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CMEs Associated with Eruptive Prominences: How to Predict?

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Abstract. Solar prominences can be viewed as pre-eruptive states of coronal mass ejections (CMEs). Eruptive prominences are the phenomena most related to CMEs observed in the lower layers of the solar atmosphere. The most probable initial magnetic configuration of a CME is a flux rope consisting of twisted field lines which fills the whole volume of the dark cavity stretched in the corona along the photospheric polarity inversion line. Cold dense prominence matter accumulates in the lower parts of helical flux tubes, which serve as magnetic traps in the gravitation field. Coronal cavity is rather inconvenient feature for observation owing to reduced emission, so prominences and filaments are the best tracers of the flux ropes in the corona long before the beginning of eruption. Thus, the problem of the CME prediction can be reduced to the analysis of the filament equilibrium and estimation of the stability store. The height of a prominence (or a filament when observed against the disk) increases with its age and the death of a filament is usually an eruption which is followed by a CME. The filament height, then, can be a measure of its age and its readiness for eruption. In inverse-polarity models the equilibrium height of a filament is related to the value of the filament electric current. The stronger the electric current, the greater the height of the filament. However, the equilibrium and stability of a filament depend not only on its current but also on the characteristics of the external magnetic field. In order to estimate the probability of eruption, we should therefore compare the observed prominence height with a value characterizing the photospheric magnetic field. This value is the critical height, which can be found in the distribution of the magnetic field vertical gradient above the polarity inversion line. We had analyzed three dozens of filaments and found that eruptive prominences were near the limit of stability a few days before eruptions. We believe that the comparison of the real heights of prominences with the calculated critical heights could be a basis for predicting filament eruptions and following CMEs.

Keywords. Sun: corona, coronal mass ejections (CMEs), filaments

1. Introduction

The “classical” structure of a coronal mass ejection (CME) consists of three parts and one of these parts, a bright core, is the remnant of an eruptive prominence (Crifo, Picat & Cailloux 1983; Sime, MacQueen & Hundhausen 1984; Hundhausen 1999). Sometimes it is possible to follow the whole process of eruption beginning from filament activation and up to the CME formation. In figure 1 one can see the polar crown filament eruption on 14 June 1999 visible in SOHO EIT He II line and the following CME observed by SOHO LASCO. The projection of the erupting filament was favorable to recognize the twisted structure of the filament loop in the core of the CME up to the distances of 3 solar radii. Of course, not every CME could be associated with observed filament eruption. The reason for it may be that large-scale phenomena high in the corona are registered now more effectively than near-surface phenomena. At least half of eruptions could originate on the backside of the Sun. Nevertheless, eruptive prominences are the phenomena most

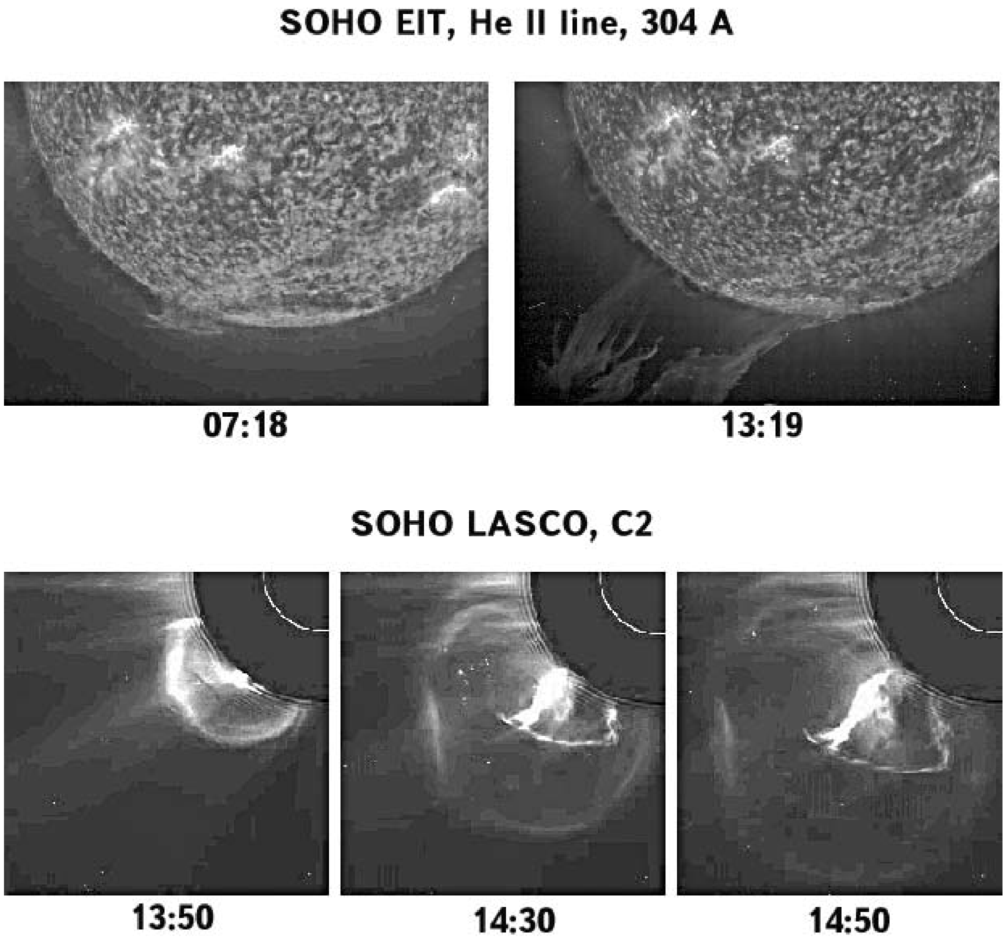

Figure 1. Polar crown filament eruption on 14 June 1999 visible in SOHO EIT He II line (top row) and the following CME observed with LASCO C2 (bottom row). (Courtesy of SOHO/EIT and SOHO/LASCO consortia. SOHO is a joint ESA-NASA project.)

related to CMEs observed in the lower layers of the solar atmosphere (Munro *et al.* 1979; Webb & Hundhausen 1987; St. Cyr & Webb 1991). So, solar prominences can be considered pre-eruptive states of coronal mass ejections (CMEs).

2. Filament stability and the critical height

A lot of filaments and prominences are seen on the Sun at epoch of rather high activity. Each of them could be assumed as the place where a CME could originate from. Thus, the problem of the CME prediction could be reduced to the analysis of the filament equilibrium and estimation of the store of stability. The height of a prominence increases with its age and the death of a filament is usually an eruption (Rompolt 1990), which is followed by a CME. The filament height, then, can be the measure of its age and its readiness for eruption. However, for the quantitative description we need a scale, which can be used to estimate whether a filament is sufficiently high or low. It is evident that as far as a filament is supported by the magnetic force, the scaling factor should depend on the scale of the background magnetic field.

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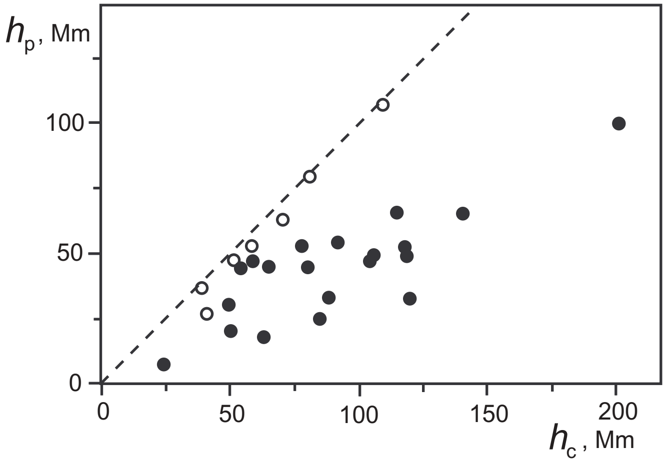

Figure 2. Critical height of stable filament equilibrium h_c versus observed prominence height above the limb h_p. The dotted line corresponding to equality of these quantities is the stability boundary. The solid circles correspond to the filaments which safely passed the west limb. The open circles correspond to the filaments which disappeared from the disk.

We analyzed the situation from the point of view of a model of inverse polarity filament or a flux rope model (Kuperus & Raadu 1974; Van Tend & Kuperus 1978; Molodensky & Filippov 1987; Priest, Hood & Anzer 1989; Forbes & Isenberg 1991; Low & Hundhausen 1995; Aulanier & Demoulin 1998) . In this model, the background magnetic field acts on the filament current with the Lorenz force directed downward and the only supporting force is filament current's repulsion from the currents induced in the photosphere. The filament current should be great enough to create the magnetic field dominating inside the filament and its vicinity. Cold dense prominence plasma could be accumulated at the bottoms of helical field lines. Sometimes helical threads easily observed in the fine structure of prominences and filaments though generally their structure is tangled.

In the simplest model, the flux rope could be assumed as a straight linear current. If the photospheric background field falls off with height faster than $1/h$, the equilibrium of the linear current could not be stable. So for a given photospheric magnetic field distribution B, the critical height h_c for stable equilibrium exists defined by equation (Filippov & Den 2000; Filippov & Den (2001))

$$h_c = \frac{B}{dB/dh|_{h_c}}.$$

Figure 2 shows the relationship between the prominence height measured on limb and the critical height calculated at the time when the filament crosses the central meridian. The filaments, which safely pass the west limb, are marked with the solid circles while the filaments, which disappear on the disc, are marked with the open circles. It is seen that the solid circles more or less evenly fill the angle between the bisector showing the limit of stability and the horizontal axis while the open circles tend to cluster about the bisector. This shows that eruptive prominences were near the limit of stability a few days before an eruption.

3. The problem of the filament height measurements

Figure 3 shows an example of a filament eruption observed on the disk. The prominence appeared on the limb on August 16. Then it was seen as well developed quiescent filament

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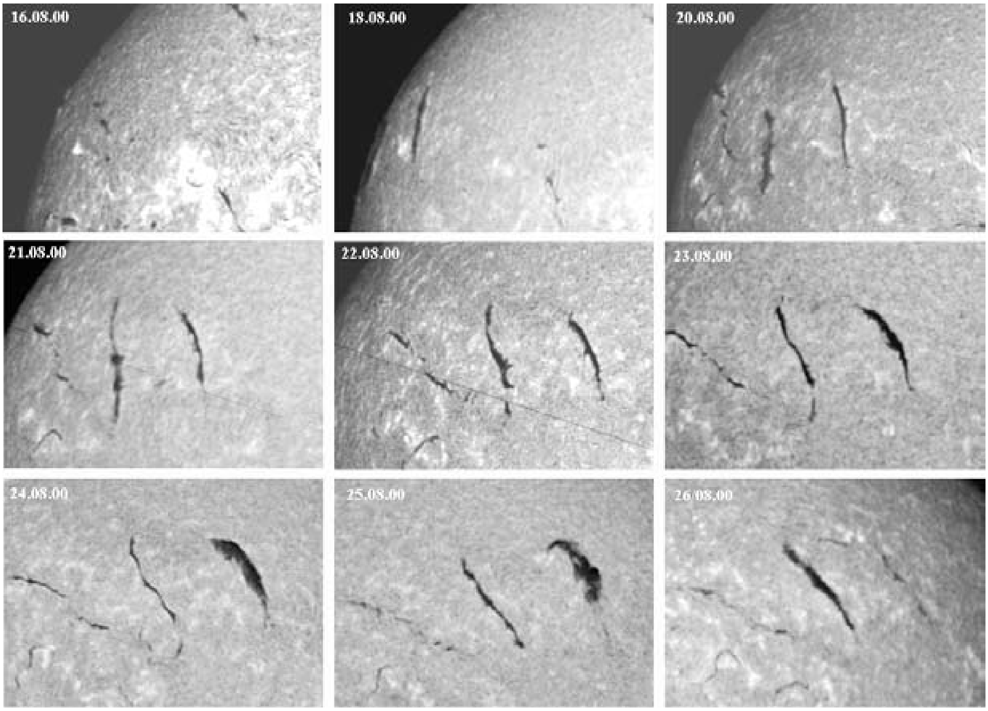

Figure 3. Filament pass through the solar disk in August 2000. Filament eruption happened on 25 August after which filament disappeared completely. It was reconstructed in part the next day. (Courtesy of Meudon Observatory.)

during eight days of its transit through the disk. The width of the filament increase from day to day revealing the increase of its size and height. On August 24 there were some indications of activation and internal motions but the filament was still stable. On August 25 at 10:40 UT the filament began to ascend rapidly and disappeared from the disk. The eruption is visible quite clearly also in the SOHO/EIT movie in Fe XII line.

We calculated the critical height h_c for this filament. It varied slightly during the days before the eruption but on average it was about 60 Mm. A small bipolar region appeared near the northern end of the filament on August 24. It could be assumed as the destabilizing factor for the filament equilibrium. However, the bipolar region seems to be well developed several hours before the eruption. On the same time, we see that rapid ascend of the filament began only after it reached high altitude. It's much harder to estimate the height of a prominence when it is projected against the disk as a filament. There were attempts to estimate the height of a filament above the photosphere based on the observed changes of its projection due to the rotation of the Sun (Vrsnak *et al.* 1999). We tried to measure the height of the filament before the eruption using different technique. At first, we found the tilt of the filament body to the vertical direction using the technique proposed by d'Azambuja & d'Azambuja (1948). It was about 20°. Then taking into account the filament heliocoordinates and its visible width we found the height of the filament h_p to be 40 Mm on August 23, about 50 Mm on August 24, and about 70 Mm just before the eruption.

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4. Conclusions

The most probable magnetic configuration of a CME source region is a flux rope. This configuration allows a catastrophic process. So the onset of eruption does not need a powerful trigger. It is not so easy to observe a flux rope on the Sun because most of its volume is filled with rear plasma and has only weak emissions. Prominences and filaments are the best tracers of the flux ropes in the corona long before the beginning of an eruption. The filament height can be a measure of its age and readiness for eruption. The comparison of the real heights of prominences with the calculated critical heights could be a basis for predicting filament eruptions and following CMEs.

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Discussion

FORBES: Could you say more about the physical significance of your stability criterion?

FILIPPOV: The criterion arises from the height dependence of the magnetic field of the so called "mirror" current that simulate the magnetic field of the currents induced by the changing of the coronal current in the photosphere. This field falls with height as 1/h in our model. So in the power law expansion of the background magnetic field the power degree should be less than 1.

YOUSEF: 1) Was this filament eruption accompanied by a CME? 2) Filament do migrate as they get older towards the pole. That means they have passed the critical height you are talking about. Have you ever seen a polar filament eruption? 3) If this filament occurred in an AR free region, would you comment on this?

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FILIPPOV: 1) The filament was accompanied by only a small CME that could be recognized only in differential images. Maybe it was masked by other CME that came from the opposite solar limb. The source region of this second CME was not observed on the disk. Maybe it was on the backside of the sun. 2) Yes we observed prominence eruptions above the poles. These happened just nearly before the polar magnetic field reversal. However in my talk I was speaking about critical height of filaments, not the critical latitude. 3) Yes, this was a quiescent filament, observed rather far from active regions. Maybe it was the reason that the eruption was not very energetic and flare ribbons were not observed after the eruption.

KOUTCHMY: In the case of the last event you showed, did you find evidence of: 1) spiraling motion(twist)? 2) brightening near the feet of the flux rope?

FILIPPOV: 1)The spiraling motion was not visible very clearly in this event but some hints of its presence could be recognized.
2) One bright spot was visible near the northern end of the filament. But it appeared a day before and was related to a emerging small bipolar region. Brightenings which lasted only during the eruption were not observed.