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Shearing motions and torus instability in the 2010 April 3 filament eruption

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Abstract. The magnetic field evolution of active region NOAA 11059 is studied in order to determine the possible causes and mechanisms that led to the initiation of the 2010 April 3 coronal mass ejection (CME).

We find (1) that the magnetic configuration of the active region is unstable to the torus instability and (2) that persistent shearing motions characterized the negative polarity, resulting in a southward, almost parallel to the meridians, drift motion of the negative magnetic field concentrations.

We conclude that these shearing motions increased the axial field of the filament eventually bringing the flux rope axis to a height where the onset condition for the torus instability was satisfied.

Keywords. Sun: filaments, Sun: magnetic fields, instabilities.

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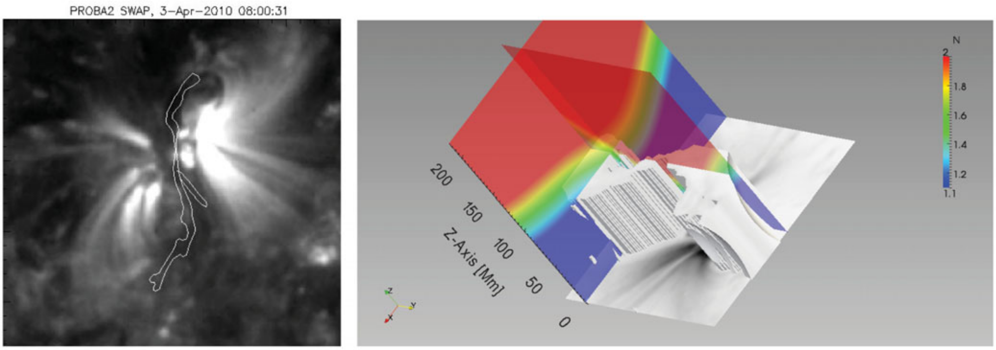
1. Introduction

On 2010 April 3 at 09:05 UT in NOAA 11059 (S25 W03) a filament eruption occurred, resulting in a geoeffective CME. Figure 1(a) shows an EUV image of the active region taken by SWAP on board PROBA2. The white contour outlines the filament observed in the H_α images taken at the Kanzelhöhe Observatory (KSO). A detailed description of the chromospheric and photospheric evolution of the active region can be found in Zuccarello *et al.* (2012). This event has also been studied by Seaton *et al.* (2011). These authors used PROBA2/SWAP and STEREO/EUVI data to reconstruct the three-dimensional trajectory of the eruption. At the moment of the eruption the top of the expanding loop system had a height of about 0.2 $R_\odot$. If the flux rope fills the entire volume between the photosphere and the top of the loops, at the moment of the eruption the flux rope axis is located at about 70 Mm from the photosphere. The three-dimensional threshold render of the SWAP intensity image, where the z direction represents the height above the photosphere of the flux rope axis, is shown in Fig. 1(b).

This work is aimed at investigating the role that the overlying magnetic field and the shearing motions played in the initiation of the 2010 April 3 CME.

2. Results

For a given magnetic field configuration, the decay index is defined as $n = -R\, d\,(\ln B_{ex})\,/dR$, where R is the flux rope major radius and B_{ex} is the external magnetic field (Kliem & Török 2006). When n is larger than a critical value (n_c) the system becomes unstable. Demoulin & Aulanier (2010) found $n_c \simeq 1.1 - 2$. Figure 1(b) shows the spatial distribution of the computed decay index (rainbow color scale) together with the three-dimensional rendering of the estimated height of the flux rope axis (see Introduction). It



(a) (b)

Figure 1. (a) SWAP EUV image taken at 174 Å : the white contour represents the boundaries of the H_α filament. (b) Spatial distribution of the computed decay index (rainbow color scale) together with a three-dimensional rendering of the estimated height of the flux rope axis (see text for more details). A color version of the figure is available in the online version.

is evident that at the moment of the eruption the flux rope was nominally torus unstable. However, it is interesting that the southern part of the dark EUV sigmoid (left in the view of Fig. 1(b)), i.e. the one that underwent the eruption, is actually the least unstable one.

Using MDI magnetograms, we determined the photospheric velocity maps (see Zuccarello *et al.* (2012) for details). We found that persistent southward-directed shearing motions, with average velocity of 0.2-0.3 km s^{-1}, characterized the fragmented negative polarity during the 24h that preceded the eruption. As a result, the negative flux concentrations moved southward by about 16-20 arcsec.

3. Conclusions

The shearing motions discussed above may have played a significant role in the eruption. In fact, even though the system was nominally torus unstable, the filament was observed for at least two days before the eruption. Therefore, other effects that are not taken into account in the estimation of the decay index, such as the line tying (Olmedo & Zhang 2010) and a non-zero toroidal component of the ambient field, may have played a role in stabilizing the filament. However, the observed shearing motions may have contributed to reduce these stabilising effects and they also resulted in the increase of the axial flux of the filament and as a consequence in the increase of its magnetic pressure. This increase in the magnetic pressure lifted up the flux rope slowly, eventually bringing its axis to a height where the condition for the torus instability was satisfied resulting in the filament eruption.

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