

EUV observations of CME-associated eruptive phenomena with the CORONAS-F/SPIRIT telescope/spectroheliograph

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Abstract. A multi-channel SPIRIT telescope/spectroheliograph aboard the CORONAS-F satellite operating in soft X-ray and EUV ranges ($T \sim 0.05\text{--}15$ MK) is an effective instrument for complex studies of CME-associated phenomena such as eruptive filaments, dimmings, coronal waves, posteruptive arcades, etc. In particular, SRIRIT observations of high-temperature ($T = 5\text{--}15$ MK) plasma structures in the MgXII 8.42 Å line show specific pre-CME sigmoid magnetic field configurations. Eruptions of filaments (prominences) and dimmings in a CME process are seen with a high contrast in the coronal 175 Å band (FeIX–XI) and the transition-region 304 Å (HeII) images. Our results are illustrated by several powerful eruptive events of the current solar cycle. We compare SPIRIT data with observations at other spaceborne and ground-based instruments (SOHO/EIT, *Yohkoh*/SXT, and $H\alpha$ images, etc.)

Keywords. Sun: corona, Sun: coronal mass ejections (CMEs), Sun: X-rays, gamma rays

1. Introduction

CMEs are complex phenomena associated with filament eruptions and solar flares. They show a variety of kinematic and thermal transformations in the solar plasmas (Zhang et al. 2001; Moon et al. 2002; Feynman & Ruzmaikin 2004). A pre-flare situation is often hinted by the presence of a sigmoidal loop system seen in hot ion lines of $T \sim 2\text{--}8$ MK (Gibson et al. 2002; DelZanna et al. 2002). To understand the origin and drivers of CMEs, important is to study the initial phase of the heating and acceleration of the erupting matter in the transition region and the corona at altitudes of several tenths R_{\odot} , where it can be observed better in the EUV spectral range. Disappearance of a filament visible in the chromospheric $H\alpha$ images is often followed by its appearance in transition-region lines and, in some cases, in coronal lines later on. This stage of the CME process is not well studied so far, because necessary observations with sufficient time resolution simultaneously in several spectral lines usually are not available.

The SPIRIT experiment carried out aboard the CORONAS-F spacecraft since August 2001 (Zhitnik et al. 2002) provides synchronous observations of the whole Sun in several spectral bands (in particular, the transition-region band of 304 Å and coronal bands of 175 Å and 8.42 Å) covering the temperature range from 0.05 to 15 MK. Here we present some examples of SPIRIT observations of CME-related phenomena around the 23rd

solar maximum and compare it with observations at other spaceborne and ground-based instruments (SOHO/EIT, *Yohkoh*/SXT, $H\alpha$, etc.)

2. SPIRIT observations and their comparison with data from other instruments

The SPIRIT performs routine observations with an interval of 15 min during 45-min non-occulted period of the 93.5 min orbit. The observations are conducted simultaneously in two bands of the transition-region line 304 Å (HeII, $T \sim 0.05\text{--}0.08$ MK) and the coronal line 175 Å (FeIX–XI, $T \sim 0.9\text{--}1.2$ MK) with an exposure time of 2–9 s. In comparison with the SOHO/EIT FeXII 195 Å line, the 175 Å band contains cooler lines of FeIX–XI with lesser dynamic range from the quiet Sun to flares. EIT images produced in 195 Å line are often overexposed during flares and contaminated with strong scattered light, thus preventing observations of any features in the flaring region. By contrast, SPIRIT images remain clear.

The images in the MgXII 8.42 Å line ($T \sim 5\text{--}15$ MK) are produced, as a rule, with an exposure time of 37 s and with an interval of 3–20 min. These images revealed hot coronal features with a typical peak temperature of ~ 10 MK and $\log N_e \sim 9\text{--}10$ (Zhitnik *et al.* 2003). They do not always coincide with active regions and significantly differ from lower-temperature (1–2 MK) structures seen in EUV coronal lines, such as 175 or 195 Å. These structures are often localized at very high altitudes of 0.1–0.3 R_\odot above the solar limb and live from minutes to days. They show fast spatial variability and have a contrast of more than two orders of magnitude.

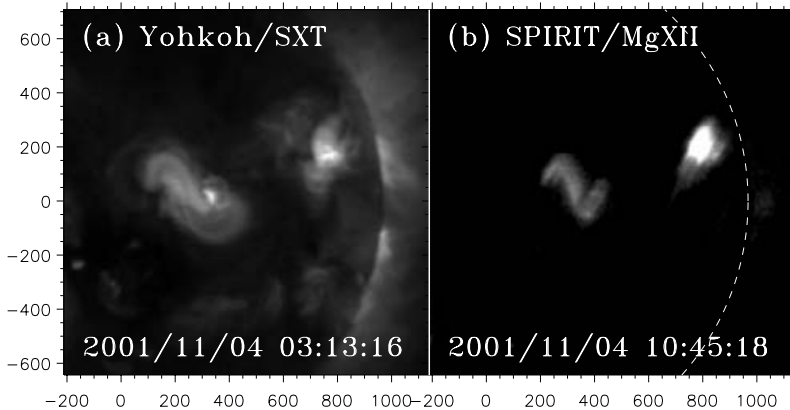


Figure 1. A ‘sigmoid’ in the flaring active region observed with *Yohkoh*/SXT and CORONAS-F/SPIRIT in MgXII line on November 4, 2001. White dashed line shows solar limb. Axes show arc seconds from solar disk center.

3. SPIRIT observations of CME-related phenomena

3.1. Pre-event ‘sigmoids’ in MgXII images

‘Sigmoids’ are believed to represent a highly sheared magnetic configuration overlying an extended filament channel (Glover *et al.* 2001) and to indicate a high probability of an eruption (Hudson *et al.* 1998). Sigmoids are clearly seen in soft X-rays, but poorly detectable in lower-temperature EUV emissions (Sterling *et al.* 2000). SPIRIT MgXII channel due to its high sensitivity to radiation of hot plasmas shows sigmoids with even

better contrast than *Yohkoh/SXT*, indicating that the temperature of high pre-flare loops can exceed 5 MK. Fig. 1 shows a comparison of *Yohkoh/SXT* and SPIRIT/MgXII images for a powerful solar eruptive event of November 4, 2001 (Chertok et al. 2004). A sigmoid in AR 9684 preceded an X1.0 flare occurred at 16:03 UT and a fast ($V \sim 1800$ km/s) halo CME at 16:35 UT. After the flare and CME, the loop structure transformed into a posteruptive arcade extending over 300 000 km for more than one day.

3.2. Posteruptive dimmings in SPIRIT 175 Å and 304 Å lines

Coronal ('EIT') waves and dimmings are regarded as the most reliable signatures of a CME (see, e.g., Zhukov & Auchère, 2004). Most often the coronal wave appears after a CME as a propagating bright front seen in coronal lines (e.g., EIT 195 Å line). Behind the wave, a dimming appears as temporary, localized depletion of EUV radiation: some of them are deep and compact, other are shallower, but more extended, being directed to neighboring active regions. Possibly, some of extended dimmings are associated with large transequatorial loops (Farnik et al. 2001; Glover et al. 2003).

SPIRIT observations show many examples of coronal waves and a variety of dimmings, in particular, observed during the period of solar extreme events of October–November 2003 (Slemzin et al. 2004). Coronal waves were observed on October 26 and November 18 by the SPIRIT in 175 Å and by the EIT in 195 Å. Dimmings observed for most powerful events of that period had very large scale to cover the hemisphere and showed conspicuous homology for many days, which suggests stability of the large-scale magnetic structure.

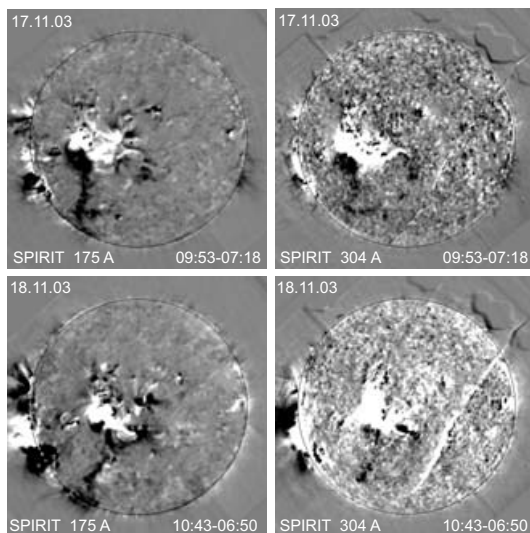


Figure 2. Structure of dimmings in CME events of November 17 and 18, 2003 in SPIRIT 175 Å and 304 Å channels

Fig. 2 shows a comparison of dimming structures observed on November 17 and 18, 2003 in the SPIRIT 175 and 304 Å bands. It is clearly seen that the main dimmings are located near the eruptive center, the most intense of them is directed to the boundary of the southern polar coronal hole. The dimmings in both 175 and 304 Å bands for two days are similar, but not fully coincide. A detailed analysis shows that they originated at the places of previous bright loop structures seen in the 175 Å band before the events. The dimmings in the transition-region HeII 304 Å line are similar in shape, but not coincide with those in 175 Å. As a rule, 304 Å band dimmings have lesser depth and sometimes appear with significant delay of several tens minutes with respect to coronal

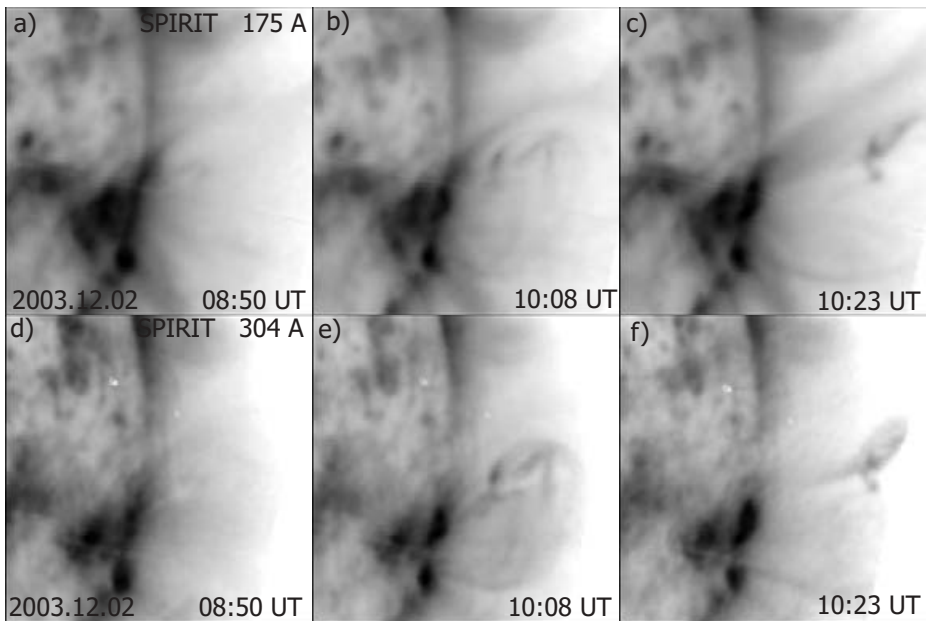


Figure 3. An eruptive event of December 2, 2003 in SPIRIT 175 Å (a-c) and 304 Å (d-f) bands (negative).

ones (Chertok et al. 2004). This probably suggests the development of the dimming from the higher coronal layers downward, up to the transition region.

3.3. Eruptions of filaments and prominences

Observations of filament (or prominence) eruptions are important to study the processes of CME formation and acceleration of eruptive mass. The temporal and spatial evolution of prominences is governed by dynamics of the magnetic field structure, but the trigger mechanism of eruption is still not well established (Schmieder et al. 2000, Marque et al. 2002). Simultaneous SPIRIT observations in 304 Å and 175 Å bands, due to their complementary temperature sensitivity ranges, are suitable to study plasmas in erupting structures at the initial stage of the CME launch.

We present two observations of eruptive events. In the first case, a fast ejection was observed after a prominence eruption on December 2, 2003 (fig. 3; Delaboudinière et al. 2005). A quiescent filament was observed during several days in $H\alpha$, 304 Å band, and 175 & 195 Å coronal lines before the eruption, which occurred on December 2 at 10:15 UT. It produced a large CME with a speed of ~ 1300 km/s. The eruptive prominence was observed first with Pic du Midi coronagraph in $H\alpha$, then with EIT at 195 Å and SPIRIT at 304 & 175 Å (fig. 3). The prominence becomes bright in both 175 and 195 Å images, which implies its heating in the course of the eruption.

Another eruptive event was observed on June 8, 2004 during early Venus transit across the Sun (fig. 4). A large prominence slowly ascended ($V \sim 55$ km/s) above the eastern limb for 40 min of observations. It was much brighter in 304 Å line, than in the coronal 175 Å line; hence, it was rather cold. It left the field of view of the SPIRIT at 05:41 UT at a height of $0.27 R_{\odot}$, and the frontal structure of the corresponding CME appeared in LASCO/C2 image at 06:26 UT at $1.86 R_{\odot}$. LASCO has not registered this event, because there were no subsequent C2/C3 observations during several hours.

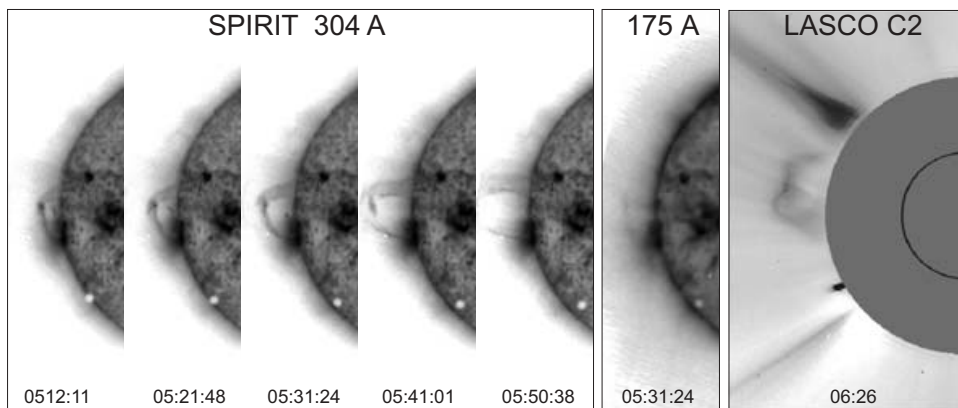


Figure 4. Eruption of a cold prominence during the Venus transit on June 8, 2004 (negative).

4. Conclusions

A multi-channel SPIRIT telescope/spectroheliograph operating aboard the CORONAS-F satellite allows studying various CME-associated phenomena in wide temperature range of 0.05–15 MK. The SPIRIT is able to record images in several spectral bands simultaneously with high cadence that is important to study dynamics of eruptive processes.

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Discussion

KAHLER: What is the time cadence of the SPIRIT images?

SLEMZIN: we have synoptic observations in several wavelengths at least once per 1.5h orbit for 15 orbits a day. For some periods we take simultaneous images in 175 Å/304 Å bands with a 15 min cadence during 45 min interval interrupted by 47-48 min occultations. We also participate in the "EIT Shutter-less" or "High cadence" program, when observations are done with a cadence less than 1 min.

P.F. CHEN: Are the data available online?

SLEMZIN: We can provide on request. Some data can be found in MEDOC. Solar data center (France), <http://www.medoc.ias.u-psud.fr>.