MANIFESTATIONS OF CME-ASSOCIATED DIMMINGS AT FOUR EUV WAVELENGTHS OF SOHO/EIT

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ABSTRACT

We describe two halo coronal mass ejection (CME) events as examples of our analysis of dimmings simultaneously in three coronal and one transition region lines by forming of rerotated SOHO/EIT difference images with 6- or 12-hour intervals. It is shown that usually the dimmings are most pronounced and have similar large-scale structures in the moderate-temperature coronal lines 171 and 195 Å. In the high-temperature line 284 Å, analogous dimmings are visible not always, and sometimes the deepest dimming fragments are visible only. On-disk CME events display also clear, but relatively small-area dimmings in the transition region line 304 Å particularly in regions joining to a main eruption source, although sometimes remote dimming patches are present as well. These results suggest that not only opening of magnetic field lines, resulting in density and emission depletion, but also temperature variations may be responsible for observed dimmings, and that these effects may also extend into cooler plasma of the transition region.

Key words: solar corona, coronal mass ejections (CMEs), dimmings.

1. INTRODUCTION

Strong reconfiguration of the magnetic fields during coronal mass ejections (CMEs) are known to be accompanied particularly by the appearance of large-scale areas and structures of reduced brightness (dimmings) of the EUV and soft X-ray emission persisting for many hours (e.g., Thompson et al., 1998; Zarro et al., 1999; Gopalswamy and Thompson, 2000; Hudson and Cliver, 2001). So far, dimmings were analyzed mainly by separate or combined consideration of data recorded with the EUV Imaging Telescope (EIT; Delaboudinière et al., 1995) aboard SOHO at 195 Å and with the Soft X-ray Telescope (SXT; Tsuneta et al., 1991) aboard Yohkoh. Only for one dimming event Thompson et al. (1998) presented original images in all four EIT lines (171, 195, 284, and 304 Å) in combination with a SXT image, and for another event Gopalswamy and Thompson (2000) analyzed difference EIT images at 171 and 195 Å with 17–28-min intervals. These studies revealed the similarity of dimmings in different emissions and brought to conclusion that dimmings may result mainly from an opening of field lines and subsequent material outflows associated with CMEs.

As for EIT data, let us remind that three coronal lines Fe IX/X (171 Å), Fe XII (195 Å) and Fe IX (284 Å) are sensitive to temperatures 1.2, 1.5 and 2.0 MK, respectively, while the 304 Å filter passes a transition region line He II (0.02–0.08 MK) and much weaker coronal component Si XI (1 MK) [Delaboudinière et al., 1995; Moses et al., 1997]. There is a serious obstacle for use these data, especially for forming corresponding difference images, in which dimmings are most pronounced: in the standard mode, the full-disk heliograms are produced every 12-min at 195 Å, but only 4 times per day near 01, 07, 13, and 19 UT at 171, 284, and 304 Å. Such a low cadence precludes a four-wave study of coronal waves propagating at a time scale of tens of minutes (e.g., Thompson et al., 1998; Zarro et al., 1999), but it is suitable for long-living dimmings.

We have carried out a multi-wave (i.e. multi-temperature) analysis of the EUV dimmings for several tens of events, initiated by halo CMEs, by forming difference images with 6- and 12-hour intervals in all four EIT lines (Chertok and Grechnev, 2003b). To avoid appearance of false darkenings and brighenings, before subtraction we compensated the rotation of the Sun by means of rerotation of all images to the pre-event time. Isolated events, culminating between 01, 07, 13, and 19 UT, were mainly considered. For the events developing near these times, the rerotated images with a 12-hour interval were formed with prior rotation of both the base and current heliograms to the central time. For each event, both fixed and running difference images and movies at 195 Å with a 12-min interval were also formed to see the development of dimmings (and coronal waves) in details.

Such a multi-wave analysis reveals some properties of dimmings that may be important for understanding of their nature and CME process as the whole. In this paper, we describe two eruptive events as typical examples using 6-hour rerotated difference images in all four EIT lines as well as subsidiary base heliograms at two wavelengths. Additional relevant data for these and other events are presented at the Web site http://helios.izmiran.troitsk.ru/lars/Chertok/Dimming/4lines.html.

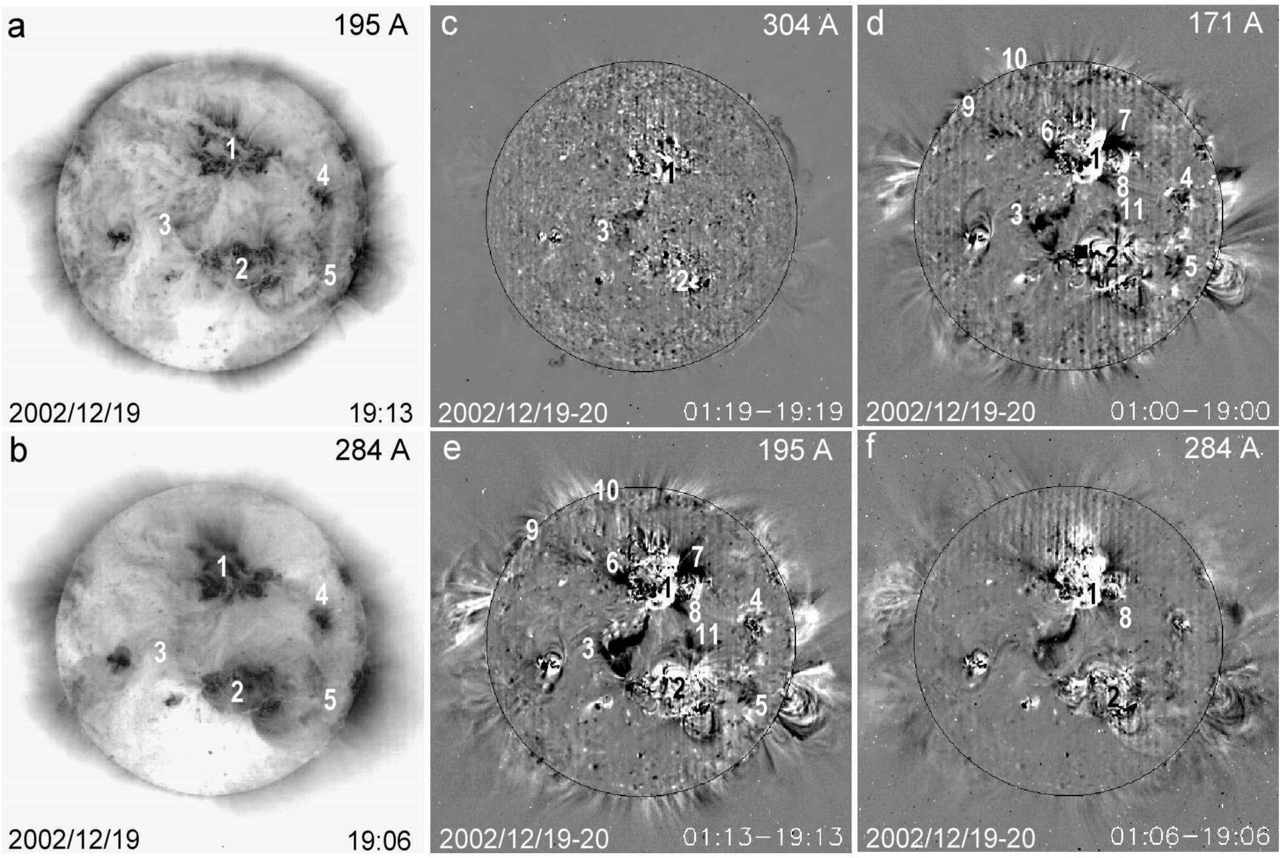

Figure 1. SOHO/EIT images related to the eruptive event of 19 December 2002: (a,b)–Inverted pre-event heliograms at 195 and 284 Å; (c–f)–Rerotated difference images with a 6-hour interval illustrating dimmings in four EIT lines.

2. EVENT OF 19 DECEMBER 2002

This event included a full-halo CME with a bright northwestern loop front and prolonged outflow as well as a 2N/M2.7-class flare peaked at 21:50 UT in a large northern active region AR 0229 (region 1 in Figure 1) located near the central meridian (coordinates N15 W09). From the pre-event images at 195 and 284 Å (Figure 1a,b) one can see that this region was connected with a southern AR 0227 (region 2) by some transequatorial emitting chains (see Chertok, 2001) and structures, particularly such as 1-3-2 and 1-4-5-2. The latter seems to be located along the eastern boundary of a narrow coronal hole that was visible at 284 Å during preceding days, but was obscured on that day due to the projection effect.

In this case, the difference images shown in Figure 1c–e were formed at each of the four wavelengths by the subtraction of the corresponding pre-event images of 19 December, 19 UT from the post-event ones of 20 December, 01 UT with prior rerotation of the latter to 19 December, 19 UT. In such difference images, dimmings look as dark features.

The images in two moderate-temperature coronal lines 171 and 195 Å (Figure 1d,e) display almost coinciding, strongly anisotropic dimmings typical for a sufficiently complicated global solar magnetosphere (Chertok and Grechnev, 2002, 2003a). Besides the dimmings 6, 7, 8 adjoining directly to the eruptive center 1, there are several outward narrow and long dimming channels, such as 6-9 and 7-10 (visible somewhat better at 195 and 171 Å, respectively). Moreover, a pronounced transequatorial dimming 1-3-2 and two dimming fragments 1-8, 11-2 stretch to the southern AR 2, which is surrounded by some additional loop-like dimmings. Fainter dimming fragments follow one more transequatorial structure 1-4-5-2. The 195 Å difference movies, presented at the site mentioned above, show that a whole global area 1-4-5-2-3-1, outlined by the pre-event emitting chains and post-event dimmings, as well as its outskirts appeared to be involved in the CME eruption.

Very similar, but somewhat different dimmings are visible in the high-temperature coronal line 284 Å (Figure 1f). The main and practically only difference in comparison with two other coronal lines is that the transequatorial interconnecting dimming structure 1-8-11-2 is visible not entirely due to the absence of the element 11-2. It is remarkable that, as Figure 1c shows, a clear transequatorial dimming 1-3-2 is revealed almost completely also in the transition region line 304 Å along with several small-area dimmings near ARs 1 and 2.

Thus, this eruptive event represents an example of the CME-initiated global dimmings which are almost identical in all three coronal lines with a pronounced dimming manifestation also in the transition region line.

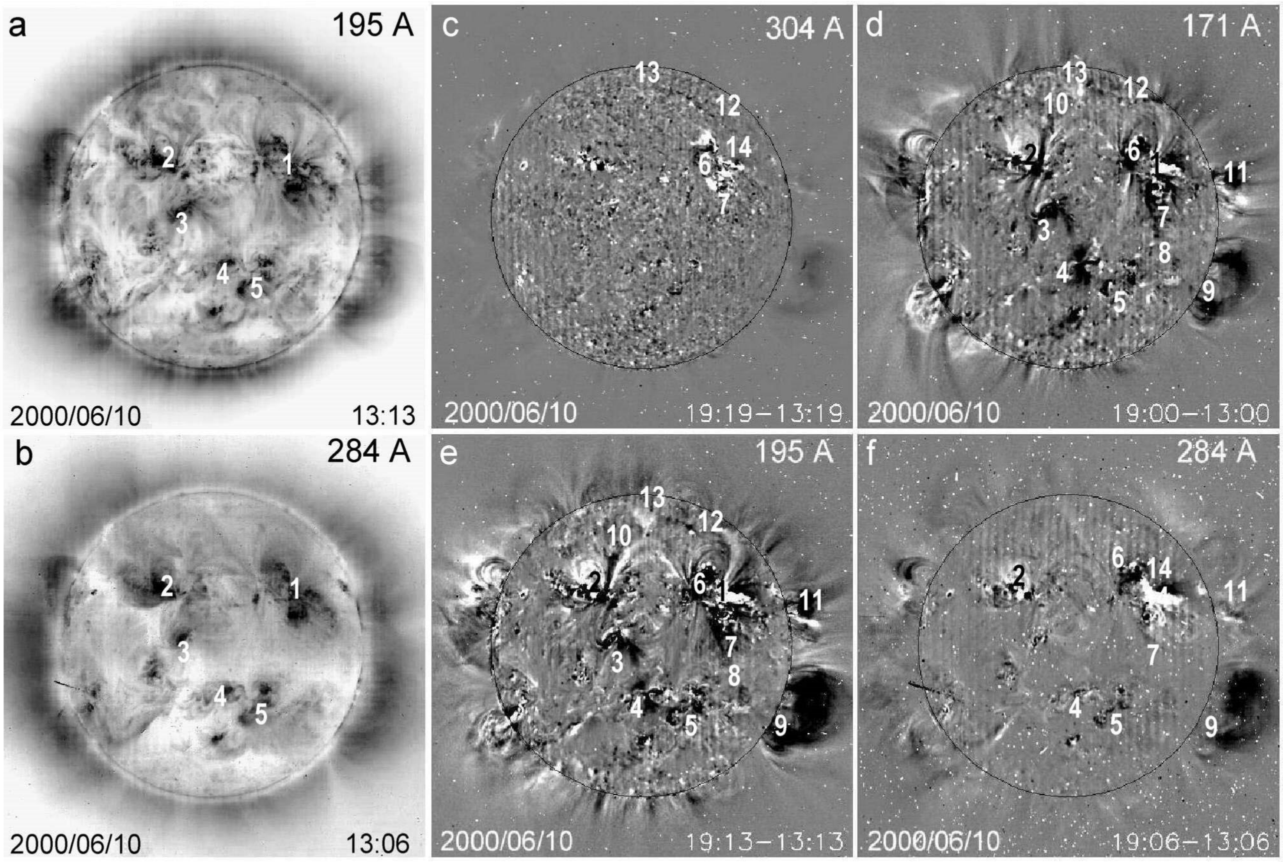

Figure 2. The same as Figure 1 but for the CME event of 10 June 2000.

3. EVENT OF 10 JUNE 2000

This event also occurred in the conditions of a highly complicated global solar magnetosphere, had several properties similar to the event described in the previous section, but revealed rather different four-line dimming manifestations. It was associated with a full-halo CMEs with a bright front over the northwestern and western limb. An eruptive center was located in AR 9026 (coordinates N22 W38; region 1 in Figure 2) where a large plasma jet started between 14:24 and 14:36 UT followed then by another similar jet at 16:36–16:48 UT and a prolonged 3B/M5.2-class flare peaked at 17:02 UT. Loops, arcades and chains in the pre-event heliograms at 195 and 284 Å (Figure 2a,b) display a magnetic connection of region 1 with other remote regions 2, 3, 4, 5 located in the northeastern and southern sectors of the disk.

Again, very similar local dimmings around AR 1 and large-scale channeled dimmings extending across the disk are observed in both moderate-temperature coronal lines 171 and 195 Å. As the corresponding rerotated difference images (Figure 2d,e) show, one transequatorial dimming structure 6-7-8-9 stretches from the northeastern outskirts of the eruptive center to the southwestern limb. The second similar structure is formed by the dimmings located along transequatorial line 10-3-4-5 connecting remote ARs. These two transequatorial structures appear to be connected directly not only by the northern system of bright loops 6-2, but also by a number of dimmings, particularly such as narrow ribbons 6-4, 4-7 and more fragmentary branch 5-8 that is visible somewhat better at 195 Å. This connection is continued further to one more western limb dimming patch due to channel 7-11. Northward of the eruptive center 1, high-latitude dimming ribbon 12-13 can be distinguished.

The most remarkable feature of this event is that both transequatorial dimming structures, visible at 171 and 195 Å, are practically unseen in the high-temperature coronal line 284 Å (Figure 2f). Only some faint signatures and fragmentary patches of these dimmings can be seen between northern ARs 1, 2 and near the southern ARs 4, 5. At the same time, the dimmings 6, 14 and partly 6-7, adjoining directly to the eruptive center 1, are displayed in the 284 Å line. At that, dimming 14 is connected with the constricted western limb dimming 11 by a dark ribbon and high loop. Some type of connection seems to exist also between over-the-limb dimmings 11 and 9.

Another peculiarity of this event, that is characteristic of many eruptive events, though, is that the dimming manifestations are comparatively poor also in the transition region line 304 Å (Figure 2c). Only small-area analogs 6, 7, 14 of the coronal dimmings, located near the eruptive center 1 and partly near other involved ARs, are distinguished on the disk in this low-temperature line. A sole exclusion is the northern high-latitude dimming ribbon 12-13 that is also visible at two moderate-temperature coronal lines 171 and 195 Å.

4. DISCUSSION AND CONCLUSION

Dimmings observed with SOHO/EIT in halo CMEs events were analyzed simultaneously in three coronal lines 171, 195, 284 Å and in the transition region line 304 Å with a 6-hour (sometimes 12-hour) interval using the technique of rerotated difference images. Consideration of the described and other halo CMEs events in four lines (see Chertok and Grechnev (2003b) and the Web site indicated above) reveals the following multi-wave features of the dimmings.

– Relatively compact dimmings adjoining directly to an eruptive center are observed in all four lines. Their shape and location in three coronal lines are usually identical, while some fragments of these dimmings are only present in the transition region line.

– Extended coronal channeled dimmings (including transequatorial those), as a rule, are most pronounced and similar in two moderate-temperature coronal lines 171 and 195 Å, although sometimes these dimmings are similarly visible also in the high-temperature line 284 Å. However, there are events, in which the extended coronal dimmings are not detectable at 284 Å, and, moreover, some brightenings can be seen in this line instead of transequatorial dimming structures observed at 171 and 195 Å.

– Extended (transequatorial) dimmings are observed in the transition region line 304 Å in different ways. Sometimes they are visible and similar to the coronal those. In other cases, they are generally absent. Furthermore, events are found, where an extended transition region dimming is observed without counterparts in any coronal line (Chertok and Grechnev, 2003b).

The coinciding dimmings in three coronal lines support their interpretation as a result of full or partial opening of magnetic field lines in some areas and structures in the course of a CME process as well as accompaning evacuation of plasmas from these structures (Thompson et al., 1998; Zarro et al., 1999; Gopalswamy and Thompson, 2000; Hudson and Cliver, 2001). Direct evidence of this interpretation is provided by Doppler observations of material outflows with Coronal Diagnostic Spectrometer (Harrison et al., 1995) on the SOHO (Harra and Sterling, 2001). The results of our multi-wave analysis show that these processes may occur not only in outskirts of an eruptive center, where the observed dimmings, as it is thought, mark feet of a CME flux rope (e.g., Sterling, 2000; Webb et al. 2000), but also in extended transequatorial dimming structures.

These structures resemble disappearing transequatorial interconnecting soft X-ray loops that are also related to CMEs (Khan and Hudson, 2000). Our consideration, as well as the analysis of Glover et al. (2003), shows that during a CME process these high-temperature structures may undergo either dimmings or brightenings, or remain invariable. This means that some temperature effects may be essential for unmatched dimming structures, along with the opening of magnetic fields.

The fact that the dimmings (both compact and extending) are also observed sometimes at 304 Å shows that the transition region plasma is also involved in a CME process due to either the opening of the magnetic field, or temperature variations. In particular, it is reasonable to suggest that extended transition region dimmings, observed without coronal counterparts near a large pre-existing coronal hole, result from the opening of the magnetic fields and plasma outflow from originally closed, low-lying structures, i.e. the formation of a transient “hole” in the transition region.

In summary, our multi-wave analysis of the dimmings confirms once again that many halo CMEs have a global character, and they affect large-scale areas extending throughout almost the entire solar hemisphere.

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