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CME-associated dimmings on the Sun observed with the EUV SPIRIT telescope on the CORONAS-F spacecraft

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Abstract

Based on observations with the EUV SPIRIT telescope aboard the CORONAS-F spacecraft, we analyze large-scale dimmings on the solar disk initiated by halo-type coronal mass ejections (CMEs). We address four powerful geo-effective eruptive events of November 4, 2001; October 28, 29, and November 18, 2003. The SOHO/EIT telescope did not observe the first event. Considering other events, we demonstrate that the CORONAS-F/SPIRIT and SOHO/EIT data well supplement each other in time and spectral coverage. The spatial coincidence of the main dimmings in different-temperature lines hints at their relation to plasma outflow from partly or completely opened magnetic structures in the transition region and corona. For some dimmings whose appearance is dissimilar in different lines, CME-associated variations of the plasma temperature can play a role as well. Peculiar propagating darkening was detected in the SPIRIT 304 Å band on November 18 between 08:23 and 09:54 UT. Most probably, the darkening is caused by some absorption of the emission in cold material of the erupted filament.

Keywords: Solar activity; Solar corona; Coronal mass ejections; Solar UV-radiation

1. Observations and data analysis

1.1. Instrumentation

The CORONAS-F space solar observatory (Oraevsky et al., 2003) launched in July 2001 carries a number of various instruments. The Spectrographic X-ray Imaging Telescope-spectroheliograph SPIRIT (Zhitnik et al., 2002) observes the Sun in several EUV and soft X-ray channels. In particular, the SPIRIT provides simultaneous pairs of full-disk solar images in EUV 175 and 304 Å bands (Herschel telescope) and consecutive images in 171, 195, 284 and 304 Å (Ritchey-Chrétien telescope) with time intervals from 5 to 45 min, having a pixel size of 2.6 arcsec (or 5.2 in the binned 2×2 mode). The FeIX–XI coronal lines, emitted by plasma with a temperature of $T_e \approx 0.8$–1.2 MK, dominate in the 175 ± 5 Å band. The 195 ± 6 Å band is centered in the FeXII line ($T_e \approx 1.6$ MK), which is blended in flares by bright FeXXIV line ($T_e > 15$ MK). The 284 ± 8 Å band contains a high-temperature ($T_e \approx 2.0$ MK) FeXV line. The 304 ± 12 Å band

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includes both the transition-region HeII line ($T_e \approx 0.08$ MK) and the lower-intensity coronal component SiXI ($T_e \approx 1.6$ MK). We use SPIRIT data to study large-scale manifestations of halo-type coronal mass ejections (CMEs) on the solar disk, particularly dimmings (sometimes referred to as "transient coronal holes") for some powerful eruptive events. To the present time, CME-associated dimmings were observed in connection with CMEs with the Yohkoh Soft X-ray Telescope as well as with the SOHO Extreme ultraviolet Imaging Telescope (EIT) and the Coronal Diagnostic Spectrometer (CDS) (e.g. Thompson et al., 1998; Delannée et al., 2000; Webb, 2000; Hudson and Cliver, 2001; Harrison et al., 2003).

1.2. Method of image analysis

We use a method of fixed-difference derotated images applied earlier for analyses of SOHO/EIT heliograms (see Chertok and Grechnev, 2003a,b, 2004). The difference images are formed in two steps. First, the solar rotation is compensated by 3D 'derotation' of all heliograms to the same time, usually to the time of the base frame observed before the event. Then this reference frame is subtracted from all subsequent frames. The derotation procedure enables to form and analyze difference images using heliograms separated by several hours. Dimmings in fixed-difference images always look as dark features.

The results of our analysis are illustrated below with four eruptive events of November 4, 2001, October 28–29, and November 18, 2003 that are among the most powerful and geo-effective events of the current solar cycle. Some of them considered in combination with SOHO/EIT images demonstrate that the CORONAS-F/SPIRIT and SOHO/EIT data substantially supplement each other.

2. Event of November 4, 2001

The November 4, 2001 event included a 3B/X1.0 flare at 16:20 UT, a full halo CME, and was accompanied by an appreciable increase of the energetic proton flux ($J_{>10\ \mathrm{MeV}} \approx 2 \times 10^3$–$10^4$ cm^{-2} s^{-1} sr^{-1}) as well as by a severe geomagnetic storm ($D_{st} \approx -300$ nT). By its main solar manifestations and space weather disturbances, this event is similar to the famous Bastille Day event of July 14, 2000 (Chertok et al., 2004, and references therein). The November 4, 2001 event was not observed with SOHO/EIT. SPIRIT data for that day are not regular. We use for the reference the nearest images before the eruptive event (11:11 UT for 175 and 304 Å, and 12:19 UT for 284 Å).

Fig. 1 shows fixed-difference SPIRIT images of the western portion of the solar disk. They display a number of coronal and transition-region dimmings (dark regions) surrounding a large, bright post-eruptive arcade 1. Light curves in the lower panels show the average brightness over $22'' \times 22''$ areas at the centers of the main dimmings. They are labeled correspondingly.

In the moderate-temperature 175 Å band (Fig. 1(c),(d)), two main, relatively compact dimmings 2 and 3, adjoin directly to the eruptive center. Besides, several narrow, channeled dimmings are visible, that stretch to remote regions, in particular, a southwestern dimming 3–4–5 and northern dimming branches 6–7 and 6–8. From the comparison of the two frames shown, one can conclude that both compact and extended dimmings persist, keeping their locations and forms for at least 3 h. Very similar dimmings, which almost coincide with those at 175 Å, are visible in the high-temperature coronal band of 284 Å (Fig. 1(e),(f)). An additional large-scale dimming area seems to exist at 284 Å south-eastward of the post-eruptive arcade 1 and the eastern compact dimming 2.

As for transition-region dimmings observed at 304 Å (Fig. 1(a),(b)), some of them coincide with the corresponding coronal dimmings at the late stage of the event. In particular, this is related to compact dimmings 2, 3 and a channeled southwestern dimming 3–4–5. However, the eastern compact dimming 2 appears in 304 Å band with a noticeable delay with respect to other dimmings (cf. frame '(a)' with others). The light curves of the main dimmings shown at the lower panels of Fig. 1 also confirm this. These light curves also demonstrate that dimmings are long-living features, and that the loss of brightness of dimmed structures amounts to several tens of percents.

3. Events of October 28 and 29, 2003

We consider two of several powerful eruptive events occurred during October–November 2003 (e.g., Chertok and Grechnev, 2005). The former one started on October 28, 2003 with an X17 flare at 09:51 UT and a halo CME at 11:01 UT, the latter one occurred on the next day with an X10 flare at 20:37 UT and halo CME at 20:35 UT. Full-disk heliograms were observed by the CORONAS-F/SPIRIT at 175 Å and SOHO/EIT at 195 Å.

Fixed-difference derotated CORONAS-F/SPIRIT images at 175 Å for the event of October 29 are shown in Fig. 2 along with corresponding SOHO/EIT images at 195 Å. The EIT images (Fig. 2(d)–(f)) are covered more and more by numerous bright spots and streaks caused by impacts on the detector of energetic particles (protons with $E > 40$ MeV and secondary particles) produced in this event. This contamination with the "snowstorm" of the post-event EIT images at

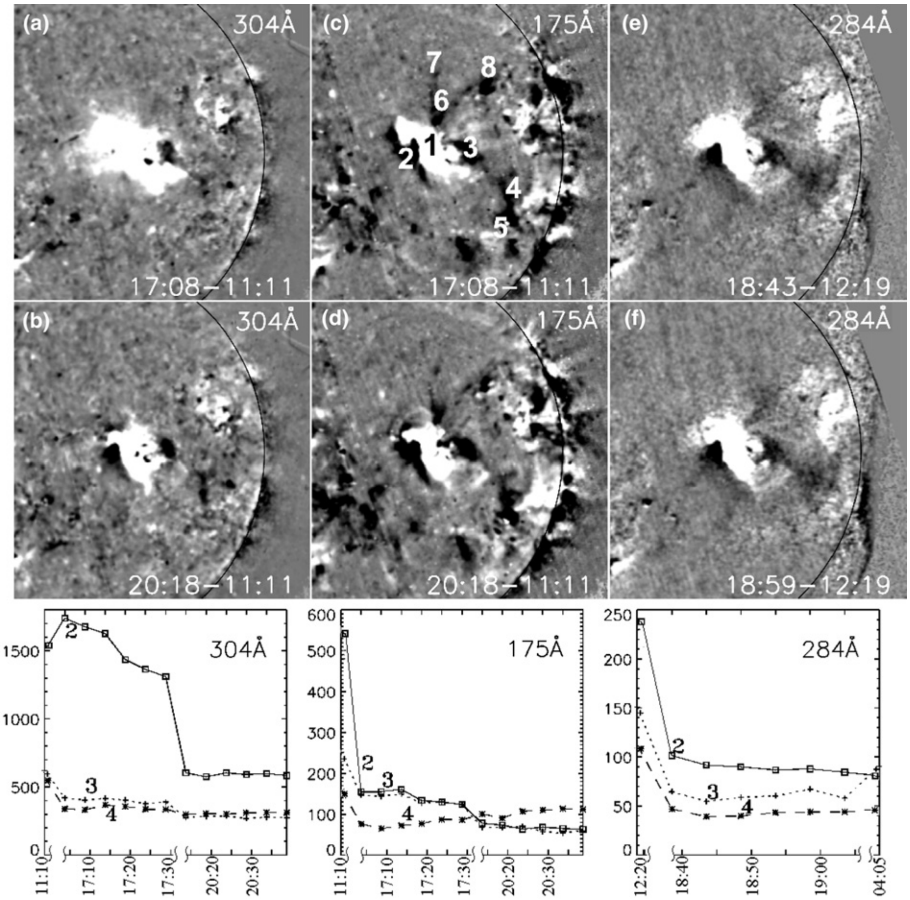

Fig. 1. Top: Fixed-difference derotated CORONAS-F/SPIRIT images of November 4, 2001 event observed in the coronal bands of 175 Å ((c),(d)), 284 Å ((e),(f)), and the transition-region band of 304 Å ((a),(b)). Bottom: Light curves of selected dimmings computed over $22'' \times 22''$ areas at their centers.

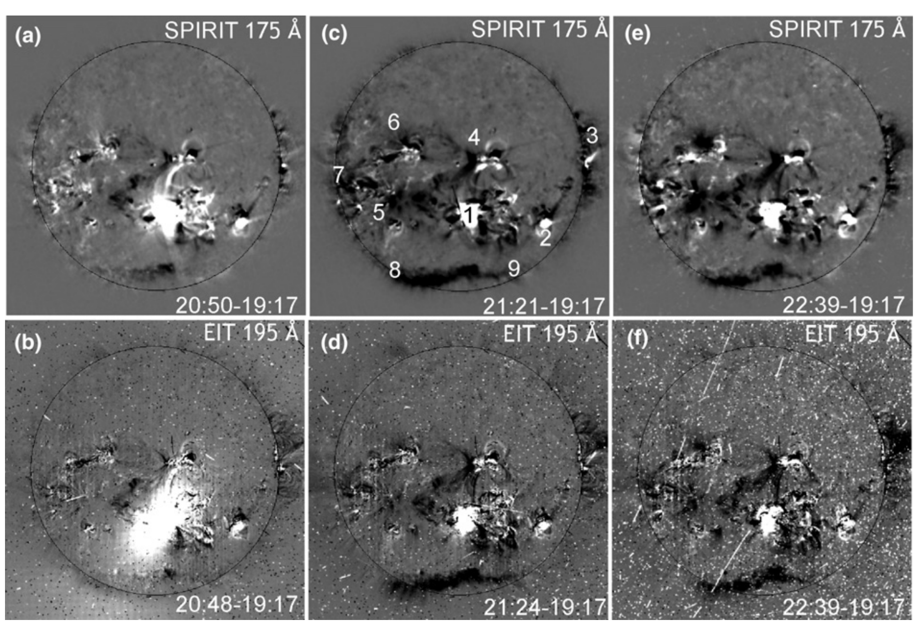

Fig. 2. Fixed-difference derotated CORONAS-F/SPIRIT images at 175 Å ((a)–(c)) of October 29, 2003 event and corresponding SOHO/EIT images at 195 Å ((d)–(f)).

171, 284, and 304 Å recorded with a 6-h interval rules out their usability for analyses. Therefore, a comparison of the 175 Å SPIRIT and EIT 195 Å images is only possible. The SPIRIT heliograms (Fig. 2(a)–(c)) show CME-associated disturbances much clearer because these images are not affected by very strong particle fluxes due to the low orbit of the CORONAS-F spacecraft inside the Earth's magnetosphere. Besides, the SPIRIT heliograms, in contrast to the EIT images, are not saturated by extremely intense emission at the flare maximum (cf. frames (Fig. 2(a) and (b)).

In spite of the "snowstorm", the 175 Å SPIRIT and 195 Å EIT fixed-difference images demonstrate coinciding long-living global dimmings to cover the entire southern half of the disk. The dimmings extend between the eruptive center 1 and remote active regions; one more dimming is located in the southern polar area. In particular, as marked in frame "(c)", a long thin dimming 1–2–3 stretches toward the western limb. A transequatorial dimming 1–4 connects the eruptive center with a low-latitudinal northern active region. Several channeled and fragmentary dimmings (e.g., 1–5, 4–5, 4–6–7) stretch eastward from active regions 1 and 4, and come to the eastern limb. A well-pronounced southern polar dimming 8–9 is of special interest, because this feature has been observed homologically in several events, starting from the central-meridian event of October 28 until the west-limb event of November 4. Before the October 28 event, another structure analogous to feature 1–2–3 was homologous in many eruptive events of this series (Chertok and Grechnev, 2005).

4. Event of November 18, 2003

This event included a 2N/M3.9 flare starting at 08:12 UT and a full halo CME at 08:06 UT that caused one of the strongest geomagnetic storm with $D_{st} \approx -472$ nT. Observations with CORONAS-F/SPIRIT at 175 and 304 Å and with SOHO/EIT at 171, 195, 284, and 304 Å substantially supplement each other. In particular, the SPIRIT data at 175 and 304 Å fill in 6-h intervals between EIT measurements at both 171 and 304 Å (Slemzin et al., 2004).

Fixed-difference derotated SPIRIT and EIT images (Fig. 3) display some identical dimmings in different coronal bands. Some of them are partly visible in the transition-region band. In particular, a dimming system 2–3–4 surrounding the eruptive center 1 from the south and west as well as a long dimming 3–5 stretching to the southeastern limb coincide completely at 175 and 195 Å and partly at 304 Å.

Moreover, the images presented and, especially, corresponding movies reveal large-scale disturbances (including a coronal wave and some dimmings) extended throughout the whole area between the eruptive center and the southern-to-western limb. In coronal lines, these disturbances have a diffuse character and occur mainly before 09 UT. A CME-initiated disturbance, which has not been described previously, was observed in SPIRIT images at 304 Å (Fig. 3(e),(f)) after 09 UT. A large-scale inverse-Y-like darkening 6–1–7 propagated from the eruptive center to the south-western limb with a velocity of order 200 km/s. We interpret the phenomenon by some absorption of the solar disk emission in remnants of the filament erupted.

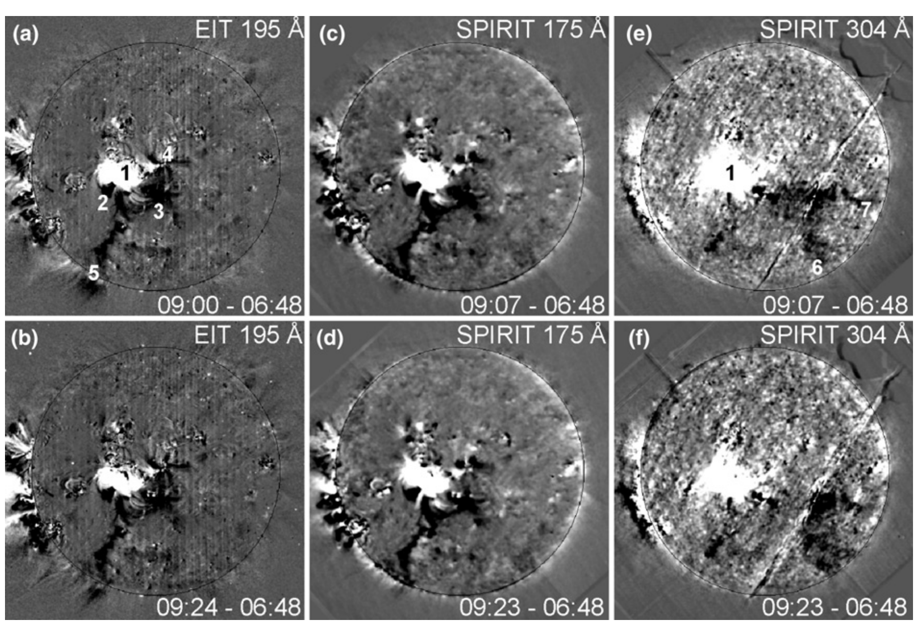

Fig. 3. Fixed-difference derotated CORONAS-F/SPIRIT images at 175 Å ((c),(d)) and 304 Å ((e),(f)) of November 18, 2003 event in comparison with SOHO/EIT images at 195 Å ((a),(b)).

5. Conclusion

Our analysis of CORONAS-F/SPIRIT data in combination with SOHO/EIT data confirms that in powerful events a CME process involves global magnetic structures over a considerable part of the solar disk. The spatial coincidence of the main dimmings in different-temperature lines hints at their relation to plasma outflow from partly or completely opened magnetic structures in the corona and transition region. For some dimmings whose appearance is dissimilar in different lines, CME-associated variations of the plasma temperature can play a role as well. In the event of November 18, a propagated CME-related absorbing feature was observed in SPIRIT images at 304 Å.

Many additional CORONAS-F/SPIRIT and SOHO/EIT images and movies related to CME-associated large-scale disturbances are presented at the Web sites: www.xras.lebedev.ru/, www.medoc-ias.u-psud.fr/operations/coronasdata.html, and www.helios.izmiran.troitsk.ru/lars/Chertok/.

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