Coronal and Stellar Mass Ejections
Proceedings IAU Symposium No. 226, 2005
K. P. Dere, J. Wang & Y. Yan, eds.

doi:10.1017/S1743921305000487

The Large-Scale Source Regions of Coronal Mass Ejections

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Abstract. Using the observations of LASCO aboard SOHO in the interval from Mar. 1997 to Dec. 2003, 301 earth-directed halo CMEs are selected and the source regions are located in MDI synoptic charts. A statistical analysis has been made with the emphasis on the CMEs' large-scale source regions as well as the correlation between CMEs and solar surface activity. The statistics show that CMEs are intrinsically related to surface activity. Four groups of CMEs' large-scale source structures are identified on the photosphere. They are: I, Extended bipole regions (EBRs) with long magnetic neutral line; II, Closely packed active regions (ARs); III, Large-scale magnetic flux of the same polarity runs through the opposite hemisphere, along the boundary there appears transequatorial filaments; IV, Between two EBRs with long filament. The result shows that CME-associated source activity is closely related to the types of large-scale magnetic structures.

Keywords. Sun: coronal mass ejections (CMEs), Sun: activity, Sun: magnetic fields

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1. Introduction

CMEs arise in large-scale closed coronal structures. Their average masses and kinetic energies are a few times 10^{15} g and 10^{31} erg. It is driven by the magnetic fields(Webb, 2000). To understand CME initiations and onset mechanisms, one should know the magnetic environment and the characteristics of magnetic evolution, or else meaningful results can never be gotten in the studies of CME mechanisms (Wang et al. 2002).

The studies of CMEs' source regions have progressed very much recently, but the problem is still far from being solved. By far, there still have no clear identification and classification about CME's source regions. Many studies about CMEs' source regions are focused on smaller scale, such as flares or filament eruptions (e.g. Sheeley et al. 1983, Hudson et al. 1995, Subramanian & Dere 2001, J.Lin 2004). However, CMEs, as a large-scale solar activity, their sources may be disproportional to such small-scale activity.

Some case studies about CMEs' sources are also attempted around the destabilization of large-scale, but these are limited in coronal structures at higher altitudes, such as coronal streamer(e.g. Hundhausen, 1993), X-ray loop(Nitta & Akiyama 1999), loop arcades (Chertok, 2001), transequatorial filaments (Wang et al, 2004, submitted) and so on. Up to now, there are no systematic studies established to investigate CMEs' source regions in large-scale magnetic structures at lower latitude. Large-scale magnetic structures are intrinsic components of solar magnetism. Their destabilization, expansion, and eruption into the interplanetary space are the basic processes which lead to the CMEs (Wang et al. 2002). To understand CME magnetism, it seems necessary to investigate the CMEs' source regions from large-scale magnetic structures at lower altitudes.

After the successful mission of SOHO and Yohkoh, the disk observations of CME initiation become possible, particularly for the earth-directed CMEs. To avoid the ambiguity in locating CME source regions, as argued by Feynman & Martin (1995), only

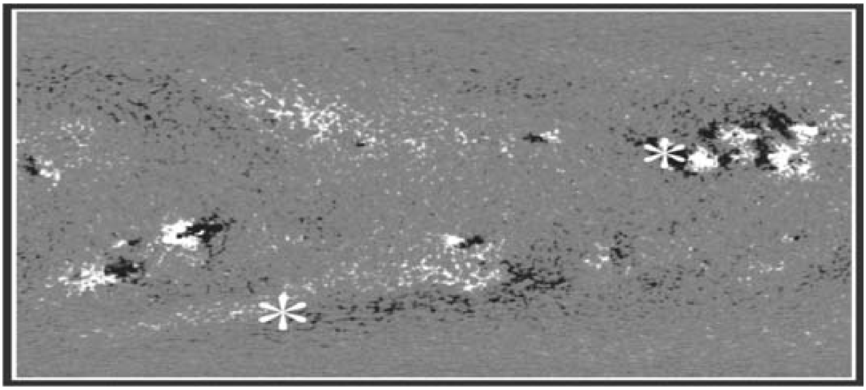

Figure 1. Two halo CMEs' source regions (indicated by asterisks) are located in the corresponding synoptic chart.

earth-directed halo CMEs are selected in this statistics. A CME with span angle greater than 130^0 is referred to as a halo CME in our approach.

In this work, the CMEs' sources are considered as the large-scale magnetic features on the photosphere. The statistics are emphasized on the CMEs' large-scale source regions, as well as the correlation between CMEs and surface activities in terms of flares and filament eruptions as Zhou et al, (2003, paper1 hereafter). The database are enlarged to 301 earth-directed events from 1997 to 2003.

The database are presented in section 2. In section 3, the correlation between CMEs and surface activity are shown. The categories of the large-scale CMEs' source structures are described in section 4. In the last section, the conclusion and discussion are given.

2. Database and source region locations

The primary database for this study is SOHO LASCO and EIT time-lapse observations. All the CMEs are from CME Category (see http://cdaw.gsfc.nasa.gov/CME list/). The GOES X-ray counts and Yohkoh SXT images are used to identify flares. Hα filaments are identified from the observations from Big Bear Hα filtergrams, Huairou Solar Observing Station (HSOS), Hiraiso Solar Terrestrial Research Center (HSTRC) and Holloman Air Force Base (HAFB).

To identify the earth-directed halo CMEs, two criteria are applied. One is the associated surface activity happen in the time interval (CME's initial time) $\pm$ 30 min. The second criterion is that the surface activity's position (PSSA) identified in the EIT images is under the span of the associated CME or just near the span's edge. If both criteria are satisfied, the CME is thought as earth-directed. 302 earth-directed halo CMEs from Mar. 1997 to Dec. 2003 are well identified. The associated surface activity are considered as the CMEs' source regions, which are located in the corresponding MDI synoptic charts as shown in Fig. 1.

In addition, according to the MDI daily magnetograms, the relationship between CMEs and ARs were also checked. If the difference between SRPA and the central position angle or the position angle (for 360^0 halo CMEs) of a CME is not greater than 20^0, we define it as symmetric, or else it is asymmetric.

https://doi.org/10.1017/S1743921305000487 Published online by Cambridge University Press

Table 1. the correlation between front-side halo CMEs (1997.3-2003.12) and the associated surface activity

Assoc. Surface activity	CME Num.	Percent
Flares	270	89%
Filaments	280	93%
ARs	268	86%
Asymmetry	153	51%
Total CMEs	302	

3. Correlation between CMEs and surface activity

Studying correlation of CMEs with other solar activity will help us to understand the physical links between the very large scale activity (e.g. CME) and the rather small scale phenomena (e.g. flares and filament eruptions).

In this study, only two primary forms of associated surface activity, flares and filament eruptions, are taken into account. Some other active manifestations, e.g. EIT wave and/or dimming, are considered as secondary active phenomena. The correlations are shown in table 1. It is found that 89% halo CMEs are associated with flares, while more than 93% are related to filament eruptions. The CMEs are intimately related to the other surface activity, as either flares, or filament eruptions, or both.

In previous work, CMEs were considered to be associated with ARs. Based on SOHO's successful observations, the relationship is checked again. The statistic shows that as many as 86% earth-directed halo CMEs are related to ARs.

In addition, we also check the asymmetry or symmetry between CMEs and associated surface activity. It is found that about 51% of the CME source regions are asymmetric with corresponding CMEs, which are contradictory to present CME models. All the results listed in table 1.

4. Categorize the CMEs' large-scale source regions

After identifying the earth-directed halo CMEs' source regions, it is found that each CME has a large-scale structure counterpart on the photosphere. Such large-scale structures are referred to as the CMEs' sources. They are distinguished by magnetic structures with distinct characteristics. The total 301 earth-directed CMEs are associated with 204 large-scale source regions, categorized as four groups. Usually, there is more than one CME corresponding to one source structure. The magnetic structures of each category are shown in the Fig. 2, in which all the plus signs denote CMEs' source locations. The statistic results are listed in Table 2.

Category I: the CMEs' source locates in one extended bipole region (EBR). EBRs are brought forward as Evolving Magnetic Structures (EMS) by Feynman (1997). It can be identified as a large-scale bipole structure in synoptic charts, whose polarity distributions follow the Hale law. 25% CMEs are associated with this kind of structures. As shown in Fig. 2I, the source of a CME on August 30 1997 located in an EBR in the northern hemisphere.

61% CMEs are associated with Category II that their source regions lie in closely packed ARs, which include more than two ARs. This category is differentiated by that the threshold of the edge magnetic intensity of each case is greater than 100 G, in the range of which the average magnetic flux is greater than 40 Maxwell/cm^2. Fig. 2II shows

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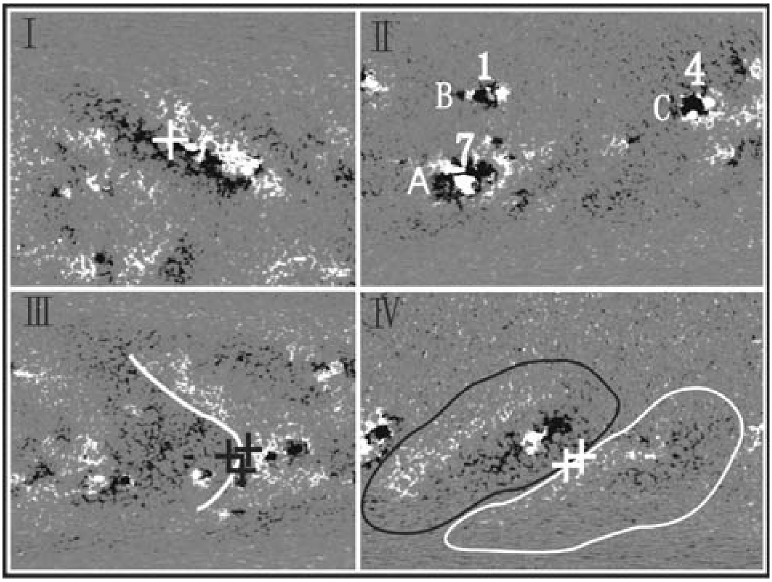

Figure 2. Four categories of CMEs' large-scale magnetic source structures: I, one EBR; II, closely packed ARs; III, single polarity that runs through two hemisphere accompanying by transequatorial filaments; IV, between two EBRs with long filament.

Table 2. statistics of large-scale magnetic structures of CMEs' source regions

Assoc. sour. struc.	Sour. num.	Sour. per.	CME num.	CME per.
I:	59	29%	73	25%
II:	107	52%	183	61%
III:	11	5%	17	6%
IV:	27	13%	29	9%
Total sour.	204			
Total CMEs	302			

three cases (shown as A, B & C) in this category, and 7,1 & 4 are the numbers of associated CMEs.

In Category III, all the CMEs' source regions lie along the single polarity that runs through two hemispheres. Such magnetic structures are always accompanied by transequatorial filaments, whose eruptions are related to CMEs. As indicated in Fig. 2III, along the boundary of the negative polarity straddling northern and southern hemisphere, there is a transequatorial filament denoted by the white curve. 6% CMEs are related to this category.

As indicated by Fig. 2IV, the CMEs' sources located between two EBRs with long filaments. Such magnetic structures are considered as Category IV, whose associated CMEs that occupy 9% are always related to the long filaments' eruptions.

From Table 2, it can be found that the predominant two kinds of magnetic structures are closely packed ARs and EBRs, with which most of CMEs are associated. It doesn't means that the other two kinds of categories are unimportant or illogical, but indicates that the physics behind the fore two categories are more easy to cause CMEs or they appear more frequently in the sun. The reason is that the surface activity related to CMEs can be distinguished from their corresponding magnetic structures on the photosphere.

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For Category I, flare and filament eruption often happen together. For Category II, flares are the main activity. Filaments' eruptions with long neutral lines are often related to Category III & IV.

5. conclusion and discussion

Using the observations from LASCO, EIT, GOES X-ray, Hα and synoptic & daily MDI magnetograms, following the former work in paper 1, we examined the relationship between halo CMEs and the surface activity by enlarged sample from Mar. 1997 to Dec. 2003. All the large-scale magnetic structures on the photosphere, as the CMEs' sources, are studied statistically.

The large-scale magnetic structures are categorized into four groups: (I), one EBR; (II), closely packed ARs; (III), the single polarity that runs through two hemispheres, which are always accompanied by transequatorial filaments; (IV), long neutral lines between two EBRs with long filaments. They four present the large-scale characteristics of CMEs' source on the photosphere.

The main results about the correlations of CMEs with surface activity are presented in Table 1. Table 2 lists the details about the categories of the CMEs' large-scale source structures. 301 earth-directed halo CMEs are identified. Their sources locate in 204 large-scale source structures on the photosphere.

The results show that CMEs are intimately linked to surface activity, which behaved as flares or filament eruptions or both. Half of the CMEs are offset to their source that is not consistent with the present CME models. More than 80% of the earth-directed CMEs have the sources inside ARs. However, all of these CMEs can be found large-scale source counterparts on the photosphere. It implies that CMEs' sources are correlated with large-scale structures more than small-scale ones, e.g. AR scale.

In addition, since both of the structures in different scales are closely related to CMEs simultaneously. It suggests there be physical interactions between them. Recently, Zhang et al. (2001) have identified that the interaction between the large-scale structures and active region scale (or small scale) magnetic field in the form of flux cancellation may transport the magnetic energy and complexity into large-scale magnetic loops. This may cause the large-scale structure to be destabilized, partially opened and erupted into interplanetary space, which often appear as CMEs.

The further work of us is to search large-scale phenomena at higher altitude, such as propagating EUV waves, large-scale magnetic loop and so on. The aim is to well understand the CME initiations and onset mechanisms, and finally establish the physics-based prediction models for CMEs.

Acknowledgements

The work is supported by the National Natural Science Foundation of China(10233050) and the National Key Basic Science Foundation(TG2000078404). We are grateful to all members of the SOHO EIT, LASCO and MDI teams, as well as BBSO team, Yohkoh team, HSTRC team, HAFB team and for HSOS station providing the wonderful data. SOHO is a project of international cooperation between the ESA and NASA.

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Discussion

PengFei Chen: You got a correlation between halo CME speeds and flare flux, while halo CMEs suffer seriously from projection effects. So, we might be cautious about the measurement of halo CME speed.

Zhou: Yes, you are right, but the results would be meaningful if projection effects were not predominant.

Nindos: What do you mean by the term “closely packed ARs?”

Zhou: Some people once referred to such magnetic structures as active region (AR) nests. In our work, the “closely packed ARs” is similar to the “AR nests”.

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