New Astronomy 26 (2014) 86–97

Contents lists available at SciVerse ScienceDirect

New Astronomy

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

Filament eruption in association with rotational motion near the filament footpoints

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HIGHLIGHTS

- We present the study of a filament eruption in the vicinity of the active region.
- Converging motion and opposite helicity injection caused the eruption.
- Observed rotational motions in both footpoints during filament eruption.
- Torque imbalance in the fluxtube caused the rotation in the footpoints.
- The rotation changed the trend in the helicity flux after the filament eruption.

ARTICLE INFO

Article history:
Received 20 October 2012
Received in revised form 20 June 2013
Accepted 1 July 2013
Available online 10 July 2013

Communicated by W. Soon

Keywords:
Solar filament
Magnetic fields
Helicity

ABSTRACT

The active region magnetic field surrounding the filament plays an important role in filament formation, their evolution and disruption. We investigated a filament eruption that occurred in southern hemisphere of the Sun on July 08, 2011 using AIA and HMI data. The filament was located in a region close to the active region NOAA 11247 with its West-most footpoint anchored in the negative polarity plage region and the East-most in the positive polarity plage region. During observations, the magnetic flux was emerging in the active region and also in the plage regions. The flux emergence was stopped in West-most footpoint of the plage region about an hour before the filament eruption. A converging motion was also observed for many hours in the Western footpoint of the filament. The filament had left-handed twist and the net injected magnetic helicity was positive in both footpoints. Both sign of magnetic helicity were observed in the Western footpoint of the filament where the eruption has initiated. Further, an anti-clockwise rotational motion was observed in both the footpoints just after the onset of filament eruption which lasted for 6 min during the eruption process. The emerging flux, converging motion and injection of opposite magnetic helicity could be responsible for destabilizing of the Western footpoint of the filament leading to eruption. The torque imbalance between the expanded portion of the flux tube and the photosphere may have caused the rotation in the footpoint region which changed the trend in the injected magnetic helicity after the filament eruption.

1. Introduction

Solar filaments are elongated thread-like, dark chromospheric structures with low temperature and high density, suspended along the polarity inversion line (PIL) between the regions of opposite magnetic polarities (Martin, 1998a). Filaments are formed in the active regions as well as in quiet magnetic field regions and may last for several days. Most of them eventually disappear with eruptions associated with flares and coronal mass ejections (CME) (Schmieder et al., 2002; Gopalswamy et al., 2003; Yan et al., 2011).

Twisted magnetic fields support the filaments in the corona. The equilibrium loss initiated by kink-mode instability in twisted magnetic fields is one of the leading mechanisms for filament destabilization and eruption (Sakurai, 1976). The kink-instability occurs when the twist of the emerged flux ropes exceeds a critical value, causing *writhing* of flux rope around its axis (Fan, 2005). As a result, the flux rope can loose its equilibrium and erupt (Liu et al., 2007). By observing an active region filament, Romano et al. (2003) found that a total twist in one of the prominence threads changed from 5-turns to 1-turn as it raised during filament activation. They concluded that prominence was destabilized by kink-mode instability and magnetic field later relaxed to a new equilibrium position. Romano et al. (2005) suggested that in one of the filament

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http://dx.doi.org/10.1016/j.newast.2013.07.001

eruption events, the injected magnetic helicity via the photospheric shearing motion exceeded the kink instability threshold.

The filament eruption could be triggered by the magnetic reconnection at low level in the solar atmosphere (Contarino et al., 2003; Contarino et al., 2006). In the photosphere it is seen as a cancellation of magnetic features (Priest et al., 1994). Many times it has been observed that magnetic flux cancellation occurs at the photosphere near the PIL (Martin, 1998a). If the flux cancellation at the photosphere continues after the flux rope has been formed, it may result in instability leading to eruption; as formulated by van Ballegooijen and Martens (1989), Amari et al. (2003) and Amari et al. (2011). It has also been observed that flux cancellation at the PIL lead to the formation of X-ray sigmoid which eventually triggers the CME (Green et al., 2011). A successive reconnection in the coronal arcade can change the configuration such that filament below the arcade can no longer be sustained. This destabilization can cause the eruption of the filament (Zuccarello et al., 2007). "Tether-cutting" mechanism is another example of magnetic reconnection where strapping of magnetic tension force is released by internal reconnection above the PIL e.g., (Moore et al., 2001) to destabilize the filament. But, Aulanier et al. (2010) found that magnetic flux cancellations at the photosphere and the tether-cutting reconnection at the coronal heights do not initiate the CMEs in bipolar magnetic field configurations. However, they are essential to buildup flux ropes in the pre-eruptive stage. Subsequently, the flux rope rises to a height at which the torus instability can set into cause the eruption.

Sunspot rotation in the vicinity of filament can also be responsible for the formation and ejection of active region filament (Yan et al., 2012). Zuccarello et al. (2012b) have observed a B7.4 class flare associated with filament eruption which occurred in the active region. By examining the magnetic field configuration and photospheric velocity maps they concluded that a shearing motion of the magnetic field lines could increase the axial field of the filament, thus bringing the flux rope to a height where the torus instability criteria is met to favor the eruption.

In this paper, we present the study of a filament eruption that occurred in the vicinity of the active region NOAA 11247 that was observed in different wavelength regimes. The filament eruption which occurred at about 23:20 UT on July 08, 2011 was followed by B4.7 class flare starting at $\sim$ 00:45 UT. Prior to eruption, a flux emergence in the vicinity of filament footpoint and converging flow were observed in two footpoints of the filament at the photosphere. These footpoints of the filament were rooted in the West-most plage region. Just after the filament activation, a rotational motion was also observed at the footpoint locations. In the next Section, we describe the data preparation and the analysis method used. The observational results starting with flux emergence, convergence flow around the filament footpoint, filament eruption and subsequent rotation in the footpoint are presented in Section 3. Finally, in the last Section, we discuss the importance of the flux emergence and converging motion associated with filament destabilization and eruption. We also give plausible explanation for the observed rotation in the footpoints.

2. Observation and method

Atmospheric Imaging Assembly (AIA; Boerner, 2012) on board the Solar Dynamics Observatory (SDO; Lemen, 2012) provides images of the Sun in ultra violet (UV) and extreme ultra violet (EUV) wavelengths that cover the regions from the photosphere to the coronal level. The pixel resolution of AIA is 0.6″ while the field-of-view is about 1.4$R_\odot$. We used EUV data from AIA at 171, 193 and 304 Å wavelengths (image cadence of 12 s) to study the filament eruption in detail. The acquired data set starting from 15:00 UT (July 08, 2011) to 04:00 UT (July 09, 2011) covers the entire filament eruption event. The level-1 data was upgraded to the level 1.5 using the software 'AIA_PREP.PRO' available in solarsoft routine. The region of interest was tracked using the 'DEROT_MAP.-PRO'. The tracked region data cube was prepared and used to study the dynamics of the filaments at the coronal level.

Complementary to the coronal data sets, we also obtained a few full-disk H_α images from the Big Bear Solar Observatory to study the morphology of the filament at the chromospheric heights. These H_α images were acquired at BBSO (Denker et al., 1999) with 2 k $\times$ 2 k pixel CCD camera having a pixel resolution of 1". Similar to AIA data, we also extracted the region of interest in H_α images by tracking it in heliographic co-ordinate system. However, due to their limited availability, we used them only for the morphological study of the filament in the chromosphere.

Helioseismic and Magnetic Imager (HMI; Schou et al., 2012) provides the line-of-sight magnetogram at a cadence of 45 s with a spatial resolution of 0.5" per pixel. We have obtained the line-of-sight magnetograms for about 2 days starting from Jul 08, 2011. The data has been interpolated to the AIA pixel resolution. Later, the obtained data has been tracked over the region of interest, corrected for the line-of-sight effect by multiplying 1/cosθ, where θ is the heliocentric angle. We averaged 4 magnetograms to reduce the noise level to 10 G. These magnetograms were then used to study the evolution of magnetic fields in and around the filament at the photospheric level.

Apart from these data sets, we also acquired the continuum intensity images from the HMI telescope for which the cadence and pixel resolution are same as the line-of-sight magnetograms. The obtained images have been tracked over the region of interest as has been done for the other data set mentioned above. The 'rotation-corrected' images were then used to determine the velocity of small features near the filament footpoints.

3. Results

3.1. Filament observations at various heights

The filament was located just outside the active region NOAA 11247 at a latitude of 19° in the southern hemisphere. The filament was visible on the Eastern limb when the active region turned towards Earth on July 05, 2011. During the filament eruption the active region was located at a longitude of 14° East of the central meridian. Fig. 1 shows the active region as observed in different wavelengths from the corona to the photosphere. The 'S-shaped' filament is vividly seen in coronal 171 Å image (top-left) and in the higher chromosphere-transition region image taken in 304 Å wavelength (top-right). The filament in EUV wavelength is observed as dark feature. In the H_α image (bottom-left) the filament is visible as a thick dark structures located away from the active region and thin thread like structures extended up to bright plage region. The thin thread like structure bifurcates into two parts. The one part extends up to the plage region and the other one terminates somewhere in the quiet sun region. The bifurcation can be clearly seen in the enlarged portion displayed in the same H_α image, indicated by an arrow. Note that the thin thread like structure seen in H_α image appears as thick dark structure in the coronal image. This bifurcation of the filament in the Western footpoint is not visible in 304 Å image rather a continuous thick dark structure which ends in the Western plage region is seen. In the H_α image the filament exhibits a discontinuity at a location of -300 to -350 arcsec along the horizontal axis. The discontinuity in filament structure is also seen in coronal image (top-left) close to the East-side that is indicated by white arrow. The photospheric