Two Different Cases of Filament Eruptions Driven by Kink Instability

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Abstract. In this work we present a comparative analysis of two filament/prominence eruptions (EP) driven by helical kink instability. First EP on 2010 March 30 presented a kink induced confined eruption of a single magnetic flux rope (FR) followed of partial FR reformation, which was associated with coronal mass ejection (CME). The second EP on 2014 May 4 represented kink induced eruptions of two coupled FRs of the same filament that were interacting and splitting during the eruption. The first FR underwent a confined eruption followed of FR reformation while the second FR underwent a successive partial eruption, which was associated with CME. The physical processes in the EPs environments, such as magnetic emergence, cancellation or shearing, reconnection signatures, overlaying magnetic arcades and the activity events accompanying the eruptions were analyzed. This work laid special emphasis on specific conditions, which are crucial for the type of the filament eruptions and their kinematics and evolution.

Key words: Sun; Solar Prominence Eruptions; Coronal Mass Ejections; Magnetic Fields; Multiwavelenght Observations

Introduction

The kink instability is one of the basic physical mechanisms that drive filament eruptions (e.g., Bi et al., 2011; Liu et al., 2007). Recent observations of kinking filament eruptions, including full, partial, and failed eruptions reveal that the type of eruption depends on the interactions of the filament with its magnetic environment (Gilbert et al., 2007). The EP on 2010 March 30 evolved as a height-expanding left-handed twisted loop with both legs anchored in a chromospheric plage region. The EP reached a maximum height of 526 Mm before contracting to its primary location, where it was partially reformed in the same place two days later. Nevertheless, this eruption triggered a CME observed in LASCO C2 (Koleva et al., 2012). The EP on 2014 May 4 consisted of two coupled filament FRs (FR1 and FR2) located along the same polarity inversion line, i.e. in the same filament channel in a quiet solar region. Only the FR1 eruption was associated with CME (Dechev et al., 2018). First event was observed as an EP above the limb from AIA/SDO, while in the EUVI/STEREO B field-of-view (FOV) it was viewed as a filament eruption (FE). Second event was well observed as an EP above the limb from AIA/SDO and EUVI/STEREO-B, while in the EUVI/STEREO-A FOV, it was observed as a FE (Fig. 1). The associated CMEs were well observed in LASCO C2 FOV.

1.Analysis and Results

The EP on 2010 March 30 revealed three distinct phases: prominence activation, an eruption with acceleration, and an eruption with a constant velocity (Fig. 2a). Its kinematic parameters given in Table 1 are typical for a single FR failed eruption.

The FR1 of EP on 2014 May 4 rose with velocities and accelerations that are typical for slow eruption (Table 2) and Fig. 2b,e. The kinematic evolution of the EP FR2 showed two phases: a slow-rise phase, during which the FR2 kinked loop underwent a short-time ascent, followed by a long-lasting of downward motion up to the original place, where it was rebuilt. Its kinematic parameters (Table 2) are rather similar to those of EP on 2010 March 30 (Koleva et al., 2012; Dechev et al., 2018). In the late eruption stage the FR of EP on 2010 March 30 clearly showed a left-handed twist of 6π, i.e. well above a critical value of 2.5π (Fig. 1 left) (Hood and Priest, 1979), which was transformed during the eruption into a left-handed writhe up to $\sim 1\pi$.

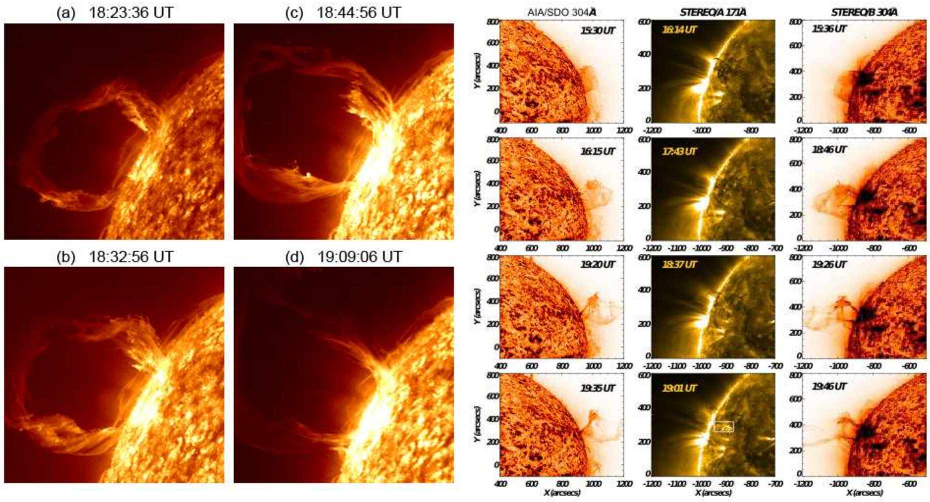

Fig. 1. EP 2010 March 30 observed in the He II 304 Å AIA/SDO channel (left) and its running difference images from the EUVI/STEREO-B 304 Å channel (right). The right panel reproduced from Dechev et al., (2018).

During the fast phase the FR1 of EP on 2014 May 4 clearly showed left-handed helical twist that was transformed during the eruption to a left-handed writhe of about a quarter turn ($\pi/2$) (Fig. 1 right). In the late stage, when the FR1 was well visible in the LASCO/C2 FOV (Fig. 3 top) its kinked structure with crossing legs suggests writhe of $\sim 1\pi$.

During the fast phase the left-handed twisted EP FR2 developed into a left-handed kinked loop that expanded up along a strong non-radial direction (Fig. 1 right). When the FR2 reached a maximum height, its kinked structure presented writhe of almost 3/4 turn ($\sim 1.5\pi$). Afterward, the FR2 began to descend and simplify and in the last stage it was rebuilt at almost the original shape and position.

Table 1. Basic phases and kinematic parameters of the EP on 2010 March 30

Phase	**UT**	**T** (min)	**H** (Mm)	**V**(kms^{-1})	**a** (ms^{-2})
Activation	17:30 – 17:55	0 – 23	18 – 33	10	
Acceleration	17:56 – 18:08	24 – 36	34 – 90	15 – 114	46 – 380
Constant Velocity	18:11 – 18:33	38 – 66	97 – 241	110	0

Table 2. Basic phases and kinematic parameters of the FR1 and FR2 of EP on 2014 May 4 (FRise - Fast Rise, SR - Slow Rise, FD - Fast Downflow, SF - Slow Downflow)

Phase	**UT**	EP FR1			EP FR2			**FOV**
		H (Mm)	**V** (kms^{-1})	**a** (ms^{-2})	**H** (Mm)	**V** (kms^{-1})	**a** (ms^{-2})	
SR	15:36-18:07	85-133	1.7-14	0.13-3				EUVI B
FRise	15:45-19:23				30-110	0.6-21	0.2-5.6	AIA
FRise	16:17-19:28	30-185	5.7-31.3	0.2-4.9				AIA
FRise	18:07-20:17	133-365	14-50	3.1-6.2				EUVI B
FRise	18:47-19:07				100-110	170		EUVI B
FD	19:07-19:37				110-80	170-75	-15.2	EUVI B
SD	19:37-21:27				80-54	75-21	-2.1	EUVI B

2. Discussion

In this study we present results from a detailed comparative analysis of two kink induced EPs observed on 2010 March 30 and 2014 May 4, that allowed us to examine the specific conditions, which are crucial for the type of the filament eruptions and their kinematics and evolution, as well.

First event presented a single EP FR eruption of a confined type followed by apparent plasma draining and a partial prominence/filament reformation in the same place, which suggests that either part of the prominence plasma has drained into the chromosphere or that not all of the plasma returned to its primary temperature (see Koleva et al., 2012). The EP was located in the northern periphery of a large-scale CME magnetic configuration and it was associated with a narrow expanding loop and an empty cavity underneath located in the northern CME periphery (see Fig. 3). Therefore, the EP had a strong asymmetrical position in the CME magnetic arcade. Several observational and theoretical studies suggest that an asymmetric background field is an important factor that leads to failed filament eruptions (see e.g., Liu et al., 2007; Shen et al., 2011, for reviews).

The second event presented more complex prominence/filament eruption because, in this case, two initially coupled FRs (FR1 and FR2) be-

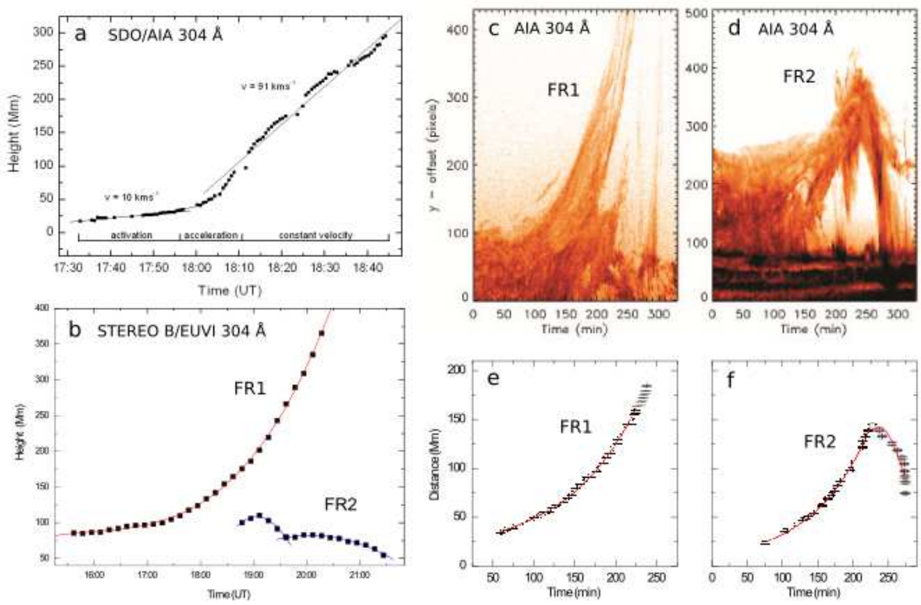

Fig. 2. Height-time profiles of the EPs on 2010 March 30 (a) and 2014 May 4, whose profiles were determined by EUVI(b) and AIA (e,f) 304 A data. Panels (c) and (d) show the FR1 and FR2 AIA 304 slice maps. Panel (a) reproduced from Koleva et al. (2012), and the rest panels reproduced from Dechev et al. (2018).

longing to the same filament body erupt. The complex character of this event results from the interaction between FR1 and FR2 during the kink induced eruption. Initially coupled FR1 and FR2 merged in a compact FR which slowly rose during the EP slow-rise phase. During the late stage of slow-rise phase and early stage of the EP acceleration two FRs underwent splitting, which began from their upper parts and after that they became well separated. Such cases of eruptions are still very rarely reported.

Despite the same driver of the EP FRs eruptions, i.e. kink instability as mentioned above, such interaction between them significantly affects their behavior and played a crucial role for their basic characteristics. As a result of that, the FR1 and FR2 showed distinctly different kinematics, propagation directions, kink evolutions and type of eruptions during the EP acceleration phase. The FR1 and FR2 merging results into a sharp upward U-shaped structure appearing between FR1 and FR2 upper parts, where EUV brightening transfer and bright blobs moving took place (Dechev et al., 2018). The observed upward U-shaped structure that was well visible in all EUV AIA channels and the availability of small bright blobs, which moved episodically along this structure suggest signatures of external type magnetic reconnection (e.g. Su et al., 2015). Moreover, this result is consistent with the study of Liu et al. (2012), which argued that such brightening evolution suggests flux transfer which must involve a transfer

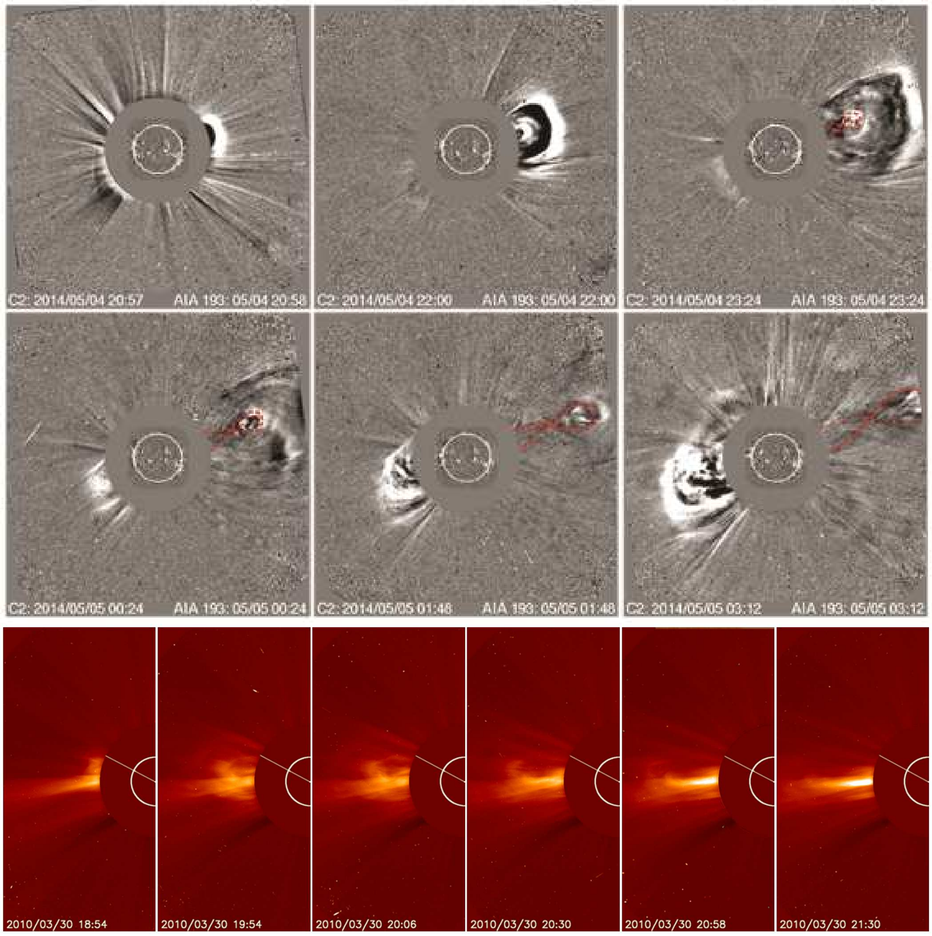

Fig. 3. Evolution of the CME associated with EP on 2014 May 4 observed by SOHO/LASCO C2 coronagraph. The red dotted line trace out the FR1 kinked structure (top). CME associated with the EP on 2010 March 30 as viewed in the SOHO/LASCO C2 images (bottom). The over-plotted white radial line indicates the EP position in the northern CME periphery. Top panel is reproduced from Dechev et al., (2018).

of current from the lower FR2 to the upper FR1. On the other hand, this result is consistent with theoretical study of Kliem et al. (2014), which argued that accumulation of flux under the apex of FR1 could contribute to its additional twist, i.e. it will increase the destabilization process.

During the acceleration phase FR1 quickly rose up in comparison with FR2 and resulted in a bright core of the associated CME, where its kink shape and evolution could be traced up to 6 solar radii in LASCO C2 FOV (Fig. 3 top). In AIA FOV the velocity of FR1 increased up to 30 km/s in the height range 30-185 Mm, while in EUVI B FOV the velocity reached

50 km/s in the height range 133-365 Mm (Table 2, Fig. 2 b, e). However, in comparison with the "pure" single FR eruption in the first event, in which the FR reached velocity of 110 km/s in a narrow height range 85-133 Mm, the FR1 presented a very slow kink eruption associated with a slow CME with linear velocity of 329 km/s.

During the EP acceleration phase the FR2 slowly rose up below the FR1 with increasing velocity from 0.6 km/s to 21 km/s. The FR2 rising accompanied by EUV brightening, well visible in AIA 171 A images that began to propagate from top to bottom along kinked loop threads up to the western FR2 threads footpoints. The FR2 propagation in the SDO/AIA POS was deflected from the radial direction under an angle of 45 deg. When the FR2 reached a maximum height of 110 Mm it developed into a narrow kinked loop with strong kink writhe of $\sim 1\pi$. Afterwards, FR2 began to descend accompanied by apparent plasma draining to the chromosphere and simplification of its morphology. Later, when FR2 exhibited a maximal kink writhing of $\sim 1.5\pi$, it began to fade from top to bottom. When the FR2 almost reached the initial height it rebuilt at the same place but with strongly simplified structure.

The long-lasting descend FR2 motion after its eruption and the stronger kink writhe of FR2 at low heights compared to those of FR1 at high heights are consistent with the model of Török et al. (2010) and could explain the confined FR2 eruption in our case. In addition, according to Shen et al. (2012), the external reconnections occurring between FR1 and FR2 upper parts could contribute to the failure of FR eruption. Such processes can cause the removal of a sufficient amount of the stabilizing field above the FR1 and increase the confinement ability of the fields above FR2. On the other hand, the sequence of the FR1 and FR2 eruptions, the EUV brightening of FR2 reaching to its footpoints and stronger FR2 kink writhe are consistent with one of the scenarios developed by Kliem et al. (2014), according which a similar FR configuration enables the eruption of the upper FR, followed by downward motion and confining of the lower FR if it is unstable.

3. Summary and Conclusions

EP on 2010 March 30 showed a "pure" kink-induced eruption of a single prominence FR.

1. The EP revealed three distinctive phases of prominence eruption: a prominence activation phase, accelerating phase, and eruptive phase with constant velocity.

2. The same sign of the EP twist and writhe, as well as the amount of twisting and writhing indicate that possible conditions for kink instability were present.

3. The filament/prominence descent following the eruption and its partial reformation at the same place two days later suggests a confined type of eruption. The asymmetric background magnetic field played an important role in the failed eruption. The FR eruption was associated with a fast CME with linear velocity of 724 km/s.

EP on 2014 May 4 presented very rarely reported kink-induced eruptions of two coupled FRs of the same prominence, which interacted during the eruption.

1. The EP FR1 and FR2 represented slow eruptions with velocities from several km/s to several tens km/s, with an acceleration of about several m/s^2. The FR1 presented a successful partial eruption, while the FR2 underwent a failed eruption followed by the FR2 rebuilding at original place. The FR1 eruption was associated with a slow CME with linear velocity of 329 km/s and its kinked shape could be traced as a CME bright core up to 6 solar radii in LASCO C2 FOV.

2. There are three arguments for kink instability to be a driver of the FR1 and FR2 eruptions: (i) The apparent left-handed twist in FR1 and FR2 converted later into significant amount of left-handed kink-writhe. (ii) The two FR's eruptions were accompanied by apparent mass draining in the legs and flare-ribbons beneath them. However, the kink instability may not be acting alone since the slow rise of the FRs was accompanied by EUV brightening, which is indicative of slow reconnection.

3. The interactions of the FR1 and FR2 upper parts played a crucial role for their basic characteristics and the type of eruption. The FR1 - FR2 system underwent long-lasting splitting during the late stage of the slow rise phase and early stage of the eruption. An upward U-shaped structure was formed at the interaction region. Its brightening in all EUV channels is interpreted as a signature of reconnection that suggests flux transfer from the lower FR2 to the upper FR1. In such scenario a similar flux rope configuration enables the eruption of the upper FR1 followed by descent, and confining of the lower FR2.

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