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Study of solar flares and filament interaction in NOAA 10501 on 20 November, 2003

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Abstract. We analyze the observations of two flares from NOAA AR 10501 on 20 November, 2003. The flares are homologous, exhibit four ribbons and are located in a quadrupolar magnetic configuration. The evolution of the ribbons suggests that the first eruption is triggered by "tether cutting" (with subsequent quadrupolar reconnection as in the "magnetic breakout" model), whereas the second one is consistent with the "magnetic breakout" model. Another interesting feature of our observations is the interaction of two filaments elongated in the north-south direction. The filaments merge at their central parts and afterwards change their orientation to the east-west direction. This merging and splitting is closely related to the evolution found in an MHD simulation as a result of reconnection between two flux ropes.

Keywords : Sun: filaments – Sun: flares

1. Introduction

Solar flares are produced by the sudden release of energy stored in the stressed magnetic field. Magnetic reconnection is believed to be responsible for this energy release. Sometimes, a series of flares can occur in the same active region within some

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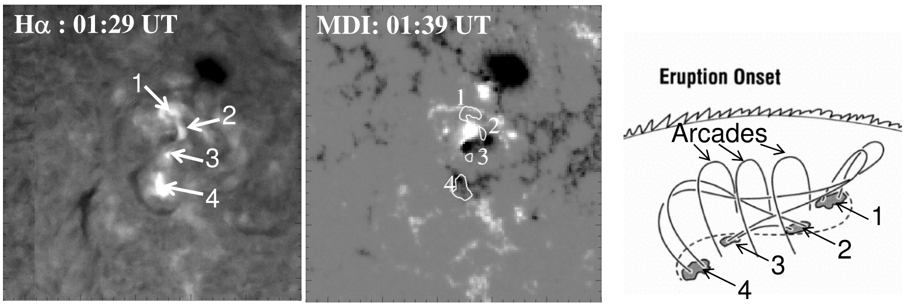

Figure 1. Hα images (left panel) at the flare onset, MDI magnetogram (middle panel) overlaid by Hα brightening (white contour) (adapted from Chandra et al. 2011) and the sketch (adapted from Moore et al. 2001, right panel), which resembles our observations. The field-of view of the images is $270'' \times 270''$

time interval. If these flares have similar morphology, such as similar shapes and locations of flare ribbons, they are termed as homologous flares. The "standard model" for eruptive flares in a single-bipolar configuration was proposed and developed by Carmichael (1964), Sturrock (1966), Hirayama (1974), and Kopp & Pneuman (1976) (the CSHKP model). This model suggests that outwardly stretched magnetic field lines successively reconnect in the corona. This model can basically explain various flare related properties, such as the filament eruption, the formation and evolution of the ribbons, and the associated CME. Later on, Moore et al. (2001) extended this model for the eruptive and also confined flares. This is known as the "tether cutting" model. In this model, converging photospheric flows induce magnetic reconnection at a low height above the photospheric inversion line, then the sheared arcade field lines are progressively transformed to a twisted field configuration. When the downward magnetic tension of the overlying arcade becomes too weak, an ejective eruption is followed. The eruption stays confined if the downward tension of the upwardly stretched magnetic field gets strong enough during the eruption.

Another model for flare initiation is the "breakout model", which is based on a quadrupolar magnetic configuration (Antiochos 1998; Antiochos, DeVore & Klimchuk 1999). In the "breakout model" an eruption is initiated by reconnection at the magnetic null point located in the corona above the magnetic field which will erupt. The reconnection at the null point progressively decreases the magnetic tension above the sheared central arcade. An eruption starts when the tension becomes too weak to compensate the outward magnetic pressure gradient.

Occasionally filaments interact and merge. Filament merging is not uncommon but it is a rarely reported phenomenon. There are a few cases reported in the literature about filament merging, as follows. In the Martin, Bilimoria & Tracadas (1994) and Schmieder et al. (2004) cases the merging of the filaments was end-to-end and, after merging, they formed a single filament which did not erupt. The cases of Bone et al. (2009) was also an end-to-end merging but the merged filament erupted. In the

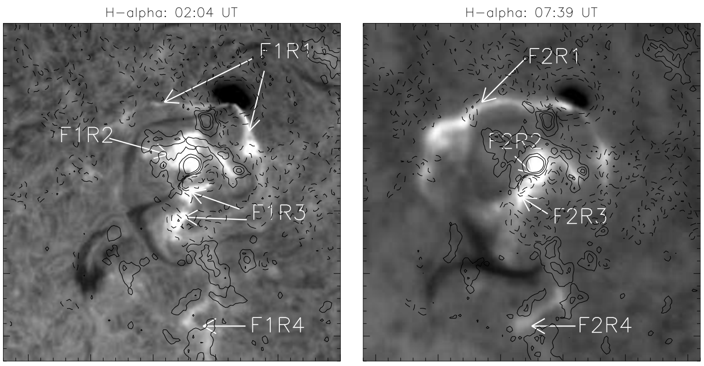

Figure 2. Hα images of first (left) and second (right) flare overlaid by the MDI magnetogram closest in time. solid/dash contours represent positive/negative polarities respectively. The field of view of the images is same as in Fig. 1.

cases of Su et al. (2007) the merging was between the center of one filament and the end of the other filament. These filaments erupted the day after the merging. On 20 November 2003, we observed the center-to-center merging of two filaments. After merging, they immediately split and moved away from each other. Comparing our observations with the cases discussed above we find an entirely different and unique case of merging.

In this paper we describe and model the filament merging/splitting apart which originated in active region NOAA AR 10501 on 20 November 2003. We also study the evolution of two homologous flares (M1.4 and M9.6, hereafter referred to as the first and second flare, respectively). On that day the active region was located at N03 W05 on the solar disc, so that projection effects are negligible.

2. Observations, results and discussions

For our current study we analyze the Hα data from Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India, that uses a 15-cm f/15 Coudé télescope (pixel size 1″). To study the magnetic complexity of the active region we use the data from the Solar and Heliospheric Observatory / Michelson Doppler Imager (SOHO/MDI, pixel size 1.98″, Scherrer et al. 1995).

Figure 1 (left panel) presents an Hα image of the pre-flare phase of the M1.4 first flare. The Hα data reveal four small brightenings, numbered as 1-4 in Fig. 1. Comparing the locations of these brightenings with the MDI line-of-sight magnetogram (Fig. 1, middle panel) brightenings 1 and 2 are located in positive polarities and 3 and 4 are located in negative polarities. The location of the brightenings, the large motion of the negative polarities associated with ribbon 3, together with the presence of highly sheared magnetic field, suggest that the flare and subsequent CME were triggered by

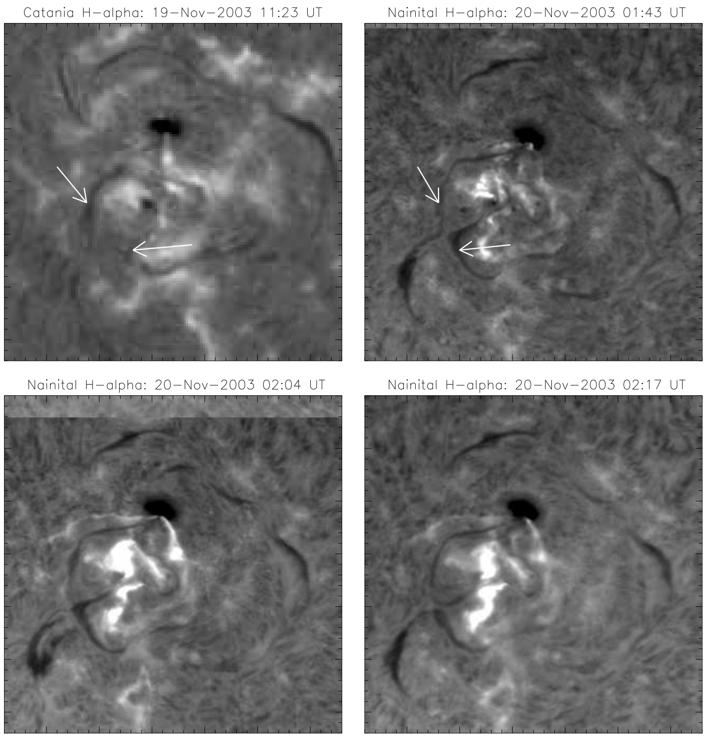

Figure 3. Hα images showing the evolution of filaments interaction before, during and after the merging. The field-of view of the images is $320'' \times 320''$.

a mechanism as proposed by the "tether cutting" model (Chandra et al. 2011). A similar observation has been recently reported by Xu et al. (2010). The presence of quadrupolar configuration in the active region may have made the "cutting" easier.

The chromospheric images of the first and second flare in Hα during their main phases are shown in Fig. 2. We observed four ribbons. Two central inner ribbons, F1R2 and F1R3, are located at the main flare site, while the outer ribbons, F1R1 and F1R4, are surrounding the main flare ribbons. Comparing the locations of flare ribbons with MDI magnetograms (see Fig. 2), ribbons F1R1, F1R2 and R1R3, F1R4 are located two-by-two pair in opposite polarity zones. The ribbons F1R1, F1R4 are fainter than the ribbons F1R2 and F1R3. The later inner ribbons appear before the outer ones. During the first flare, we did not notice any filament eruption. However, at 02:48 UT LASCO we observed a CME, temporally associated with the flare. Extrapolating backward on the LASCO height-time plot we found that the initial event producing the CME starts around 01:40 UT.

Around 07:35 UT the northern filament started to erupt. Later on, the southern filament also started to erupt. Finally both filaments erupted and did not reappear. It

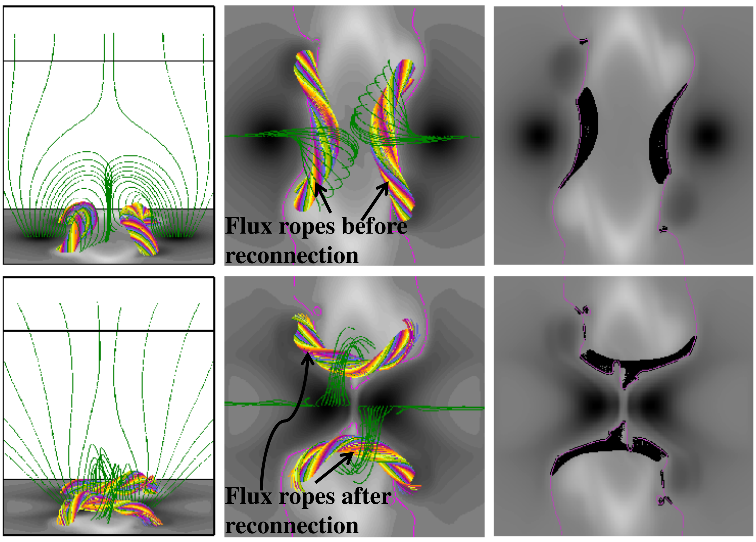

Figure 4. MHD simulations of reconnection between two flux ropes. The simulated magnetogram is shown in grayscale with strong positive (negative) flux in white (black). Left panels: 3D view along the flux ropes, showing their cores and ambient field lines. Middle panels: top view. Right panels: top view, showing field line dips in black (adapted from Török et al. (2011)).

seems that the eruption of the northern filament initiated the onset of the second M9.6 flare. The flare starts to brighten first in the left part of F2R1 ribbon and, afterwards the brightening propagates along the right part. This propagation can be explained by slip-running reconnection as proposed by Aulanier et al. (2007). The ribbon locations almost coincide with the first flare ribbon site but they are brighter and more extended. The central two F2R2 and F2R3 ribbons clearly separate with time as seen in typical two ribbon flares. Schmieder et al. (2011) associated the eruption of 20 November 2003 with the weak signature of a magnetic cloud due to the trajectory of the cloud with respect of ACE position. However, in the three dimensional reconstruction of interplanetary scintillation data a clear ICME was found.

The Hα morphological evolution of two filaments before, during and after their merging on 20 November, 2003 is presented in Fig. 3. On 19 November they appear as two separate filaments. At the beginning of 20 November around 01:27 UT, the filaments were separated and elongated along the north-south direction, which are clearly visible at 01:43 UT (see Fig. 3). Afterwards, they came closer at their central location and merged around 01:58 UT (Fig. 3, bottom left panel). After merging, the two filaments restructured and elongated in the East-West direction (Fig. 3, bottom right panel). Kumar, Manoharan & Uddin (2010) and Chandra et al. (2011) proposed that the merging of the filaments at their central locations is due to reconnection between the two magnetic configurations supporting the filaments. Török et al. (2011) tested this proposition using a three-dimensional (3D) magnetohydrodynamic (MHD) simulation with an initial condition for the magnetic field based on a modified version of the coronal flux rope model of Titov & Démoulin (1999). Indeed, the photospheric evolution imposed in the simulations induced the approach, then reconnection of the two flux ropes (Fig. 4). They interchange their photospheric connections and two new flux ropes are formed. Assuming that dense plasma is caught in the magnetic dips (Fig. 4, right panels), this MHD simulation reproduces the main features of the observed filaments (Fig. 3).

3. Conclusions

In summary, the morphological structure of the flare ribbons and of the magnetic configuration shows that the flares are homologous. Based on the pre-flare brightenings appearance and evolution, we concluded that the first flare is triggered by the "tether cutting" as well as the "magnetic breakout" mechanism, while the second flare was triggered by the "magnetic breakout" mechanism. However, the quadrupolar reconnection was occurring in the reverse way in the two flares (see Chandra et al. 2011).

The observed two filaments approached each other in their central part, then reconnected and reformed two new filaments. We found a comparable evolution in the MHD simulation of two flux ropes. This result extends the study of Linton (2006) and Linton, Dahlburg & Antiochos (2001) on reconnection of flux ropes in convection zone, by showing that slingshot reconnection can occur between two coronal flux ropes too.

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