between the jet-base explosive closed field and the open field for those jets.

Via three-dimensional magnetohydrodynamical simulations, Wyper et al. (2018) present a breakout model for the minifilament-jet events as a small-scale extension of the well-known breakout mechanism for large CMEs. The basic magnetic setup consists of the background open fields and an embedded bipolar field, separated by a null point. They give a persistent shearing motion at the bipolar footpoints in their simulations. Over time, a sheared filament channel forms and expands in the core of the bipolar filed, and the magnetic pressure within the bipolar field increases constantly. Subsequently, the breakout current sheet is built because the null point above the bipolar field becomes increasingly compressed. As the breakout reconnection opens the strapping fields above the minifilament to some extent, the minifilament inevitably erupts upward toward the breakout current sheet. The field
(possibly a flux rope) holding and threading the rising minifilament continues to reconnect with the open fields, producing an apparent jet spire. Meanwhile, the flare reconnection under the erupting minifilament occurs impulsively, accelerating the escape of the ejecta and making a miniature flare-like brightening at the jet base. Wyper et al. (2018) suggest that the breakout mechanism for jet generation is robust in despite of varying inclinations of the background open fields. In addition, the breakout behavior is not sensitive to whether the minifilament in the core of the bipolar field is held by a sheared arcade or true flux rope.

In this paper we present a jet produced by successive eruptions of two minifilaments lying at the pre-jet base. The jet displays typical fan-spine topology where the breakout reconnection plausibly occurs at the null point, evidenced by a current sheet directly detected before the onset of the jet. However, the current sheet displays an interesting behavior: it shortens its length to zero along its orientation, and then lengthens toward an orthogonal direction relative to its initial orientation. The entire process is plausible in self-generation. The change of the current sheet indicates that the inflow and outflow regions of the breakout reconnection interchange each other. This is reminiscent of the “oscillatory reconnection” featured by a series of reconnection reversals in a self-consistent manner, which was first reported in numerical simulations (Murray et al. 2009), but has not yet been found in observations.

2. Observations and Data

The jet is recorded by SDO and the Interface Region Imaging Spectrograph (IRIS; De Pontieu et al. 2014) simultaneously. The jet started at about 15:26 UT, peaked at around 15:34 UT, and became faint after 15:50 UT on 2014 November 16 near the Active Region AR12209 (S15E32) on the solar disk.

SDO provides full-disk imaging data by the onboard telescopes Atmospheric Imaging Assembly (AIA; Lemen et al. 2012) and Helioseismic and Magnetic Imager (HMI; Schou et al. 2012). AIA images the Sun at UV–EUV wavelengths with cadences of 24–12 s and pixel sizes of 0.6”. HMI gives the photospheric magnetograms with a 45 s cadence and a 0.5” pixel size. In the jet, the AIA images at EUV wavelengths (e.g., 131 Å) image plasmas at the coronal temperature (above $10^5$ K), and thus are used to reveal the fan-spine shape of the jet. The current sheet associated with the jet can be observed at all of the EUV wavelengths of AIA including the He II emission line at 304 Å, and six Fe emission lines at 171, 193, 211, 335, 131, 94 Å. Therefore, plasmas within the current sheet can be diagnosed with the almost simultaneous observations of the six AIA Fe lines via differential emission measure (DEM) analysis (e.g., Aschwanden & Boerner 2011; Cheng et al. 2012; Su et al. 2018). The AIA UV channel 1600 Å is dominated by a chromospheric continuum and transition-region line emission, and thus is used to show the circular flare ribbon and remote brightening in the fan-spine jet and the time profile of the flare emission. HMI line-of-sight magnetograms are used to inspect the magnetic field configuration and evolution in the jet source region.

IRIS imaged the jet source region from 14:54 UT to 15:34 UT with its slit-jaw camera at 1330, 2796, and 1400 Å. The observational period covers the pre-jet evolution and the growing phase of the jet. The 1400 Å slit-jaw images (SJIs) are used here with a cadence of 37 s and a high spatial resolution of 0.5”33. The SJI 1400 Å images reflect plasma of the bright chromospheric continuum and SiIV transition-region line emission, and thus are easily aligned to the AIA 1600 Å images. Due to the extremely high resolution of IRIS, the current sheet is discernibly detected to undergo the changes of its length and orientation. In addition, the two minifilaments at the pre-jet base are also found by IRIS/SJI observations.

3. Results

Figure 1 presents the overview of the jet with the SDO data. A time sequence of the interesting region for the jet is displayed in panels (a1)–(a4) with AIA 131 Å images at four different moments. At 15:18 UT and 15:22 UT, the jet spire was not seen and the jet-base region (outlined by the orange boxes) did not become bright. At 15:29 UT, the jet base became a compact, bright dome and a long, bright jet spire stemmed from the top of the bright dome. The jet spire arose along preexisting, far-reaching coronal loops, and a bright brightening appeared at the far end of those loops. The AIA 1600 Å image in panel (d) further detected a circular bright ribbon in the jet base as well as the remote brightening. Combined with the magnetogram (panel e), it is known that the circular ribbon is located at some scattered positive polarities that surround a negative polarity (N) at the center. There are two main positive patches, labeled as P1 on the north of N and P2 on the south of N. These features point to the existence of a magnetic configuration of the fan-spine topology (Masson et al. 2009, 2014; Hou et al. 2019). At 15:38 UT, the jet spire developed multiple separate strands and broadened to about the width of the jet base, displaying the typical morphology of a blowout jet (Moore et al. 2010).

Two linear-shaped bright structures were seen near the jet base before the onset of the jet. They are the line segment C1 at 15:18 UT and C2 at 15:22 UT, as shown by the close-up views of the jet base in panels (g) and (h), respectively. Each end of C1/C2 presents a bifurcate structure, connecting a very bent curve of bright structure. This pattern is reminiscent of the classical 2D picture of magnetic reconnection, indicating that C1/C2 is the projection of a current sheet (Parker 1957; Sweet 1958; Petschek 1964). The current sheet separates two sets of antiparallel fieldlines at its two sides as the inflow regions before reconnection, and connects the reconnected fieldlines at its two ends as the outflow region after reconnection. Recently, small current sheets between two sets of antiparallel loops have been reported in several papers (Yang et al. 2015, 2018; Xue et al. 2016, 2018; Yang & Xiang 2016). For the present jet, the existence of C1/C2 indicates the happening of the so-called interchange reconnection between the closed field and “open” field (Crooker et al. 2002).

According to the linkage of C1/C2 with the surrounding bent bright structures and the overlaid magnetic fields in panels (g) and (h), we can infer the connectivity of the inflow and outflow fieldlines for the interchange reconnection at C1/C2. For C1, magnetic reconnection should take place between the closed fieldline connecting P1 to N and the open line along the jet spire rooted at P2. As a result, one outflow fieldline is open with a footpoint at P1, as traced out by the bent bright structure contacting the left end of C1, and the other outflow fieldline is a closed loop connecting P2 to N. Again, for C2, magnetic reconnection should occur between the closed fieldline connecting P2 to N and the open line along the jet spire.
rooted at P1. Consequently, one outflow fieldline is open with a footpoint at P2, and the other one is the closed loop connecting P1 to N. Comparing C1 with C2, it is concluded that (1) the orientation of C1 is orthogonal to that of C2, as C1 is roughly horizontal while C2 is roughly vertical; (2) the inflow region and the outflow region of C1 are, respectively, the outflow region and the inflow region of C2. By overplotting C1/C2 in panel (a3), it is seen that C1/C2 are located at the joint-point of the jet spire and the fan-shaped dome. Thus, C1/C2 seem to be built in the vicinity of the null point in the fan-spine magnetic configuration. The bright structures connecting the end of C1/C2 to N and open, respectively, may trace out the inner and outer spine, while those linking the ends of C1/C2 with P1 and P2 indicate the projection of a separatrix of the fan dome.

Figure 2 presents the results of the DEM analysis on C1 at 15:18 UT and C2 at 15:22 UT. The current sheets are simultaneously imaged by multiwavelengths of AIA, as shown in the three-passband composite images for 171, 211, and 131 Å (C1 in panel (a1) and C2 in panel (a2)). Via the DEM method, the temperature maps for C1/C2 are constructed as displayed in panels (b1) and (b2), and the emission measure (EM) maps in panels (c3) and (c4). Apparently, it is seen that the current sheets are hotter and denser than ambient regions.

The DEM distributions of plasmas inside C1/C2 are further derived as shown in Figures 2(e) and (f). The results are computed by using the mean digital numbers over an area (outlined by the boxes in panels (a1) and (a2)) subtracted by a background value determined from the nearby quiet regions. With 100 Monte Carlo simulations of the DEM inversion

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\text{Figure 1. The present jet is fully detected by SDO. Panels (a1)–(a4): AIA 131 Å images showing the initiation and growth of the jet. Panels (g) and (h): the close-up views within the orange boxes in panels (a1) and (a2), respectively. To enhance the visibility of the possible current sheets C1/C2, the present 131 Å images are the average of five consecutive snapshots in 1 minute of the 12 s cadence AIA 131 Å snapshots. Panel (d): AIA 1600 Å image showing the circular ribbon and remote brightening during the jet. Panel (e): HMI line-of-sight magnetogram showing the photospheric magnetic fields associated with the jet. The magnetic field in the source region of the jet consists of a negative patch (N) roughly surrounded by some scattered positive patches (mainly P1 and P2). Green/blue contours in panels (g) and (h) are the levels of the HMI magnetic field at (−200, −80)/(200, 80) G, while in panel (d) at −100/100 G.}
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C1 has an average temperature of 6. Four domains, A and B, and a width of 1028 cm\(^{-2}\) are multithermal as signed by the broad log\(T_\text{TD}\) distributions from log\(T_\text{TD}\) = 5.5 to log\(T_\text{TD}\) = 7.5. Both them have the peak temperature at log\(T_\text{TD}\) = 6.2 (\textasciitilde1.6 MK). The total EM \(\text{DEM} = \int \text{DEM}(T) dT\) and \(T = \int \text{DEM}(T)TdT/\text{EM}\). C1 has an average temperature of \textasciitilde7 MK, slightly hotter than that of 6.8 MK for C2. But C2 with an EM of \(2.5 \times 10^{53} \text{ cm}^{-3}\) is denser (or has a greater extent along the line of sight) than C1 with an EM of \(1.4 \times 10^{53} \text{ cm}^{-3}\).

The jet source region is simultaneously watched by \textit{IRIS}. With the unprecedented high resolution of \textit{IRIS}/SJI 1400 Å images, it allows one to discuss the evolution of C1/C2 in detail. Figure 3 shows a successive process from C1 to C2. At 14:55 UT, no current sheet was seen at the pre-jet base, but two minifilaments, F1 and F2, were found lying at the base. With the overlaid magnetic field, it is shown that F1 resided along the neutral line between P1 and N, while F2 resided along the neutral line between N and P2. This also indicates the existence of an X-type null point above the two minifilaments, similar to the situation with an X-type null point above the twin magnetic arcades under a coronal pseudostreamer (Wang et al. 2007; Bi et al. 2013; Yang et al. 2015). The yellow arrow points to the approximate location of the expected X-type null point where the current sheet C1 appeared later.

C1 was faintly seen around 14:58 UT for the first time in 1400 Å images. It was still faint at 15:09:26 UT, but later gradually became discernible. When C1 was longest at 15:17:32 UT, jet-like flow emitting from the left end of C1 was also discernible. At this time, C1 was estimated to have an apparent length of \textasciitilde2\textdegree.3 and a width of \textasciitilde0\textdegree.6. Four domains, registered with “A,” “B,” “D,” and “E” in the 15:17:32 UT image, were separated by C1. According to the classic model of magnetic reconnection, it is known that the domains A and B at each side of C1 represent the inflow regions for the reconnection, while D and E indicate the outflow regions at the two ends of the current sheet. From the 15:17:32 UT image with overlaid magnetic contours, it is inferred that the inflow region A is occupied by an open field rooted near P2, while the inflow region B contains a closed inflow region linking P1 to N. Therefore, interchange reconnection took place between the open field in A and the closed field in B (Crooker et al. 2002). Consequently, a new open field along which the jet-like flow propagated outward was formed to be rooted at P1 in the outflow region D. A new closed field linking N to P2 was piled in the outflow region E.

Note that the reconnection at C1 actually removed the magnetic arcade (P1-N) that covers the underneath minifilament F1. In this respect, the interchange reconnection corresponds to the so-called breakout reconnection as a trigger for many large filament eruptions (Antiochos 1998; Antiochos et al. 1999). However, the breakout reconnection did not trigger F1 to erupt immediately. Instead, the breakout current sheet, C1, started to shorten itself at one moment after 15:17:32, as its
outflow regions D–E were approaching each other. It is seen that C1 at 15:20:01 UT was shorter than at 15:17:32 UT. At 15:21:16 UT, the outflow regions D–E met each other, and an X-type structure instead of C1 was built separating the four domains around the reconnection site, i.e., C1/C2. In the right bottom panel is a 1400 Å time-slice plot that is made from slits along the long arrow. The yellow dotted lines on the time-slice image indicate the duration of C1 and C2. The blue (green) contours indicate magnetic field strength at levels of 80, 200 (−80, −200) G. Figure 3. Detailed evolution of the current sheets C1/C2 before the jet in the IRIS/SJI 1400 Å images. In the first panel, F1 represents the pre-jet minifilament lying along the magnetic polarity inversion zone between P1 and N, while F2 represents the other one between P2 and N. The letters A, B, D, and E indicate the four regions around the reconnection site, i.e., C1/C2. In the right bottom panel is a 1400 Å time-slice plot that is made from slits along the long arrow. The yellow dotted lines on the time-slice image indicate the duration of C1 and C2. The blue (green) contours indicate magnetic field strength at levels of 80, 200 (−80, −200) G.

A time-slice plot, as shown in the last frame of Figure 3, was constructed by the slit along the long arrow in the 15:22:31 UT image of Figure 2. It displays the duration of C1 and C2, as the slit passes across C1 and along C2. C1 lasted about 23 minutes from 14:58 UT to 15:21 UT, while C2 lasted around 7 minutes from 15:22 UT to 15:29 UT. The transition from C1 to C2 took place in 1 minute between 15:21 UT and 15:22 UT.

Although F1 did not erupt immediately because of the breakout reconnection at C1, F2 started to brighten and rise as soon as the breakout current sheet of C2 appeared. Figure 4 presents the eruptive phase of the jet. At 15:27:30 UT, F2 was already rising up as a bright arch-like feature seen in the 1400 Å snapshot of Figure 4(a1), but F1 was still stable as a dark feature. The exact time of the start of the rise could not be determined due to F2’s very small size and projection mask. However, F2 seems to be activated to be bright immediately after the appearance of C2, as suggested by the 15:22 UT 131 Å image of Figure 4(b1). From panels (a1) to (a2), it is seen that F2 expanded itself and approached C2, keeping its arch shape. Meanwhile, a brightening appeared between the magnetic polarities N and P2, similar to the initial brightening underlying a large-scale erupting filament. Circular brightening also appeared along the ambient positive polarities close to P2, indicating the enhancement of the null-point/breakout reconnection at C2. A narrow, hot jet spire was thus aroused at the same time, as shown by the 131 Å image in panel (b2).

The explosive change took place when F2 reached C2, after which F2 was not seen but a 1400 Å jet spire was launched,
leaving a remarkable brightening in the base (panel (a3)). Base on the intertwined substructure of the jet around 15:29 UT, it is conjectured that F2 should be broken by the null-point/breakout reconnection. As a result, its twist and cool material were transferred into the jet body (Wyper et al. 2018). We further found that F1 was also ejected out approximately after 15:30 UT, although the start of its eruption was obscured by the eruption of F2. Due to the joint action of both mini-filament eruptions, the jet has grown a wide spire, accompanied by the development of a circular bright ribbon at the jet base (see panels (a2)–(a5)). Examples for a filament eruption triggered by the adjacent eruption of another filament were also reported by other authors (e.g., Török et al. 2011; Sterling et al. 2014). Li et al. (2018) also discussed the detailed development of a circular flare by successive eruptions of two mini-filaments in another event.

After 15:34:27 UT, the jet was only observed by SDO, while IRIS ended its observation on this region. The jet/minifilament eruptions continued to propagate plasmas along its path as shown by the 131 Å images of Figures 4(b3)–(b4). It decayed gradually after 15:40 UT and was almost invisible after 16:00 UT. However, following the later phase of its evolution, we found that a bright linear feature, pointed by the yellow arrows, seems to connect the jet spire to the top of the miniature flaring arcade at the base. This linear feature is likely a flare current sheet in the wake of the eruption of F1, analogous to the large current sheet in the wake of CMEs (e.g., Lin et al. 2015; Li et al. 2016; Mei et al. 2017; Kumar et al. 2018; Yan et al. 2018). Therefore, we observed both types of current sheets in a single jet event, including the breakout current sheet before the onset of the jet and the flare current sheet in the wake of the jet. This result further suggests the self-similarity among the narrow, small jets and the wide, large CMEs that is triggered under the breakout mechanism (Wyper et al. 2018).

Another evident characteristic of the jet is the photospheric magnetic cancellation, which is observed in the source region from before to after the jet by the HMI. This took place at the neutral line between negative flux N and the surrounding positive flux (mainly P1 and P2), in which F1 and F2 also erupted. Figure 5(a) shows the time sequence of HMI magnetograms for the jet source region. It is seen that the areas of magnetic polarities P1, N, and P2 have decreased dramatically from 14:53 UT to 15:49 UT due to the cancellation among them. During the cancellation, the reversal of the breakout reconnection was built above the source region, as sketched by the superimposed axis of F1/F2, the current sheets C1/C2, and their connectivity to P1, P2, and N. Figure 5(b) shows the time profile of magnetic flux of N and the 1600 Å light curve of the source region. It is seen that the magnetic flux continuously decreased through the time of the breakout phase when C1/C2 were present and the jet phase when F1/F2 were erupting. Two peaks in the 1600 Å light curve are found during the jet phase, which possibly result from the successive eruption of both mini-filaments (e.g., Wang et al. 2018). The relationship among the reversal of the observed breakout reconnection, the minifilament eruptions, and the
magnetic cancellation will be further discussed in the next section.

4. Discussion and Summary

Solar jets are often found to be made by the explosive eruption of the pre-jet base arcade. In general, this eruption results from an eruptive structure as seen in a minifilament (e.g., Hong et al. 2016) or a microsigmoid (Raouafi et al. 2010) or even a small flux rope (Zhu et al. 2017; Joshi et al. 2018). The production of solar jets is thought to be produced by the interaction of these eruptive structures with open fields or far-reaching loops (Sterling et al. 2015; Hong et al. 2016; Moore et al. 2018; Wyper et al. 2018). Here, we report a jet that originates from successive eruptions of two minifilaments in the pre-jet base. One minifilament, F1, lies along the neutral line between positive magnetic flux P1 and negative flux N, while the other one, F2, lies along the neutral line between N and P2. The magnetic field at the pre-jet base should mainly consist of twin magnetic arcades (respectively cover F1 and F2).
tied with an X-type null point above (Wang et al. 2007). The breakout reconnection/current sheet is definitively found before the eruption, which is plausibly built at the X-type null point. The jet is triggered when F2 first erupts toward the breakout current sheet and participates in the breakout reconnection. F1 erupts immediately following the breaking of F2. Similar to a large filament eruption, a small flare current sheet appears in the wake of the eruption of F1, which connects the jet spire with the miniature flare arcade in the jet base. Both F1 and F2 are broken and ejected into the jet body. Therefore, the present jet suggests the breakout model for solar jets proposed by Wyper et al. (2018). This result is also consistent with the observational inspection of the trigger for polar X-ray jets by Moore et al. (2018).

Magnetic cancellation is also observed at the jet base, which mainly occurred at the neutral lines under F1 and F2. It is well known that magnetic cancellation plays an important role in triggering different scales of filament/jet eruptions (e.g., Moore & Roumeliotis 1992; Hong et al. 2011, 2014; Huang et al. 2012; Panesar et al. 2016). The observed jet should result from the joint action of both the breakout reconnection above the base arcade and the magnetic cancellation under the minifilaments. Just before the onset of the jet, F1 does not erupt immediately following the breakout reconnection at C1, while F2 gets bright and rises up as soon as the appearance of C2. We conjecture that this is possibly because the magnetic cancellation under F1 did not disturb F1 as much as it disturbs F2. This point needs to be verified in future work.

Properties of this jet, including the breakout reconnection, the minifilament eruptions, and the magnetic cancellation, are similar to those commonly observed in large-scale CMEs. Thus, in line with other literatures (e.g., Raouafi et al. 2010; Schrijver 2010; Wyper et al. 2017), the observations suggest again that multiscales (from jets to CMEs) of solar eruptive activities are self-similar in terms of observational properties and triggering mechanisms.

However, the breakout reconnection undergoes a reversal, indicated by the transition of the breakout current sheet from C1 to C2. C1 is orthogonal to C2. The current sheet displays as C1 for about 23 minutes. Then it shortens in length to zero and grows out again as C2. The transition from C1 to C2 takes about 1 minute. After that, C2 lasts about 7 minutes until the start of the jet. As a result, the inflow and outflow regions around C1 become the outflow and inflow regions around C2, respectively. The breakout reconnection thus undergoes a reversal, causing the effect that weakens the magnetic constraint on F1 switching to that which weakens the magnetic constraint on F2. This leads F2 to move away from being balanced.

The reversal of magnetic reconnection is first found in the solar atmosphere. The occurrence of reconnection reversal is possibly a self-consistent behavior (Murray et al. 2009). Using a 2.5-dimensional numerical simulation, Murray et al. (2009) first report an “oscillatory reconnection” that is characterized by a series of reconnection reversals initiated in a self-consistent manner. The reconnection is first built between an emerged bipolar arcade and ambient open fields in their simulation. Then the reconnection lasts in distinct bursts. The inflow and outflow regions of one burst of reconnection become the outflow and inflow regions in the following burst of reconnection. The magnetic system finally settles toward equilibrium through consecutive bursts of reconnection. They argue that oscillatory reconnection occurs if the outflow regions are quasi-bounded during each burst of reconnection. The reconnection reversal occurs because the gas pressure in the bounded outflow regions increases above the level of that in the inflow regions. For the present jet, the outflow regions around the current sheet C1 are actually quasi-bounded, thus the reversal occurs and the current sheet changes from C1 to C2. In turn, the observed reversal of reconnection provides direct evidence of the oscillatory reconnection proposed by Murray et al. (2009). However, different from the simulation, we do not observe two or more reversals of reconnection that keep the magnetic system stable. Instead, the magnetic fields in the jet base become unstable and erupt out only after one reversal. This is because of the release of free energy stored in the magnetic fields of the minifilaments in the jet base. Zhang et al. (2014) report repeating magnetic reconnection in a coronal bright point, which is likely a case of oscillatory reconnection. More observations are needed for an in-depth understanding of the nature of the reversal of magnetic reconnection and to confirm if the reconnection reversal is prevalent in the solar atmosphere.

In summary, the present observations directly image the evolution of the breakout current sheet that precedes the eruption of a minifilament-jet event. The breakout current sheet has an apparent length less than 3″ and a width less than 1″. In particular, according to the transition of the current sheet from the horizontal C1 to the vertical C2, we conclude that the breakout reconnection undergoes a reversal in the vicinity of a potential coronal null point. The entire evolution of the current sheet can be detected in images of multiwavelength emissions including AIA EUV and IRIS transition-region lines. Via DEM analysis, C1/C2 are found to be multithermal in nature, with mean temperatures of about 7/6.8 MK, a peak temperature of 1.6 MK, and EMs of 1.4/2.5 × 10^{28} cm^{-3}. Similar processes referring to such a reconnection reversal are only found in numerical simulations for oscillatory reconnection (Murray et al. 2009; Archontis et al. 2010; McLaughlin et al. 2012; Thurgood et al. 2017).

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