

Flux Cancellation Leading to CME Filament Eruptions

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Abstract

Solar filaments are strands of relatively cool, dense plasma magnetically suspended in the lower density hotter solar corona. They trace magnetic polarity inversion lines (PILs) in the photosphere below, and are supported against gravity at heights of up to ~100 Mm above the chromosphere by the magnetic field in and around them. This field erupts when it is rendered unstable, often by magnetic flux cancellation or emergence at or near the PIL. We have studied the evolution of photospheric magnetic flux leading to ten observed filament eruptions. Specifically, we look for gradual magnetic changes in the neighborhood of the PIL prior to and during eruption. We use Extreme Ultraviolet (EUV) images from the Atmospheric Imaging Assembly (AIA), and magnetograms from the Helioseismic and Magnetic Imager (HMI), both on board the Solar Dynamics Observatory (SDO), to study filament eruptions and their photospheric magnetic fields. We examine whether flux cancellation or/and emergence leads to filament eruptions. We find that continuous flux cancellation was present at the PIL for many hours prior to each eruption. We present two CME-producing eruptions in detail and find the following: (a) the pre-eruption filament-holding core field is highly sheared and appears in the shape of a sigmoid above the PIL; (b) at the start of the eruption the opposite arms of the sigmoid reconnect in the middle above the site of (tether-cutting) flux cancellation at the PIL; (c) the filaments first show a slow-rise, followed by a fast-rise as they erupt. We conclude that these two filament eruptions result from flux cancellation in the middle of the sheared field, and thereafter evolve in agreement with the standard model for a CME/flare filament eruption from a closed bipolar magnetic field [flux cancellation (van Ballegoijen and Martens 1989 and Moore and Roumelrotis 1992) and runaway tether-cutting (Moore et. al 2001)].

Introduction

Solar filaments mainly consist of relatively cool plasma that is suspended in the solar corona. They are known as solar prominences when they are seen on the limb of the Sun. Filaments form above polarity inversion lines (PILs), that separate positive and negative magnetic flux on the photosphere. Filaments can be classified based on where they are located on the Sun. Active region filaments are found in and around active regions, intermediate filaments are found between the boundaries of active regions and the quiet Sun, and quiescent filaments are found on the quiet Sun. All types of filaments can erupt, leading to Coronal Mass Ejections (CMEs). The eruptions release a large amount of stored magnetic energy via reconnection. The eruption of a filament can be ejective or confined. Ejective eruptions produce CMEs, confined eruptions do not. Many eruptions begin with a slow rise of the filament followed by a fast rise. The tether cutting model of filament eruptions explains how filament eruptions might occur due to flux emergence or cancellation along the PIL at the site of reconnection between two opposite elbows of a sigmoid field holding the filament.

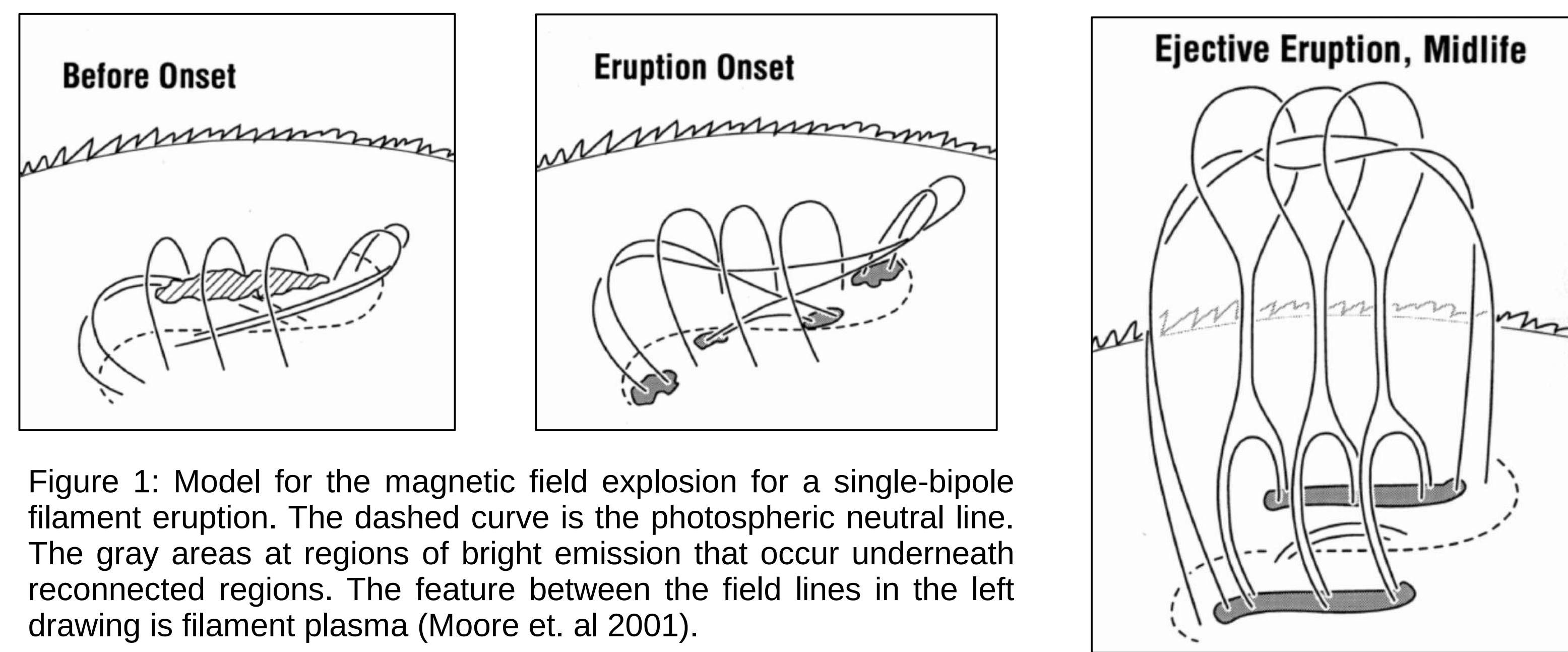


Figure 1: Model for the magnetic field explosion for a single-bipole filament eruption. The dashed curve is the photospheric neutral line. The gray areas at regions of bright emission that occur underneath reconnected regions. The feature between the field lines in the left drawing is filament plasma (Moore et. al 2001).

Methodology

We used Extreme UltraViolet (EUV) images from the Atmospheric Imaging Assembly (AIA), and magnetograms from the Helioseismic and Magnetic Imager (HMI), both on board the Solar Dynamics Observatory (SDO), to study ten different filament eruptions and their photospheric magnetic fields. Here we present and show detailed analysis of two filaments, an intermediate filament that erupted at 02:15 UT on May 4, 2013 (B 9.0) class flare) and a quiescent filament that erupted at 16:54 UT on January 26, 2016 (C1.3 class flare). We used AIA images of wavelengths 304 Å (He II, 5.0×10^4 K), 193 Å (Fe XII & XXIV, 1.6×10^6 K & 2.0×10^7 K) and 94 Å (Fe XVIII, 6.3×10^6 K). AIA provides full sun-disk images with a high spatial resolution ($0.6'' \text{ pixel}^{-1}$) and high temporal cadence (12s). We used magnetograms from HMI with a spatial resolution of $0.5'' \text{ pixel}^{-1}$ and high temporal cadence (45s). The images and magnetograms were downloaded from the Joint Science Operations Center (JSOC) website¹ and analyzed using IDL and SolarSoft. The AIA images were downloaded for 3-5 hours at a cadence of 1m. We primarily used 304 Å and 193 Å AIA images because they are the best wavelengths for observing filaments. We used 94 Å AIA images because they are the best for observing the coronal arcade. The HMI magnetograms were downloaded for 8-12 hours at a cadence of 5m. The EUV images were co-aligned with respect to the HMI magnetogram images and solar rotation was removed from the images. We created several movies to study the dynamics of each filament region and their related photospheric magnetic fields. We found sites of isolated magnetic cancellation and plotted either the negative or the positive cancelling flux.

Introduction

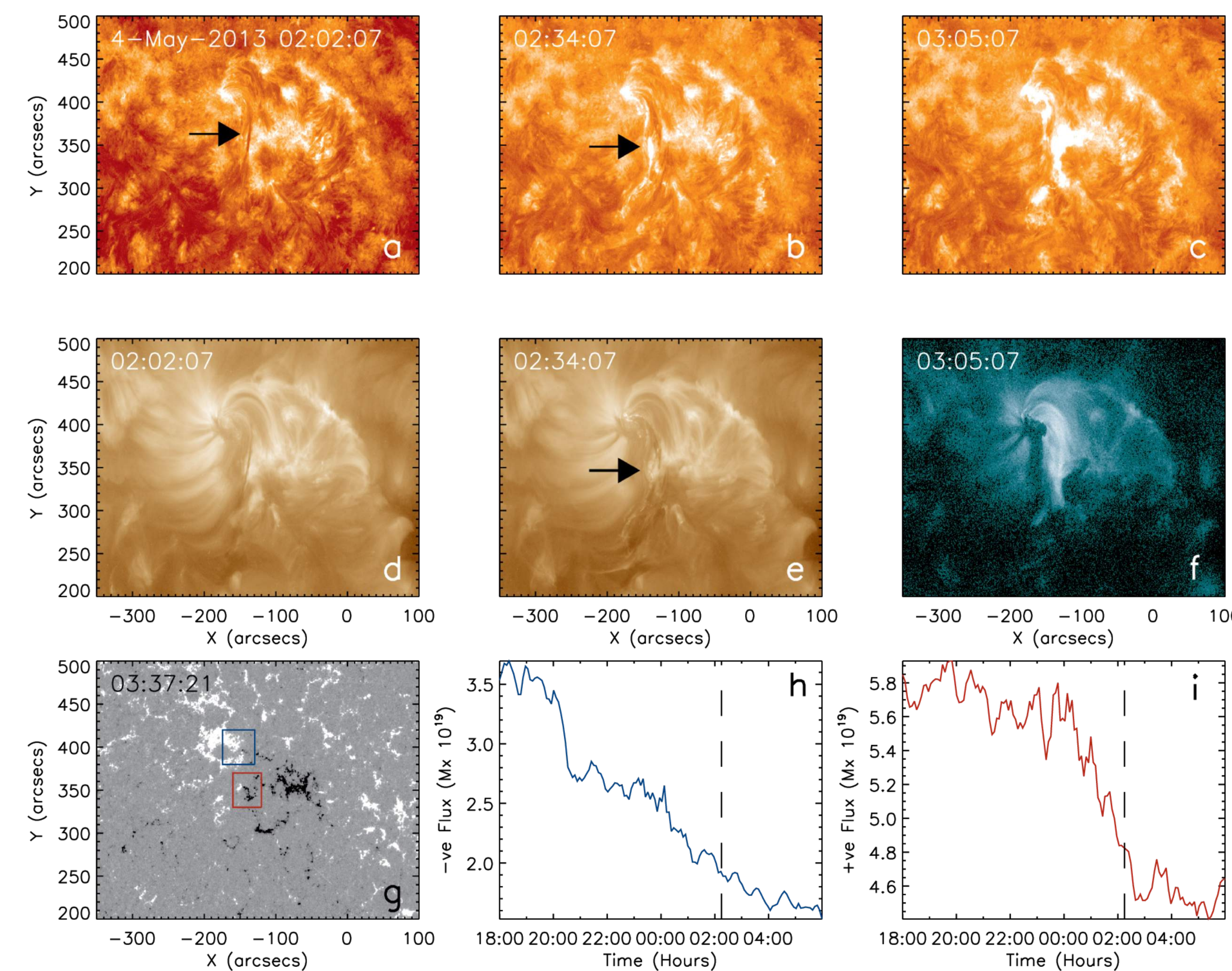


Figure 2: Filament eruption observed on May 4, 2013. (a-c) AIA 304 Å intensity images of the filament (a) before, (b) during, and (c) after the eruption. The arrow in (a) points to the filament, and the arrow in (b) points to brightening at site of flux cancellation shown in the red box in (g). (d-e) AIA 193 Å intensity images of filament before and during eruption. The arrow in (e) points to the brightening in the middle of the PIL. (f) AIA 94 Å intensity image after eruption that shows the post-eruption flare loops. (g) HMI magnetogram of the filament region. The cancellation of minority polarity flux in the boxes in (g) is tracked in (h) and (i). The color of each box corresponds with the color of the plot of the flux. (h-i) Cancelling Magnetic flux curves, smoothed by running mean of two time steps (10 m). (h) is a plot of negative flux over time. (i) is a plot of positive flux over time. The dashed lines represent the time of the main flare brightenings (02:15 UT). Both plots show clear cases of flux cancellation.

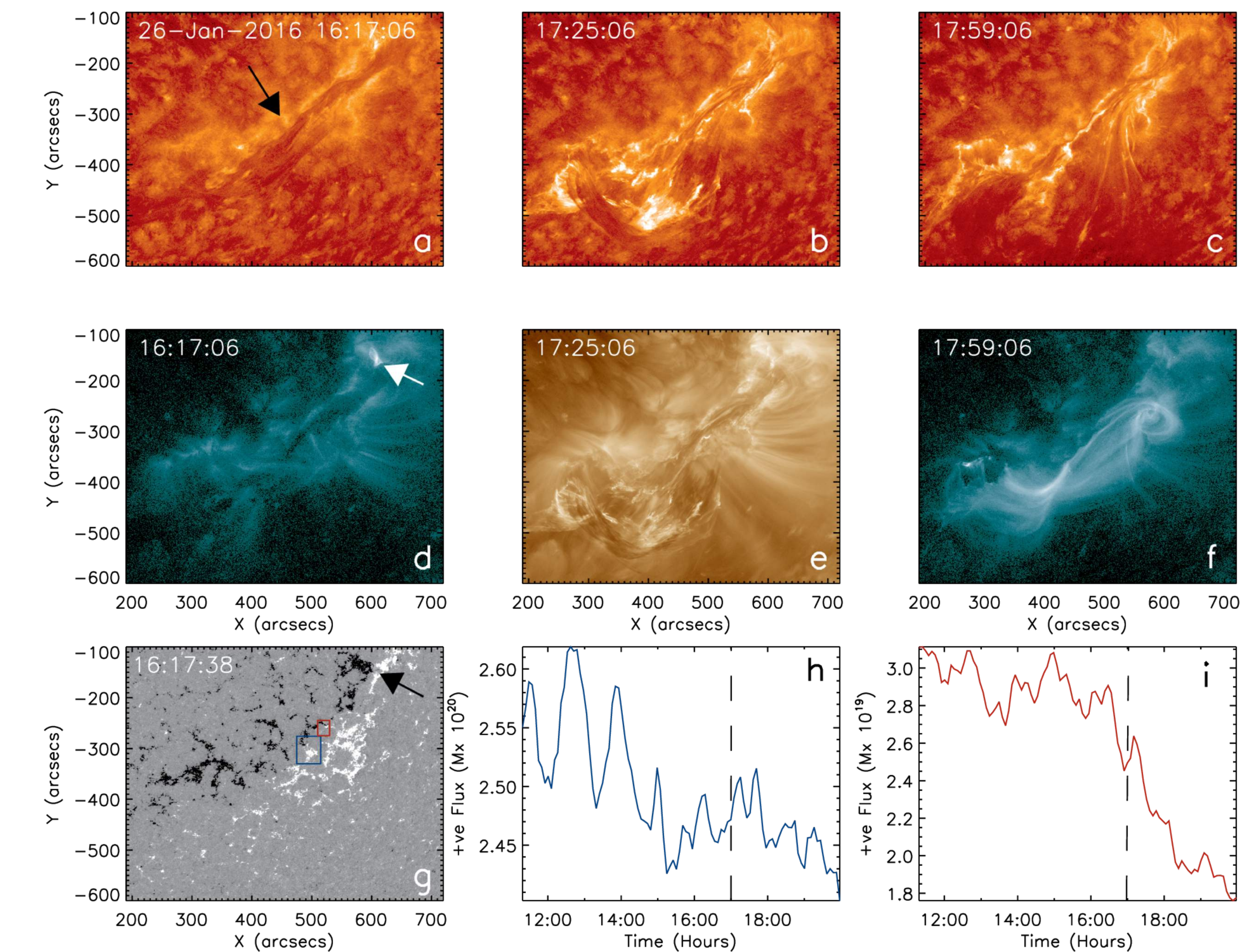


Figure 3: Filament eruption observed on January 26, 2016 (a-c) AIA 304 Å intensity images of the filament (a) before, (b) during and (c) the eruption. The arrow in (a) points to the filament. (d) AIA 94 Å intensity image of filament before eruption. The arrow points to brightening at site of flux emergence shown by the arrow in (g). Later the flux that emerges cancelling with the existing flux (e) AIA 193 Å intensity image of filament during eruption. (f) AIA 94 Å intensity image after eruption that shows the post-eruption flare loops. (g) HMI magnetogram of the filament region. The black arrow points to a site of flux emergence. The cancellation of minority polarity flux in the boxes in (g) is tracked in (h) and (i). The color of each box corresponds with the color of the plot of the flux. (h-i) Plots of positive flux over time, smoothed by by running mean of two time steps (10 m). The dashed lines represent the time of the main flare brightenings (16:54 UT). Both plots show clear cases of flux cancellation.

Discussion

- We studied ten filament eruptions by using data from SDO/AIA and SDO/HMI, including the two filaments featured here.
- Our work supports that continuous flux cancellation contributes to the eruption of the filaments.
- Both filaments first show a slow -rise, followed by a fast-rise as they erupt.
- The slow rise for the May 4, 2013 filament starts at 01:53, and the fast rise starts at 02:15 UT.
- The slow rise for the January 26, 2016 filament starts at 16:00 UT, and the fast rise starts at 16:58 UT.
- Both of the two filaments exhibit a highly sheared core field in the shape of a sigmoid above the PIL, with reconnection occurring above the middle of the site of flux cancellation over the PIL.
- These observations show that these filament eruptions are in agreement with the standard model for a CME/flare filament eruption in that they erupt from a from a closed bipolar magnetic field. They appear to progress via flux cancellation (van Ballegoijen and Martens 1989 and Moore and Roumelrotis 1992) followed by runaway tether-cutting reconnection (Moore et. Al 2001)

References

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