New Astronomy 59 (2018) 45–53

Contents lists available at ScienceDirect

New Astronomy

journal homepage: www.elsevier.com/locate/newast

Kink-induced full and failed eruptions of two coupled flux tubes of the same filament

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HIGHLIGHTS

- The EP source was two coupled filament segments in a quiet solar region.
- Eruption belongs to the class of causally linked eruptions of two coupled segments.
- EUV signatures suggest magnetic flux and current transfer between filament segments.
- The segments have same helicity over the critical values for kink instability to act.
- Two segments produced successive (partial) and failed kink-induced eruptions.

ARTICLE INFO

Article history:
Received 7 March 2017
Revised 18 August 2017
Accepted 1 September 2017
Available online 14 September 2017

Keywords:
Solar filaments
Prominences
Coronal mass ejections (CMEs)
Flares
Magnetic topology
UV radiation
Multiwave observations

ABSTRACT

In this work, we report results from the study of a filament/prominence eruption on 2014 May 4. This eruption belongs to the class of rarely reported causally linked eruptions of two coupled flux tubes (FTs) of a quiet region filament. We made a comparative analysis based on multiwave observations from Solar Dynamics Observatory (SDO) and Solar Terrestrial Relations Observatory (STEREO) A and B combining the high temporal and spatial data taken from three different viewpoints. The main results of the study are as follows: (1) The source of the eruptive prominence consists of two coupled FTs located near the eastern limb: top-located one (FT1) and bottom-located one (FT2). (2) FT1 and FT2 had the same helicity, i.e. left-handed twist and writhe. Their untwisting motion during eruption suggests that kink instability seems to act. (3) The kinematic evolution of the FT1 suggests a slow successful eruption that was associated with a slow CME. (4) The FT2 exhibited failed kinked eruption with a non-radial propagation followed by its reformation. This eruption was accompanied of apparent mass draining in the legs, flare-ribbons and post-flare EUV arcade.

1. Introduction

It has been widely accepted that the filament/prominence eruptions, coronal mass ejections (CMEs), and flares, are three different manifestations of a large single physical process, whose energy source is derived from the free energy contained in sheared or twisted coronal magnetic fields (e.g. Forbes, 2000; Lin et al., 2003; Su et al., 2011). Observationally, the eruptive prominences (EPs) are frequently associated and physically related to CMEs and flares (Tandberg-Hanssen, 1995; Forbes, 2000; Priest and Forbes, 2002; Lin et al., 2003) and some of them are followed by two ribbon flares (Choudhary and Moore, 2003; Chandra et al., 2011).

Observed in white light, CMEs are often seen as a three-part structure of a bright CME leading front (rim), followed by a dark cavity, and a bright core (e.g. Illing and Hundhausen, 1986; Gibson et al., 2006; Chen et al., 1997; Chen, 2011; Vourlidas et al., 2013). The cavity is suggested to be the upper portion of a helical flux rope with an EP at its bottom that is a white-light counterpart of the CME bright core (e.g. Munro et al., 1979; House et al., 1981; Low, 1996; 2001; Chen et al., 2006; 2014). In recent years, the typical rim-cavity-prominence coronal mass ejection (CME) morphology has been hypothesized to be the result of underlying magnetic flux-rope (FR) geometry. This hypothesis has been applied to the description of prominences, CMEs, and to combined FR-Prominence-CME structures (see e.g. Krall and Sterling, 2007; Green and Kliem, 2009, for detailed reviews).

An outstanding question about CMEs and EPs structures is whether they are driven by a pre-existing FR through ideal processes, such as loss of equilibrium or magnetohydrodynamic (MHD) instabilities (e.g. kink or torus), or by non-ideal (resistive) processes, i.e., magnetic reconnections, which either lead to expul-

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http://dx.doi.org/10.1016/j.newast.2017.09.002
1384-1076/

sion of the pre-existing FR or to the FR formation on-the-fly during the eruption (see, e.g. Schmieder et al., 2013; Cheng et al., 2014; Song et al., 2014b, and references therein). The arguments in favor of a FR topology preceding the eruption is based on both modeling (see Green and Kliem, 2009, for detailed reviews) and observations. Many observations of events in the lower corona indicate the presence of FRs (Cheng et al., 2014; Song et al., 2014a; 2014b, for detailed reviews). According to Ouyang et al. (2017), 89% of the eruptions have pre-existing flux ropes, and 11% have sheared arcades before eruption.

According to Gilbert et al. (2007), there are three basic types of the filaments/prominences eruptions: full, partial, and failed (confined). Sometimes, two and more filaments erupt in a close temporal and spatial correlation with causal linkage between them (e.g. Jiang et al., 2011; Joshi et al., 2016). There is a wide class of such events and in some of them the eruptions of different types are involved. Very interesting and rarely reported are the cases that present the causal linked eruptions of near-by located filaments or such ones that lie in the same filament channel (e.g. Liu et al., 2012; Bi et al., 2012; Sterling et al., 2012; Li and Zhang, 2013; Kliem et al., 2014; Zhu and Alexander, 2014; Xue et al., 2016).

In this work, we report results from the study of a filament/prominence eruption on 2014 May 4, that belongs to aforementioned last class of very rarely reported causally linked eruptions. A comparative analysis was made by multi-wavelength observations from Solar Dynamics Observatory (SDO) and Solar Terrestrial Relations Observatory (STEREO) A and B. We examined two main rising flux tubes (FTs), which represent two neighbor segments of a filament. The first prominence flux tube (FT1), which is associated with a CME, represents kinked successful (partial) eruption. The second one (FT2) that was composed of a number of threads was a source of a kinked failed eruption (Ji et al., 2003). Combining the high temporal and spatial observations taken from three different viewpoints, we examined the positions of the two erupting FTs, their dynamics, the relationships and interaction between them, and the activity at their footpoints during the eruptive process.

2. Data and observations

We analyzed the prominence eruption that occurred at the north-west solar limb between 15:36 UT and 21:36 UT on 2014 May 4.

For the present study we used data from Solar Dynamics Observatory (SDO) and the two Solar Terrestrial Relations Observatory (STEREO) spacecraft, which allows us to observe the prominence eruption from three different points of view.

We used 1-min cadence images taken by Atmospheric Image Assembly/SDO (AIA) (Lemen et al., 2012) in the He II 304 Å and Fe IX/X 171 Å channels. The AIA image field-of-view (FOV) reaches 1.3 solar radii with a spatial resolution of $\sim 1.5''$and cadence of ~ 12 s. We used level 1 reduced data, i.e. with the dark current removed and the flat-field correction applied.

Line-of-sight magnetograms taken by the Helio-seismic and Magnetic Imager (HMI) (Scherrer et al., 2012) with a 45 s cadence are used in this study to examine the pre-eruptive evolution.

We also analyzed observations from the Extreme UltraViolet Imager (EUVI) onboard STEREO Behind (B) and Ahead (A) spacecraft (Howard et al., 2008). EUVI has a FOV of $1.7R_\odot$ and observes in four spectral channels (He II 304 Å, Fe IX/X 171 Å, Fe XII 195 Å and Fe XIV 284 Å) that cover the 0.1 to 20 MK temperature range (Kaiser et al., 2008). The EUVI detector has a pixel size of $1.6''$. We used images in the He II 304 Å channel with an average cadence of 10 min from STEREO B and A, and Fe IX/X 171 Å channel with cadence of 1 min from STEREO A.

The kinematics of associated Coronal Mass Ejection (CME) was analysed using images from the inner and outer white light coronagraphs COR1 and COR2 on board the STEREO B, which have FOVs from 1.5 to 4 $R_\odot$ and from 2.5 to 15 $R_\odot$, respectively. Images obtained by the Large Angle and Spectrometric Coronagraph (LASCO)/C2 ($2-6\ R_\odot$) and C3 ($3.7-30\ R_\odot$) onboard SOHO (Brueckner et al., 1995) were also analysed.

The eruptive event was well observed as prominence eruption above the western limb of SDO/AIA FOV and the eastern limb in EUVI B FOV. The separation angle between STEREO B and SDO was 165°. STEREO B was the furthermost from the Sun and $R_\odot$ in its FOV was the smallest ($938''$) versus these in SDO ($952''$) and Stereo A ($999''$) FOVs. In addition, STEREO B was rolled from the solar north under an angle of $\approx 6°$, which provides the optimum perspective for EP observation, where the EP could be followed up at a distance in order of 1 $R_\odot$. In AIA FOV the EP could be pursued at a distance in order of 1/3 $R_\odot$.

In the EUVI A FOV, because of the large separation angle (157°) between the STEREO A and SDO, the eruptive event was mainly observed as a filament eruption. At such angle, the prominence lift-off takes place in front of the STEREO A plane-of-sky (POS) and it rapidly fading with the height in the images (see e.g. Zuccarello et al., 2012) . The initiation and early phase was well observed by EUVI A in 304 Å and 171 Å channels as an eruption of two coupled filament FTs located near the eastern limb.

Using Carrington longitudes (CL) of the solar central meridians in the different FOVs, we determined the positions of SDO and STEREO A POSs with respect to the EP location. The CL of the SDO western limb was 88°, while these of the eastern limbs of STEREO A and B were 65° and 103°, respectively. The erupting filament FTs observed in EUVI A images were located northeast between CLs 75° and 105°. Therefore, the AIA POS was located of 23° west of the eastern limb in EUVI A images and it was near to eastern legs of the erupting FTs, which are well visible in the AIA images (Fig. 1, left panels). The EUVI B POS was located of 38° west of EUVI A eastern limb and thereby it almost coincided with the low latitude western loops' legs, which are well visible in the EUVI B images (Fig. 1, right panels).

3. Morphology and kinematics

The source of the EP was the filament that was located at mean Carrington longitude 97.4°. It is situated along a polarity inversion line (PIL) located in a quiet solar region, which is far away of any active regions.

3.1. Prominence eruption observed by SDO/AIA

The eruptive filament part is composed of two closely coupled flux tubes (FT): top-located compact one (FT1) and bottom-located more diffuse one (FT2) (see Fig. 2). In the SDO/AIA field of view the EP appeared in the west limb at PA 288°. The prominence eruption was registered by AIA instrument between 15:30 UT and 21:15 UT. The eruption began as a slow rising "compact" object with intricate fine structure. The slow rising phase lasted until 18:30 UT, when the onset of eruption phase was registered. The FTs morphology remained complicated during the slow-rising phase and the early stage of eruption phase up to 19:15 UT when FT1 and FT2 became recognizable. During these time periods significant changes in the FT1-FT2 system took place that were associated with the treads dynamics and their brightening evolution, which were more pronounced in the AIA 171 Å and 131 Å channels.

3.1.1. SDO/AIA 304 Å field-of-view

After 19:15 UT one can clearly identify FT1 and FT2 with noticeable fine structure and apparent twisting. The FT1 progressively