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Instability analysis of an active prominence

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Abstract. Using EUV images aquired by TRACE, we analysed the eruption of a prominence, occurred on July 19, 2000 in the Active Region NOAA 9077. We approximated the prominence to a cylindrical curved flux tube and estimated the behaviour of several geometrical parameters during the activation and the eruption phases. We found a decrease in the total twist of one helical thread from $\Phi \sim 10\pi$ to $\Phi \sim 2\pi$ during the prominence eruption, indicating a relaxation of the magnetic field towards a more stable configuration. Moreover we determined that, at the onset of the activation, the number N of turns of a magnetic field line over the whole length of the prominence was ~ 5.0, while the value of the ratio P/r_0 between the pitch of the magnetic field lines and the prominence width was ~ 0.45, in agreement with the kink mode instability.

Key words. Active prominence – Helical-like structure

1. Introduction

The evolution of prominences over their lifetime is characterized by several stages during which the initial structure gets more and more complex. When the structure becomes too intricate, the prominence becomes unstable and erupts.

One of the most important properties of eruptive prominences is their helical magnetic configuration. On the basis of this observational evidence, several prominence models involve helically twisted cylindrical magnetic field configurations (Priest (1990)).

If we consider a prominence as a magnetic flux tube, the onset of its ascending motion can be interpreted as being due to kink mode instability (Sakurai (1976)). The study of the linear instability of magnetic flux tubes, for the magnetic field configuration used by Dungey and Loughhead (1954) or by Gold and Hoyle (1960), showed that the kink instability sets in if P/r_0 (ratio between the pitch of magnetic field lines and the prominence width) decreases and/or the number N of turns of a magnetic field line over the whole length of the prominence increases. These variations can be caused by photospheric motions winding up the filament at both ends or by the emergence of a new twisted flux.

Several recent works have singled out that the prominences, typically observed in the Hα line, correspond, in EUV lines, to intensity depletions, usually referred to as EUV

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filament channels (Aulanier and Schmieder (2002)). It has been proposed that EUV filament channels are due to the absorption of the background EUV radiation by Lyman continuum of hydrogen, in suspended cool plasma condensations in which neutral hydrogen is present (Chiuderi Drago et al. (2001)). Moreover, EUV lines are emitted in the corona, where the high magnetic Reynolds number and high electric conductivity allow us to use the bright filamentary structures in the prominences as tracers of the magnetic field (Romano et al. (2002)). In this context, we considered a prominence model proposed by Vršnak et al. (1988) to study the eruption of a prominence, occurred on July 19, 2000 in the Active Region NOAA 9077 and observed by TRACE at 171 Å at the west limb. We analysed this event, characterized by a clear helical-like pattern, to verify the observational criteria for the onset of the eruptive instability described in the model (Romano et al. (2003)). In section 2 we describe the analysis of the geometrical parameters of the helical-like pattern. In section 3 we discuss the results obtained and draw our conclusions.

2. Data Analysis

A big eruptive prominence on the limb (N13 W83) occurred on July 19, 2000 from 23:10 UT to 23:48 UT and was observed by TRACE in several wavelengths (171 Å, 195 Å, 1216 Å, 1550 Å, 1600 Å, 1700 Å and white light) and by the BBSO telescope in the Hα line. We carried out our analysis using only 171 Å images, which have dimensions of 768×768 pixels, a spatial resolution of 1 arcsecond and an average cadence of about 1 minute. The high spatial and temporal resolution allowed us to follow all the phases of the eruption and to provide a detailed description of the event in the corona.

At 171 Å the EUV filament channel, corresponding to the Hα prominence, showed evident structural changes and rised towards higher atmospheric layers before the eruption phase. More precisely, between 22:34 UT and 22:50 UT the EUV filament channel increased its dimensions until it reached a characteristic apparent shape of a "question mark" and rose with an average speed of $\sim 50\ km/s$. Few minutes later, we observed a downward motion of the prominence. During the eruption phase, which started at 23:10 UT, the prominence rose very fast (maximum speed $\sim 150\ km/s$) and collided with higher loops which surrounded the cooler prominence plasma. From 23:20 UT to 23:30 UT, after a deceleration in the upward motion, the prominence reached the highest point from the solar surface.

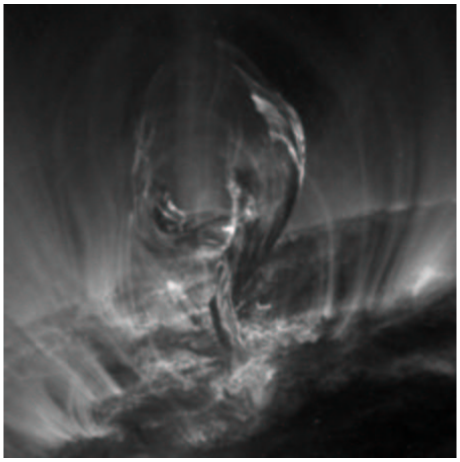


Fig. 1. *171 Å image taken by TRACE at 23:29 UT during the prominence eruption. We note the bright helical structures in the prominence legs. North is on the left, west on the top.*

We approximated the prominence to a cylindrical curved flux tube, anchored at boths ends in the photosphere, and determined several geometrical parameters, using the model proposed by Vršnak et al. (1988). Moreover, in order to avoid errors due to prospective effects we computed the values of the azimuthal and inclination angles of the prominence plane relative to the solar surface (Loughhead et al. (1983)).

Before the activation, the prominence footpoint separation was $\sim$ 75000 km and its width was $\sim$ 40000 km. The height of the summit of the prominence from $\sim$ 90000 km at the beginning of the activation, reached $\sim$ 200000 km at 23:25 UT.

We used 171 Å images to measure the angle of twist ϑ in the prominence legs, considering the bright helical structures as tracers of the magnetic field (Fig. 1). The typical error of a measurement was $\pm 5^o$.

In Fig. 2 we report the value of X = tanϑ as a function of time. The angle of twist has the maximum value ($65^o \pm 5^o$) at the beginning of the activation phase and decreases as time proceeds.

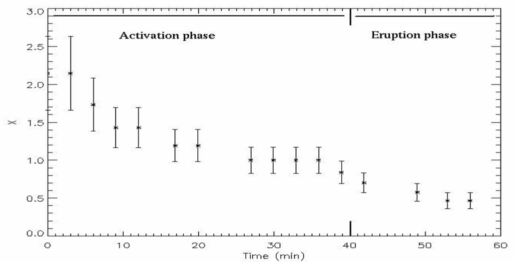


Fig. 2. *Value of X=tanϑ as a function of time. t=0 corresponds to 22:30 UT. The error bars indicate the standard deviations.*

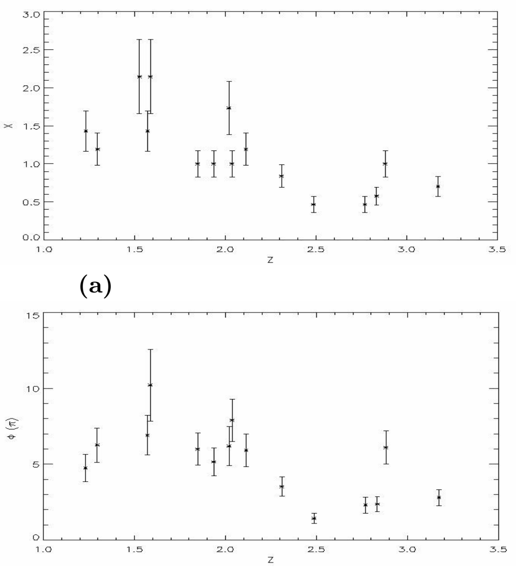
Fig. 3a shows the value of X = tanϑ as a function of Z (the ratio between the height and the half footpoint separation). This graph clearly shows a decrease in the angle of twist of the magnetic field while the prominence height increases.

Assuming that the angle of the helix along the axis of the prominence is constant, the total twist of one helical thread can be expressed as:

$$\Phi = 2\ \pi\ N = l_o\ \frac{X}{r_o} \tag{1}$$

where N is the number of turns of the helix along the prominence length and l_0 is the ratio between the prominence length and $D = d/r_o$ (where d is the half footpoint separation and r_o the half width).

Fig. 3b displays the values of Φ as a function of Z. We can see that at the beginning of the activation phase the value of Φ, corresponding to $X = 2.2 \pm 0.5$, is $10\pi \pm 2.5\pi$, while at the end of the eruption phase Φ is $2\pi \pm 0.5\pi$. Therefore it decreases while the prominence rises towards higher levels and expands.



(a)

(b)

Fig. 3. *(a) Value of X=tanϑ as a function of Z; (b) Value of the total twist of one helical thread as a function of Z. The error bars indicate the standard deviations.*

Moreover, from equation (1), we find that $\Phi = 10\pi \pm 2.5\pi$ corresponds to $N = 5.0 \pm 1.25$ and using the expression:

$$tan\vartheta = 2 r_0 \pi / \lambda, \tag{2}$$

where λ is the pitch length, we find that $X = 2.2 \pm 0.5$ corresponds to a ratio between the pitch of magnetic field lines and the prominence width $P/r_0 \sim 0.45$.

3. Discussion and Conclusions

The prominence does not show a linear rising motion: it initially rises with an average speed of $\sim$ 50 $km\ s^{-1}$, then it slows down and seems to move in the opposite direction, i.e. towards the solar surface; then the rise motion starts again and an average rising velocity of $\sim 150\ km\ s^{-1}$ is reached at the onset of the eruption phase.

Therefore, we can conclude that the prominence motion is characterized by an initial winking oscillating behaviour (Vrs̆nak (1993)) and a successive abrupt rising.

From the analysis of the angle of twist ϑ and of the total twist of one helical thread Φ, we inferred a decrease in the twist of the prominence magnetic field during the prominence eruption. More precisely, at the onset of the activation, the prominence shows a value of $\vartheta = 65^o \pm 5^o$ and a value of the total twist of one helical thread $\Phi = 10\pi \pm 2.5\pi$ at $Z \sim 1.6$. Successively, while the prominence rises towards higher coronal layers and expands, Φ decreases and reaches a value of $2\pi \pm 0.5\pi$.

This behaviour is indicative of a phase of energy release, attained while the prominence magnetic field is passing from a highly stressed configuration to a more relaxed one.

Moreover, these values are comparable with those reported by Vrs̆nak et al. (1993) and agree with the study of prominence instability proposed by Vrs̆nak, Ruz̆djak and Rompolt (1991), who found that at the onset of the eruption, prominences have a pitch angle $\vartheta > 50^o$ and a height $h > 0.8\ d$. Our results are also in good agreement with the kink instability model. In fact, we found that, at the beginning of the activation, the value of the number of turns of a field line over the whole length of the prominence is $N = 5.0 \pm 1.25$ and the value of the ratio between the pitch of field lines and the prominence width is $P/r_0 \sim 0.45$. These values coincide with the highest instability growth rate o btained by the linear stability analysis of magnetic flux tubes with force-free magnetic field configuration, proposed by Dungey and Loughhead (1954) and by Gold and Hoyle (1960).

This is the first study in which an EUV line is used to measure the geometrical parameters of the helical-like pattern of the prominence magnetic field. The agreement with previous studies carried out using images in the Hα line, indicates that the bright structures observed along prominences in EUV lines can describe the magnetic pattern with an equal approximation as that obtained in the Hα line.

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