TEMPORAL AND SPATIAL DYNAMICS OF CME-RELATED SOLAR STRUCTURES FROM EUV OBSERVATIONS WITH THE CORONAS-F/SPIRIT AND SOHO/EIT TELESCOPES

V. Slemzin*, S. Kuzin, S. Bogachev

*P.N. Lebedev Physical Institute, Lenisky pr., 53, Moscow, 119991, Russia, *Email: slem@mail1.lebedev.ru*

ABSTRACT

Temporal and spatial dynamics of CME-related dimmings has been studied using the observational data of the CORONAS-F/SPIRIT and SOHO/EIT telescopes. The SPIRIT data contain simultaneous pairs of full-disk solar images in the 175 and 304 Å bands (for some periods only in the 175 Å band), produced with a cadence of 15–30 min, in the same periods as regular 12 min EIT 195 Å images. Analysis of the powerful eruptive events of October 28 and November 17 - 18, 2003 has shown that the typical variation of intensity in the area of large-scale dimmings starts with brightening several hours before the eruption followed by slow decrease, fast decay to minimal value and gradual recovery. The fast decay in all remote dimming regions independently of their location coincides within the sampling accuracy with the LASCO projected CME onset time. Extended dimmings with the length up to 3.10^5 km develop with the propagation speed more than 400 km/s. We give possible explanation of the results.

1. INTRODUCTION

Both dimmings and coronal waves ("EIT waves") are suggestive large-scale phenomena associated with restructuring of the solar corona during the eruption process. It is well established that dimmings (or "transient coronal holes") are the signatures of material evacuation due to opening magnetic field lines (Hudson et al. 1996; Thomson et al. 1998). In order to identify the places of CME onset, dimmings were studied by many authors using Yohkoh/SXT and SOHO/EIT images (e.g. Zarro et al. 1999) as well as SOHO/CDS spectra (Harrison and Lyons 2000; Harrison et al. 2003). To the present, a full description of the eruption process as well as its unambiguous theoretical interpretation is still absent, so further study with higher spatial and temporal resolution is needed.

Since August 2001, two instruments – SPIRIT (**S**pectro-graphic **I**maging **R**öntgen spectrohel**I**ograph and **T**elescope) aboard the CORONAS-F (**C**omplex **OR**bital **O**bservatory for **N**ear Earth observations of **A**ctivity of the **S**un) satellite and EIT (Extreme Ultraviolet Imaging Telescope) aboard the SOHO simultaneously observe the Sun in similar EUV bands. A combination of the data of these instruments gives good opportunity to study highly dynamic eruptive phenomena with better temporal resolution (Slemzin et al., 2005a-b, Grechnev et al, 2005). Multi-wavelength morphologic analysis of dimmings using the SPIRIT and EIT data has been done for the eruptive events accompanied the Bastille-like flare of November 4, 2001 (Chertok et al. 2004) and the solar extreme events of October - November, 2003 (Slemzin et al. 2005a,b; Grechnev et al. 2005).

The task of the current study is to investigate the intensity variations in separated regions of large-scale dimmings appeared in the SPIRIT and EIT images during several powerful eruptive events of October - November 2003.

2. OBSERVATIONS

The SPIRIT complex aboard the CORONAS-F satellite (Zhitnik et al. 2002) incorporates two XUV-solar telescopes – one is a four-band Ritchey-Chretien EIT telescope (171, 195, 284 and 304 Å) with the optics similar to that of the EIT SOHO telescope, another – a Herschel-type two-band (175 and 304 Å) telescope with off-axis parabolic mirrors. The first one produces four images every 6 hour a day (like the EIT does), the second mostly operates in the synoptic mode with a cadence from 15 min to 1.5 hours. Now the SPIRIT archive of observational data contains more than 400000 images and spectra and has the total volume more than 130 Gigabytes. The SPIRIT data are available at the site: http://spirit.xras.lebedev.ru.

For the current study we selected powerful eruptive events occurred on October 28 and on November 17 - 18, 2003. The CME onset times were taken from LASCO CME catalog (Catholic University of America, http://lasco-www.nrl.navy.mil/lasco.html). In both cases dimmings spread over significant area near the center of the solar disk, consisting of many isolated regions. We analyzed intensity profiles in the dimming regions using the SPIRIT and EIT images with compensation of the solar rotation. In order to avoid too large distortions between the structures with different heights typically seen in the EUV band (Sterling and Moore 2004), the periods of such compensation were taken no more than one day (both before and after the event).

3. DATA PROCESSING

Dimmings are known as rather stable features existing for many hours after sudden intensity decrease related to eruption. They can be better revealed using the "base difference" images, in which the same reference image taken before the event subtracted from other images. Using of "running difference images" is not effective for dimmings because this method shows only variations between two neighboring images (like a derivative of a function), whereas dimmings are developing during several hours.

To study dimmings, the processing of the SPIRIT and EIT images includes the following operations:

- Pre-processing, scaling to the same solar radius and normalizing the intensity to compensate variations due to sensitivity and exposure time.
- Selection of reference image (as a rule, one hour before the event time) and dimming image after the event (one hour later), when the dimming is fully displayed. Creation of data cube of base difference images.
- Primary selection of the dimming regions by the method of minimal and maximal pixel maps (Podladchikova and Bergmans 2005).The maximal pixel map contains all pixels below $(-s)$ value, where s is a standard deviation of intensity over the dimming difference image. The minimal pixel map is constructed by selecting the 1% darkest pixels from the difference image. Then we select the isolated regions from primary pixel map having common intersection points with minimal pixel map (region growing principle), label them and sort in accordance with their contribution to the total dimming intensity.
- Creation of the difference intensity profiles for each isolated dimming region by integration of intensity in consequent difference images over the area of this region.
- Selection of the regions most probably belonging to the same event. At first, we calculate the Pearson correlation coefficients *Cp* for the profile of each region and the profile of the main region (with the largest contribution to the total dimming intensity). Then we select regions with *Cp* > 0.5. According to the *t*-test, the confidence level for such selection is more than 0.95, if the number of sampling points is more than 15.
- Creation of relative difference profiles for finally selected dimming regions by division of their intensities on the intensities in the reference image integrated over the same regions.
- Creation of the total dimming intensity profile over the full dimming area relative to the total intensity of the whole reference image. In the case of several wavelengths the integration area corresponds to the intersection of corresponding dimming areas.

4. EVENT OF OCTOBER 28, 2003

On October 28, 2003 the most powerful halo CME (v = 2460 km/s) originated in the vicinity of AR 0486 with the projected LASCO onset time (LOT) 11:01:36 UT. Fig. 1a and b display the data for SPIRIT 175 Å. The dimming map superimposed on the difference image (11:59:37–10:26:13 UT) is shown in fig. 1a, in which blue contours correspond to the dimming regions with *Cp* >0.5, green contours – to the regions with C_p < 0.5. Relative difference profiles for the main dimming region #1, for one of the regions with high correlation (#2) and with low correlation (#5) are shown in fig. 1b. The total dimming intensity profiles for both 175 and 195 Å are presented in fig. 1c.

The total intensity in the dimming area started to increase at 08:00 UT, reaching the maximum at ~ 09:30 UT and then slowly decreased till the time of fast decay. Comparison with corresponding GOES 1-8 Å light curve (fig. 1d) shows that the initial brightening in the dimming area occurs ahead of growing of hot flare loops and possibly reflects a specific behavior of the middle temperature (~ 1MK) solar structures before eruption.

The fast decay of intensity in all correlated dimming regions started at ~11:00 UT and well agreed with the LOT. Then, intensity reached the minimum at 12:00-12:30 UT and partially recovered in the next 3-4 hours. The graph in fig. 2 shows the Pearson correlation coefficients for all dimming regions calculated from the difference profiles from the beginning to the LOT (red) and after the LOT to the end of the data set (blue). In the most cases after eruption corresponding correlation coefficients became sufficiently lower or even changed the sign. It suggests that initially the dimming regions had some interconnections which sufficiently decreased or were completely lost as a result of eruption.

The EIT 195 Å profiles are similar to that of 175 Å, except fast growing of the intensities in 195 Å images after 13:00 UT due to the streaks of solar energetic particles (fig. 1c). The SPIRIT images are less suffered from this effect because most of the particles are deflected by the magnetosphere of the Earth before reaching the CORONAS-F orbit.

5. EVENT OF NOVEMBER 17, 2003

During November 17-18, 2003 SPIRIT observed the Sun in both 175 and 304 Å bands together with EIT 195 Å. Dimmings arose twice in the vicinity of AR 0501 with the LASCO CME onset times: November 17, 09:02:57 UT and November 18, 08:05:55 UT. Dimming maps in all wavelengths were built from difference

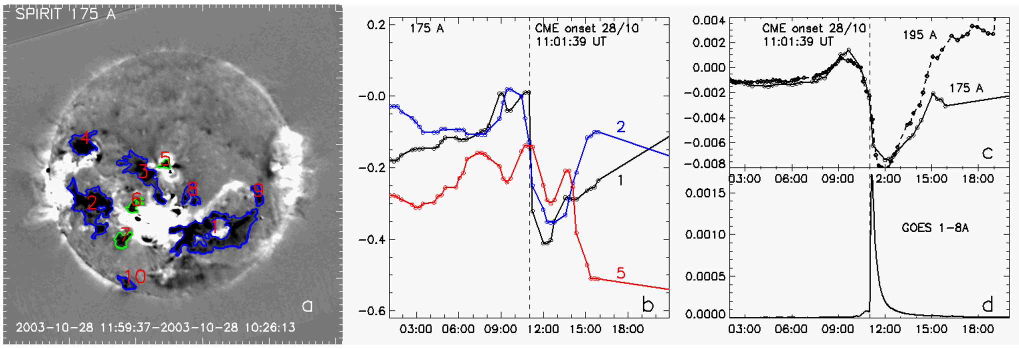


Figure1. SPIRIT 175 Å data for the event of 28/10-2003, 11:01:39 UT: (a) - dimming map; (b) - intensity profiles for regions 2 (high correlation with region 1) and 5 (low correlation); (c) – total intensities in the 175-195 intersection dimming area divided to the total intensities in the corresponding reference images; (d) – GOES 1-8 Å light curve.

.

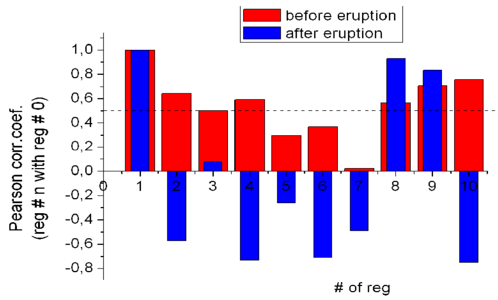
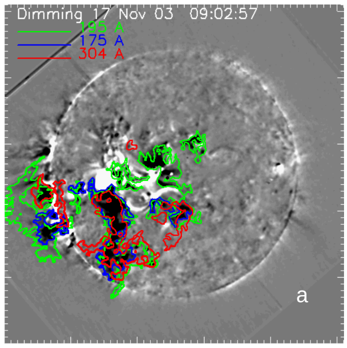


Figure 2. Pearson correlation coefficients for the dimming regions marked in the map of fig. 1: red bars – before the LOT, blue bars – after the LOT.



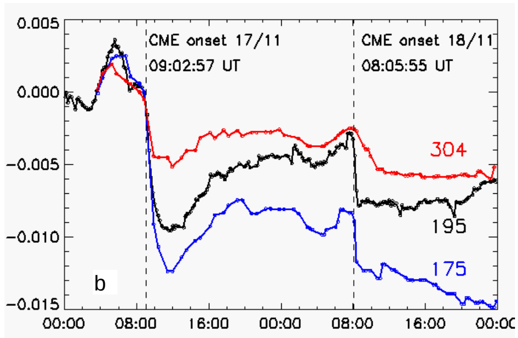


Figure 3: (a) – The dimming map for the event of November 17, 09:02:57 UT in the 175, 304 and 195 Å; (b) – total dimming profiles for the same wavelengths taken over common intersection mask.

images: 11:26-08:50 UT (SPIRIT 175 and 304 Å), 11:22-08:46 UT (EIT 195 Å). Fig. 3a shows the contours of correlated dimming regions: red in 304 Å, blue in 175 Å and green in 195 Å, superimposed on the difference image in 175 Å. These dimmings do not fully coincide, but have common intersection parts.

Fig. 3b shows a comparison of total intensity profiles for different wavelengths in the common dimming intersection area. In all wavelengths the brightening started at 03:00UT, the fast decay – near 09:00 UT, which well coincides with the LOT for the first CME event. After partial recovery, a day later, at November18, 08:05:55 UT intensity in the same area dropped once more at ~ 08:00 UT, which is close to the LOT 08:05:57 UT of the second CME. Intensity in 304 Å in the second case decreased more gradually and with some delay in comparison with variations in 175 and 195 Å.

To study the dimming propagation process we took the profiles in several boxes of the same size as in the previous case along the most extended region #1 in the 195 Å difference image (fig. 4). The time derivatives of the difference profiles for the boxes #1-6 are well coincide independently on their locations at the dimming area. Intensity in the box #7 delays in all points with respect to others, possibly designating, that this region of the dimming is originated in some secondary process relative to the main dimming part. Taking into account the distance between the boxes #1 and #6 of ~3.10^5 km and the sampling interval of 12 min, we can conclude that possible lower limit of the propagation speed for this case is ~ 400 km/s.

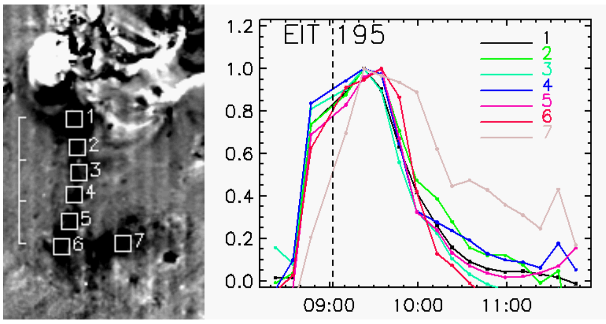


Figure 4. Left panel: a map of sampling boxes at the 195 Å dimming. Scale: one tick corresponds to $1 \cdot 10^5$ km. Right panel: time derivatives of the box profiles divided to their maximal value (the sign is changed to positive). Dotted line shows the LOT 08:05:57 UT.

6. CONCLUSIONS

§ The intensity profiles of different dimming regions in 175 and 195 Å show similar behavior. In the event of October 28 both profiles are coincide, in the events of November 17 - 18 the intensity minimum in 175 is deeper. The profiles in transition region 304 Å coincide or delay in time with respect to those in the coronal lines and have lesser depth.

§ In all cases under study a typical development of the total intensity in the dimming area passes several stages: initial brightening and slow decrease during 3-6 hours before the LOT, fast decay ±0.5 h around the LOT, gradual decrease to the minimum - (1-3 hours, in some cases – more than 12 h after the LOT), and partial recovery during 4 - 14 hours after the LOT, never reaching the initial level before the eruption.

§ The fast decay stage in the coronal lines coincides with the projected LASCO CME onset time with a sampling accuracy (12-15 min) in all remote dimming regions independently on their location.

§ Extended dimmings develop with the propagation speed more than 400 km/s in all parts except extreme peripheral points.

§ The regions probably belonging to the same event show similar behavior and high mutual correlation before the event. In most cases this correlation decreases after the event or even changes the sign. Pearson correlation coefficients may be used for selection of such regions if the number of the data points is sufficient.

§ Intensity correlations and coincidence of fast decay times for remote dimming regions suggests an idea that these regions were previously interconnected and linked with some "eruption center" high in the corona with near the same distances from each of them. Such connections may be associated with trans-equatorial loop system disappearing during eruption (Delannée and Aulanier 1999, Khan and Hudson 2000, Glover et al. 2003, Pohjolainen et al. 2005).

SOHO is a project of international cooperation between ESA and NASA.

This work was partly supported by Russian Foundation for Basic Research, project # 05-02-17415.

7. REFERENCES

Chertok I. M. et al. *Analysis of a Solar Eruptive Event on November 4, 2001 Using CORONAS-F/SPIRIT Data*, Astronomy Reports, 48, No. 5, 407–410, 2004.

Delannée C. and Aulanier G. *CME associated with transequatorial loops and a bald patch flare*, Sol. Phys., 190, 107–129, 1999.

Glover A. et al. *The association of transequatorial loops in the solar corona with coronal mass ejection onset*, A&A, 400, 759–767, 2003.

Grechnev V. V. et al. *CORONAS-F/SPIRIT EUV observations of October–November 2003 solar eruptive events in combination with SOHO/EIT data,*, JGR, 2005 (in press).

Harrison R.A. and Lyons M. *A spectroscopic study of coronal dimming associated with a coronal mass ejection*, A&A, 358, 1097–1108, 2000.

Harrison R. A. et al. *Coronal dimming and the coronal mass ejection onset*, A&A 400, 1071–1083, 2003.

Hudson H. S. et al. *Coronal X-ray Dimming in Two Limb Flares*, ASP Conf. Ser., 111, 379-382, 1996.

Khan, J. I. and Hudson, H. S. *Homologous sudden disappearances of transequatorial interconnecting loops in the solar corona*, GRL, v. 27 (8), 1083-1086, 2000.

Pohjolainen S. et al. *Early signatures of large-scale field line opening*, A&A, 434, 329–341, 2005.

Podladchikova O.and Bergmans D. *Automated detection of EIT waves and dimmings*, Solar Phys., 228, 1, 267-286, 2005.

Slemzin V. A. et al. *EUV observations of CME-associated eruptive phenomena with the CORONAS-F/SPIRIT telescope/spectroheliograph*, Proc. IAUS 226, 21-26, 2005b.

Slemzin V.A. et al. Results of observations of solar EUV radiation with the CORONAS-F/SPIRIT and SOHO/EIT telescopes. Solar System Reports, 2005c (in press).

C. Sterling A. C. and Ronald L. Moore R.L. External and internal reconnection in two filament-carrying *magnetic cavity solar eruptions*, ApJ, 613, 221–1232, 2004.

Thomson B. J. et al. *SOHO/EIT observations of an Earth-directed coronal mass ejection on May 12, 1997*, GRL, 25 (14), 2465-2468, 1998.

Zarro D.M. et al. *SOHO EIT observations of* extreme-ultraviolet "dimming" associated with a halo coronal mass ejection, ApJ, 520,L139–L142, 1999.

Zhitnik I. et al. SPIRIT X-ray telescope/spectroheliometer results, ESA SP-506, v. 2, p. 915 – 918, 2002.