J. Astrophys. Astr. (2006) **27,** 139–149

Magnetic Source Regions of Coronal Mass Ejections

Brigitte Schmieder
Observatoire de Paris, LESIA, 92195, Meudon CEDEX Prinicipal, France.
e-mail: brigitte.schmieder@obspm.fr

Abstract. The majority of flare activity arises in active regions which contain sunspots, while Coronal Mass Ejection (CME) activity can also originate from decaying active regions and even so-called quiet solar regions which contain a filament. Two classes of CME, namely flare-related CME events and CMEs associated with filament eruption are well reflected in the evolution of active regions. The presence of significant magnetic stresses in the source region is a necessary condition for CME. In young active regions magnetic stresses are increased mainly by twisted magnetic flux emergence and the resulting magnetic footpoint motions. In old, decayed active regions twist can be redistributed through cancellation events. All the CMEs are, nevertheless, caused by loss of equilibrium of the magnetic structure. With observational examples we show that the association of CME, flare and filament eruption depends on the characteristics of the source regions:

- the strength of the magnetic field, the amount of possible free energy storage,
- the small- and large-scale magnetic topology of the source region as well as its evolution (new flux emergence, photospheric motions, cancelling flux), and
- the mass loading of the configuration (effect of gravity).

These examples are discussed in the framework of theoretical models.

Key words. Coronal mass ejection—flare—filament eruption.

1. Introduction

Coronal mass ejections (CMEs) are large expulsions of mass and magnetic field from the Sun to the interplanetary medium. These mass ejections carry a bulk of material of around 10^{15}g at speeds of 100 to 2700 km s^{-1} (mean value 487 km s^{-1} according to Gopalswamy, this issue). In order to forecast CMEs, it is important to understand where they come from on the Sun and how they are related to other flare phenomena (flares, eruptions in particular). With SOHO, it becomes clear that some CMEs are associated with filament eruption occurring in quiet regions of the Sun (decaying active region or polar crown filament). Several statistic analysis have been done to classify CME related to flares, active regions (AR), quiet regions (Saint Cyr & Webb 1991; Webb 1998; Zhou *et al.* 2003). Subramanian & Dere (2001), based on a sample of 32 CMEs, found that 85% of them are associated with ARs and 15% with so-called quiet regions. Zhou *et al.* (2003) with a sample of 197 front side halo CMES observed by LASCO coronographs between 1997 and 2001, find respectively the ratios of 79% and 21% for CMEs associated with AR or not. These two statistics are consistent.

The main characteristics of the source regions have been intensively described in the reviews of Wang (2002) and Schmieder & van Driel-Gesztelyi (2005). CMEs are large scale or global scale activity. An average size of CMEs is as big as five active regions. The CME activity must be related to some other types of large scale magnetic entities. Different types of large scale magnetic structures have been tentatively identified: giant magnetic loops connecting two active regions in opposite hemispheres of the Sun (Delannée and Aulanier 1999) or giant filaments in filament channel (polar crown filament, see Zhou *et al.* 2003) or two rows of opposite polarity field extending to more than 60 heliographic degrees (Wang *et al.* 2002). An example of such a long filament was the transequatorial filament observed before the Bastille Day activity in 2000 (Wang 2002). The destabilization of this huge filament precedes the onset of the flare by many hours. Type II radio storm emissions and radio observations confirm the globalness of the activity. CMEs are also observed after the birth of transient coronal holes (Srivastava *et al.* 2000). These holes of coronal emission are of a different nature than the large dimming regions appearing during the launch of CMEs. Falconer *et al.* (2002) and Deng *et al.* (2001) found correlations of CMEs and global magnetic non-potential configuration. Yan *et al.* (2001) identified the formation of flux ropes in a non-linear force-free-field extrapolation approach.

On the other hand, CMEs have commonly small scale core fields limited to an active region which can be as small as a pore or a new emerging flux (Mandrini *et al.* 2005). Zhang *et al.* (2001) identified magnetic field cancellation associated to CME initiation. In conclusion, the morphology classification of the types of source regions does not bring a good insight of the conditions for getting CMEs. Let us define the necessary conditions for CMEs with and without flares or eruptions.

2. Conditions for CMEs

2.1 *General conditions*

There is a consensus that the presence of significant magnetic stresses in the source region is a necessary condition for CME.

In the corona the magnetic field can be computed by extrapolation using different approaches: potential, linear force free field or non-linear force-free field. The magnetic helicity quantifies how the magnetic field is sheared or twisted compared to its lowest energy state (potential field). Observations provide plenty of evidence for the existence of such stresses in the solar magnetic field and their association with flares and CME activity.

In young active regions, magnetic stresses are increased by (i) twisted magnetic flux emergence and the resulting magnetic footpoint motions (Wang *et al.* 1994; Leka *et al.* 1996; López-Fuentes *et al.* 2003; Schmieder *et al.* 2002) as well as (ii) torsional Alfvén waves which bring up helicity from the sub-photospheric part of the flux tube and replenish coronal helicity after CME events (Longcope & Welsch 2000; Démoulin *et al.* 2002; Green *et al.* 2002). A possible manifestation of such torsional

Alfvén wave is sunspot rotation, which has indeed been observed (e.g., Brown *et al.* 2003). In old, decayed active regions twist can be redistributed through cancellation events transferring helicity from small towards the large scales, it can be increased by large scale photospheric motions (differential rotation) (DeVore 2000; Démoulin *et al.* 2002b; Berger & Ruzmaikin 2000) or brought up by torsional Alfvén waves (Démoulin *et al.* 2002a; Green *et al.* 2002). Whether the eruption is possible or not, the strength of the magnetic field overlying a sheared arcade or a twisted flux tube may play an important role. Since such an overlying field has a stabilizing effect, a strong field can actually prevent the eruption (Török *et al.* 2004; Roussev *et al.* 2003).

2.2 *Current models for the initiation of CMEs*

Current models for the initiation of flares, eruptions or CMEs share the assumption that the stored energy lies in a low lying magnetic flux system (twisted or sheared). This system is the so-called core flux or flux rope. The models differ in the way the eruption is initiated and the precise role played by the overlying field which is assumed to be nearly current-free. All these models naturally lead to the configuration of the so-called standard model for the main phase of eruptions (Shibata 1999; Lin & Forbes 2000), in which the long lasting energy release is driven by fast reconnection. The standard model still misses a link between the core flux and the full 3D expansion CMEs. I will not review the CME models but classify the current models of CME's initiation. We can distinguish three types of such models: Forbes & Isenberg (1991) and Isenberg *et al.* (1993) developed 2D and 2.5D models where the eruption is preceded by converging photospheric motions towards the magnetic inversion line of a bipole (Fig. 1). A loss of equilibrium leads to the rise of a flux rope situated along the inversion line. Reconnection occurring in the current sheet formed *under* the flux rope allows the flux rope to escape.

In 3D flux rope models an ideal MHD instability is assumed to destabilize single flux tube anchored in the photosphere. Relevant instabilities are a global expansion of a highly twisted rope (Titov & Démoulin 1999) or the kink instability of a twisted flux tube (Török & Kliem 2003; Török *et al.* 2004). The emerging twisted flux rope model is called tether cutting model in the classification of storage and release energy models of Klimchuk (2001) (Fig. 2). It implies magnetic reconnection *within* the core flux. Finally the third model is the breakout model (Antiochos 1998; Antiochos *et al.* 1999; Aulanier *et al.* 2000; Wang 2002) where magnetic reconnection is assumed to be *above* the core flux and breaks its balance with the overlying flux, thus initiating an eruption. A quadrupolar magnetic configuration is required in this model.

I shall review a few examples and point out the main important factors which could be responsible for the CME and what type of models would be most relevant to explain the CME.

- High field strength and magnetic stress
- Evolution of active regions
- Amount of twist: large sigmoids
- Mass loading in prominences

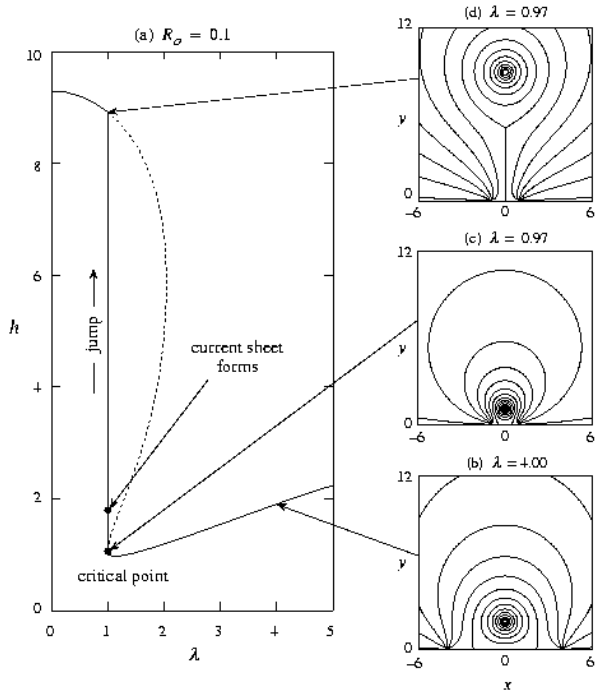

Figure 1. Loss of equilibrium model: sketches of coronal field lines showing converging motions of the footpoints of overlying arcades leading to loss of equilibrium of the structure (Isenberg *et al.* 1993). Reconnection occurs below the magnetic flux rope.

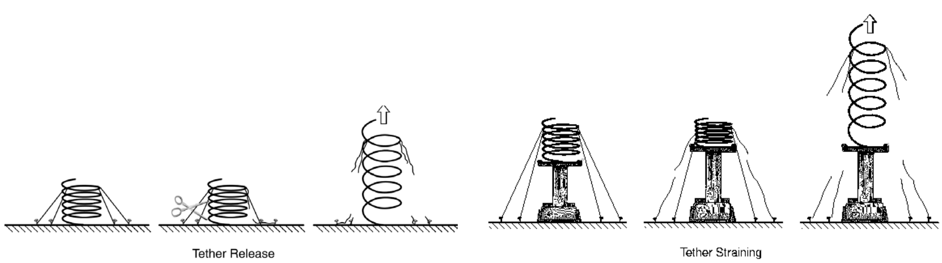

Figure 2. Sketches of models of energy release, left: tether cutting, right: tether straining (Klimchuk 2001).

3. Review of examples

3.1 *Large strength of magnetic field and high stress*

Commonly, active regions with strong magnetic field and high stresses are sites of large energetic flares producing fast CMEs (e.g., the Bastille day flare, the Halloween flares during the period of October–November 2003). The twelve X-ray class Halloween flares come from three complex active regions NOAA 10484, 10486 and 10488. These three source regions are delta-spot regions formed through numerous episodes of flux emergence. As an example, the active region NOAA 10486 has an overall quadrupolar

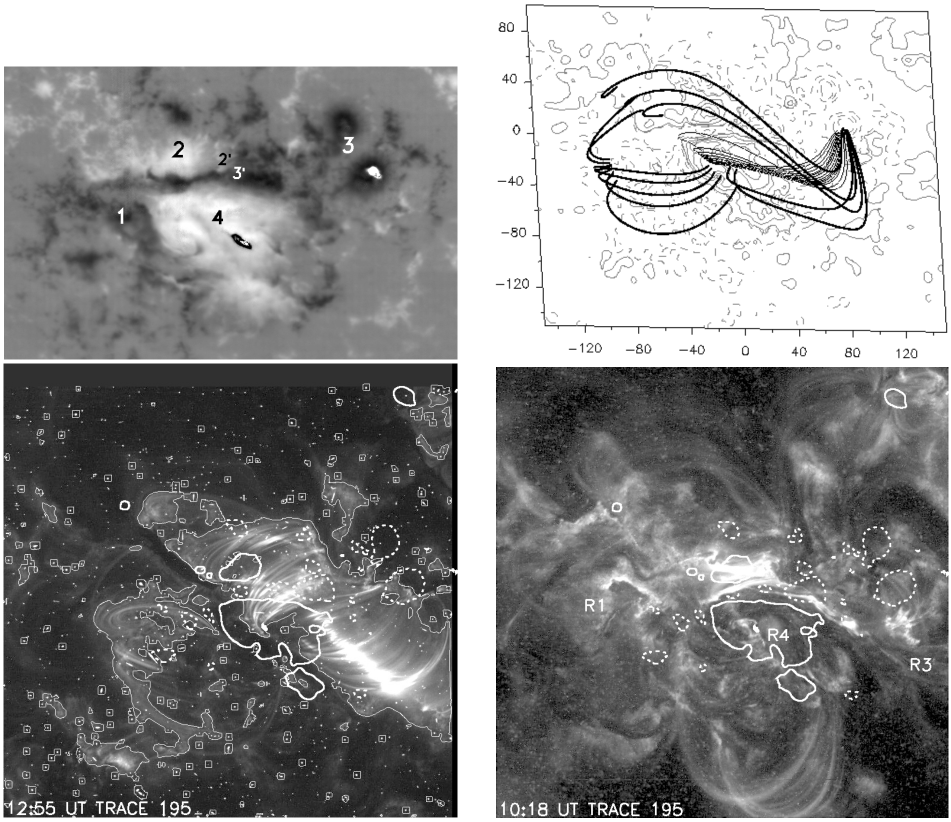

Figure 3. X-ray 17 Flare of October 28, 2003, (**top left**) magnetogram of the active region 10486 observed with THEMIS showing the four main polarities, (**top right**): magnetic field lines of the quadrupolar reconnection before the flare, (**bottom left**): TRACE observations of the loops after the X17 flare, (**bottom right**) TRACE observations of the four ribbons signature of the quadrupolar reconnection before the flare (Schmieder *et al.* 2006).

magnetic configuration on October 28, 2003 (Schmieder *et al.* 2006; Mandrini *et al.* 2006). The magnetic field strength was still high although the active region had entered into its decaying phase, when an X17 GOES class flare and associated CME occurred (Fig. 3). The magnetograms of Huairou indicate continuous emergence of new flux and the build-up of a strong shear along the two parallel inversion lines which squeezed a bridge of negative polarities between two positive polarities (Zhang *et al.* 2003).

3.2 *Evolution of active regions*

Comprehensive analyses of the long term evolution of two active regions confirm that evolving magnetic flux density plays an important role in CME activity and its evolution must influence all the activity signatures (van Driel-Gesztelyi *et al.* 2003; Green *et al.* 2002). The first analysis concerns an isolated active region (NOAA 7978 July–December 1996). The magnetic field of the AR was clearly distinguishable for at least seven solar rotations. It was found that flares mainly occur when the magnetic field of the AR has the highest complexity and magnetic flux density during the two

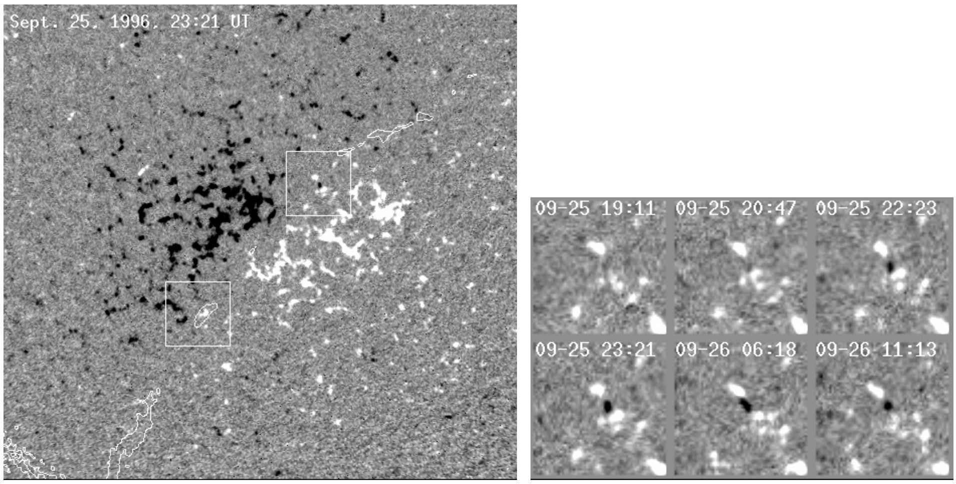

Figure 4. (**Left panel**) SOHO/MDI magnetogram of September 25, 1996 at 23:21 UT with the 2 boxes where we follow the evolution of the small polarities. The contours indicate the position of the Hα filament. (**Right panel**) New emergence of magnetic field and cancellation observed versus time in the upper box (Schmieder *et al.* 2002).

main flux emergence phases (1st two rotations in July and August 1996) and while the number of CMEs is sustained and may be more closely related to the magnetic stresses in the region, since the value of the linear force-free α parameter was found to be roughly proportional with the CME rate. During the first observed flux emergence phase 10^{22} Mx flux surfaced. During the decay phase magnetic flux gradually spreads over an ever increasing area, flare activity shows a sharp decrease and practically ceases with the disappearance of sunspots, while CME activity remains on a relatively high level (3–4 CMEs per rotation). During the decaying phase of the active region **cancelling flux** along the major inversion line was identified and could participate to the redistribution of the twist (Fig. 4). The filament which was lying along the inversion line erupted after a sustained period of cancellations (Schmieder *et al.* 2002). The position and the time of this flux cancellation lead us to propose that it could be responsible for the destabilization of the filament, which was probably close to loss equilibrium already. A similar evolutionary pattern was found in NOAA AR 8100 by Green *et al.* (2002).

3.3 *Sigmoids of small and large scale*

Sigmoids, in many cases, indicate the presence of high magnetic stresses and have been linked to CMEs (Gibson *et al.* 2002; Manoharan *et al.* 1996). Though the sigmoid–CME connection is still statistically ambiguous (Canfield *et al.* 1999; Aulanier *et al.* 2005) it has been suggested that the magnetic helicity content in S-shaped magnetic configuration may reach a threshold leading to instability and eruption (van Driel-Gesztelyi *et al.* 2000; Török & Kliem 2003). The sigmoid observed on 25 Oct. 1994 by Yohkoh is a good example to understand the process leading to CME (Manoharan *et al.* 1996). In soft X-rays the region had a sigmoidal shape (Fig. 5). Van Driel-Gesztelyi *et al.* (2000) proposed a model involving reconnection in a sheared arcade, which

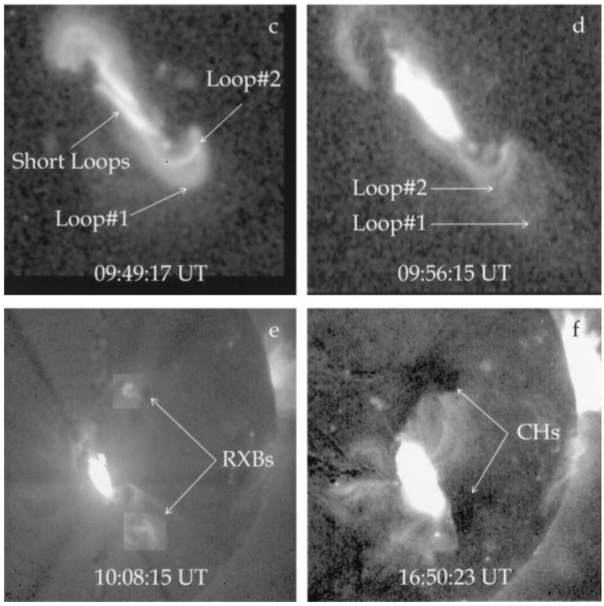

Figure 5. Sigmoid in X-ray before the flare and the reconnected loops after the flare observed with Yohkoh (Manoharan *et al.* 1996).

leads to the formation of short, highly sheared loops in the centre and long sigmoidal loops connecting the outer edges of the bipole. The long sigmoidal loops may become unstable leading to a CME. As the sigmoid expands, a current sheet is formed under it and a cusp structure appears.

A similar event was observed in the center of the disk but related to a very small bipole, which had a magnetic flux which was two orders of magnitude less than a usual active region. Mandrini *et al.* (2005) provided several independent supporting arguments for the eruptive nature of this tiny active region, linking the sigmoid eruption to a small interplanetary magnetic cloud.

4. Role of magnetic topology

4.1 *Bipolar or quadrupolar magnetic configuration*

The coronal environment of the ejection of coronal mass is certainly important to produce fast and large heliographic extended CMEs (Low & Zhang 2002). In this review I shall not consider the global structure of the CME source environment. The environment defines mainly the morphology of the CME but not the reason of the launch of a CME. I shall concentrate on the photospheric magnetic configuration of sources. Do CME source regions have bipolar or quadrupolar magnetic structure? That is not clear.

In bipolar region, converging motion of opposite polarities and consequent cancellation along the magnetic inversion line before CMEs have indeed been observed (van Driel *et al.* 2002). It was the case for the CME of September 1996 before the eruption of the filament as we have already shown (Fig. 4). This latter example is relevant to the loss equilibrium proposed by Forbes & Isenberg (1991) in a bipolar region. Such an eruption could also be relevant to the tether cutting model. The filament starts to rise slowly, as more and more of the tethers have been cut. During that time the twist in the flux tube increases.

However, it is still a question of whether or not topological complexity is indispensable for CMEs. Does the loss of equilibrium of a flux rope, in which twist exceeded threshold level (see Török *et al.* 2004 and references within), provide sufficient condition for CME? The latter seems to work even in a simple bipolar magnetic configuration.

However, the highly CME-active source regions are magnetically complex! What is the main role of a multipolar magnetic structure in the CME process?

From the analysis of the magnetic field evolution, topology and multi-wavelength data before and during the X 17 flare on October 28, 2003, we conclude that a large twisted flux tube supporting the long filament lying along the main inversion line must have been formed and erupted. The slow build-up of magnetic stress through converging motions along the magnetic inversion line begins well before the eruption. If we try to classify the X 17 flare within the scenario of 'storage and release' models (Klimchuk 2001) i.e., tether cutting or tether straining (Fig. 2), it appears that two mechanisms could be present: firstly, the twist in the flux rope built up as small-scale cancellation events (reconnection) occurs in a sheared arcade aligned along the main neutral line. The flux tube starts to rise slowly, as more and more tethers are being cut. During that time the twist in the tube increases. Before the X 17 flare, two episodes of large-scale quadrupolar reconnections occur in the active region (Schmieder *et al.* 2006). The second episode, being more intense, implies more important field-rearrangements. These quadrupolar reconnection events remove stabilising field lines from above the flux rope (filament) which succeeds to break out. Reconnection under the erupting flux rope starts after the lift-off, forming a post-flare loop arcade. For this flare it appears that first there is reconnection in the low atmosphere. The stored energy could only escape when the overlying field lines reconnected in the higher corona. This evolution is similar to the breakout model. Similar scenarios were proposed for the 14 July 1998 CME by Aulanier *et al.* (2000) and for the 15 July 2002 CME by Gary & Moore (2004). In the breakout models the quadrupolar magnetic configuration is a necessary condition.

4.2 *Magnetic field strength*

It has been a long-standing question regarding which comes first: flare or CME? Both observations and models suggest that an inflation of the magnetic structure due to increasing magnetic stresses is the first step – this makes observers say that CME starts before flare. The main flare energy release occurs during the reconnection of field lines extended by the eruption, which, again, points towards that CME should come first. However, both in the tether cutting (flux rope) and the tether straining (breakout) models pre-eruption reconnection is required under or above, respectively, of the erupting twisted/sheared magnetic structure (filament). In the breakout model this pre-eruption reconnection is expected to occur high in the corona in a region of weak field, releasing too little energy to be observed. However, if the reconnection occurs in a strong field region, like in a complex active region, where tethers are not external weak fields overlying the sheared core field but are part of the active region having a quadrupolar configuration, the released magnetic energy can be high enough to qualify as flare, therefore we may find that an impulsive, quadrupolar flare precedes the CME, while the latter includes a filament eruption and a related two-ribbon flare representing the post-eruption arcade.

In any case, in the models most relevant to observations (storage and release models) the build-up of magnetic stresses, i.e., strong shear and twist are necessary conditions for CME to occur. In observations twisted CME structures are frequently seen and there is a mounting evidence that considerable amount of twist is being carried away from the Sun by CMEs. These emphasize the importance of magnetic helicity in the CME process.

5. Mass loading in prominences

Finally, another important parameter for getting CMEs is the mass loading. The pressure increases over the stressed magnetic field the kinetic energy is increasing during the disruption of the field. This can be the case for filament eruption in or out of active regions. The free energy stored in a stressed magnetic structure prior to the eruption depends on the strength of the background field. The stronger the background field is, the more free energy can be stored, and thus the more energetic the eruptive process will be (Lin 2004). This eruptive process refers to any disruption of the coronal magnetic field that causes either a flare, or a filament eruption or CME or all of them. In the case of CMEs related to quiet sun region, there is a critical strength of the background magnetic field (< 27 G) where the effect of gravity becomes significant enough to prevent the CME from progressing (Isenberg *et al.* 1993). If the field is larger than this value, the system evolves smoothly in response to the slow change in the boundary conditions and can end up with a slow CME (Schmieder *et al.* 2000). The gravity of the filament or prominence may play an important role in the process of slow CMEs by prohibiting the catastrophe to occur at the very beginning. A prominence rises slowly before erupting and can reach an altitude as high as 200 mm. The mass of CMEs inferred from SOLWIND observations from 1979 to 1981 (Howard *et al.* 1985) ranged from 2×10^{14} to 4×10^{16} g. The amount of mass and the mass concentration should be important for the CME-eruptive prominence association. Recently it has been found that solar filaments observed in EUV lines are much more extended than their Hα counterparts (Heinzel *et al.* 2001; Schmieder *et al.* 2003). The total filament mass could be larger than that derived for the Hα filament itself by a factor 1.5 or 2 and this may have consequences for the structure and the mass loading of CMEs (Heinzel *et al.* 2003).

6. Conclusion

The driver behind solar flares, prominence eruptions and CMEs is the instability of stressed coronal magnetic fields which have been driven towards a highly stressed state by photospheric motions and twisted flux emergence. From a theoretical point of view (Lin 2004) and observations of CME source regions, it appears that some parameters are important to determine which type of CME the region is able to expel. The strength of the magnetic field and the complexity of the magnetic configuration prior to the eruption determines the correlation between flares and CMEs, and the impact of the gravity on the above correlation can be important (mass and concentration of mass in prominence) if the background magnetic field is weak. The size of the region is not an important parameter, even very small magnetic regions are able to produce CME. An increase of stress in the source region is a crucial factor, and the strength of the field determines how much free energy can be stored in it. However, the strength of the overlying field, which has an important stabilizing effect, appears to play an important role in whether or not eruption occurs. The correlation between CME and eruptive prominence depends on the amount and the concentration of the plasma mass in the related magnetic configuration. The CME may commence with an apparent prominence eruption if the mass inside the structure is larger than 4.5×10^{15} g.

Acknowledgements

This research was supported by the European Commission through the RTN programme ESMN (contract HPRN-CT-2002-00313).

References

Antiochos, S. K. 1998, *Astrophys. J.*, **502**, L181.
Antiochos, S. K., DeVore, C. R., Klimchuk, J. A. 1999, *Astrophys. J.*, **510**, 485.
Aulanier, G., DeLuca, E. E., Antiochos, S. K., McMullen, R. A., Golub, L. 2000, *ApJ*, **540**, 1126.
Aulanier, G., Démoulin, P., Grappin, R. 2005, *Astron. Astrophys.*, **430**, 1067.
Berger, M. A., Ruzmaikin, A. 2000, *J. Geophys. Res.*, **105(A5)**, 10481.
Brown, D. S., Nightingale, R. W., Alexander, D. *et al.* 2003, *Solar Phys.*, **216**, 79.
Canfield, R. C., Hudson, H. S., McKenzie, D. E. 1999, *Geophys. Res. Lett.*, **26**, 627.
Delannée, C., Aulanier G. 1999, *Solar Phys.*, **190**, 107.
Deng, Y., Wang, J. X., Yan, Y., Zhang, J. 2001, *Solar Phys.*, **204**, 13.
Démoulin, Mandrini, van Driel 2002a, *Solar Phys.*, **207**, 87.
Démoulin, P., Mandrini, C. H., van Driel-Gesztelyi, L. *et al.* 2002b, *Astron. Astrophys.*, **382**, 650.
DeVore, C. R. 2000, *Astrophys. J.*, **539**, 944.
Falconer, D. A., Moore, R. L., Gary, G. A. 2002, *Astrophys. J.*, **569**, 1016.
Forbes, T. G., Isenberg, P. A. 1991, *Astrophys. J.*, **373**, 294.
Gary, G. A., Moore, R. L. 2004, *Astrophys. J.*, **611**, 545.
Gibson, S., Fletcher, L., DelZanna, G. *et al.* 2002, *Astrophys. J.*, **574**, 1021.
Green, L. M., Lopez-Fuentes, M. C., Mandrini, C. H., Démoulin, P., van Driel-Gesztelyi, L., Culhane, J. L. 2002, *Solar Phys.*, **208**, 43.
Heinzel, P., Schmieder, B., Tziotziou, K. 2001, *Astrophys. J.*, **561**, L223.
Heinzel, P., Anzer, U., Schmieder, B., Schwartz, P. 2003, *ESA SP*, **535**, 447.
Howard, R. A., Sheeley, J. N. R., Koomen, M. J., Michels, D. J. 1985, *J. Geophys. Res.*, **90**, 1356.
Isenberg, P. A., Forbes, T. G., Démoulin, P. 1993, *Astrophys. J.*, **417**, 368.
Klimchuk, J. A. 2001, In: *Space Weather* (Geophysical Monograph 125), (eds) Song, P., Singer, H., Siscoe, G. (Washington: Am. Geophys. Un.), pp. 143–157.
Leka, K. D., Canfield, R. C., McClymont, A. N., van Driel-Gesztelyi, L. 1996, *Astrophys. J.*, **464**, 1016.
López Fuentes, M. C., Démoulin, P., Mandrini, C. H., Pevtsov, A. A., van Driel-Gesztelyi, L. 2003, *Astron. Astrophys.*, **397**, 305–318.
Lin, J., Forbes, T. G. 2000, *J. Geophys. Res.*, **105**, 2375L.
Lin, J. 2004, *Solar Phys.*, **219**, 169.
Longcope, D. W., Welsch, B. 2000, *Astrophys. J.*, **545**, 1089.
Low, B. C., Zhang, M. 2002, *ApJ*, **564**, L53.
Mandrini, C. H., Pohjolainen, S., Dasso, S., Green, L. M., Démoulin, P., van Driel-Gesztelyi, L., Copperwheat, C., Foley, C. 2005, *Astron. Astrophys.*, **434**, 725.
Mandrini, C., Demoulin, R., Schmieder, B., DeLuca, E. E., Pariat, E., Uddin, W. 2006, *Solar Phys.*, in press.

Manoharan, P. K., van Driel-Gesztelyi, L., Pick, M., Démoulin, P. 1996, *Astrophys. J.*, **468**, 73.
Roussev, I. I., Forbes, T. G., Gombosi, T. I., Sokolov, I. V., DeZeeuw, D. L., Birn, J. 2003, *Astrophys. J.*, **588**, 45.
Saint Cyr, O. C., Webb, D. F. 1991, *Solar Phys.*, **136**, 379.
Schmieder, B., Delannée, C., Deng, Y. Y., Vial, J. C., Madjarska, M. 2000, *Astron. Astrophys.*, **358**, 728.
Schmieder, B., van Driel-Gesztelyi, L., Aulanier, G., Démoulin, P., Thompson, B., De Forest, C., Wiik, J. E., Saint Cyr, C., Vial, J. C. 2002, *Adv. Space Res.*, **29**, 1451.
Schmieder, B., Tziotziou, K., Heinzel, P. 2003, *Astron. Astrophys.*, **401**, 361.
Schmieder, B., Mandrini, C. H., Démoulin, P., Pariat, E., Berlicki, A., DeLuca, E. 2006, *Adv. Space Res.*, **37(7)**, 1313.
Schmieder, B., van Driel-Gesztelyi, L. 2005, *IAU*, **226**, 149.
Shibata, K. 1999, *Ap.SS*, **224**, 129.
Subramanian, P., Dere, K. D. 2001, *Astrophys. J.*, **561**, 372.
Srivastava, N., Schwenn, R., Inhester, B., Martin, S., Hanaoka, Y., 2000, *Astrophys. J.*, **534**, 468.
Titov, V. S., Démoulin, P. 1999, *Astron. Astrophys.*, **351**, 707.
Török, T., Kliem, B. 2003, *Astron. Astrophys.*, **406**, 1043.
Török, T., Kliem, B., Titov, V. S. 2004, *Astron. Astrophys.*, **413**, L27.
van Driel-Gesztelyi, L., Manoharan, P. K., Démoulin, P. *et al.* 2000, *J. Atm. Solar-Terr. Phys.*, **62/16**, 1437.
van Driel-Gesztelyi, L., Démoulin, P., Mandrini, C. H. 2003, Second Franco-Chinese Meeting on Solar Physics, 'Understanding Active Phenomena, Progress and Perspectives' (eds.) Hénoux, J.-C., Fang, C., Vilmer, N., World Publishing Corporation, 37.
Wang, J. X. 2002, Proceedings of the second French-Chinese meeting (eds.) Hénoux, J. C., Fang, C., Vilmer, N., World Publishing Corporation, 145.
Wang, Tongjiang, Yan, Yihua, Wang, Jialong, Kurokawa, H., Shibata, K. 2002, *Astrophys. J.*, **572**, 580.
Wang, T., Xu, A., Zhang, H. 1994, *Solar Phys.*, **155**, 9.
Webb, D. F., 1998, In: IAU Colloquium 167 (eds) Webb, D., Rust. D., Schmieder, B., APS Conference Series, **150**, 463.
Yan, Y., Deng, Y. Y., Karlický, M., Fu, Q., Wang, S. J., Liu, Y. 2001, *Astrophys. J.*, **551**, L115.
Zhang, H. Q., Bao, X. M., Zhang, Y., Liu, J. H., Bao, S. D., Deng, Y. Y. *et al.* 2003, *Chinese J. Astron. Astrophys.*, **3(6)**, 491.
Zhang, J., Dere, K. P., Howard, R. A., Kundu, M. R., White, M. 2001, *Astrophys. J.*, **559**, 452.
Zhou, Guiping, Wang, J. X., Cao, Z. L. 2003, *Astron. Astrophys.*, **397**, 1057.