PRELIMINARY ANALYSIS OF A CME OBSERVED BY SOHO AND ULYSSES EXPERIMENTS

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ABSTRACT

Over the last week of November 2002 SOHO/LASCO observed several Coronal Mass Ejections, most of which occurring in the NW quadrant. At that time SOHO/UVCS was involved in a SOHO-Sun-Ulysses quadrature campaign, making observations off the west limb of the Sun, at a northern latitude of 27°. Here we focus on data taken at 1.7 solar radii, over a time interval of ≈ 7 hours, on 26/27 November, 2002, when a large streamer disruption was imaged by LASCO C2 and C3 coronagraphs. UVCS spectra revealed the presence of lines from both high and low ionization ions, such as C III, O VI, Si VIII, IX and XII, Fe X and XVIII, which brighten at different times, with a different time scale and at different positions and are apparently related to different phenomena. In particular, the intensity increase and fast disappearance of the C III 977 Å line represents the passage through the UVCS slit of cold material released in a jet imaged by EIT in the He II 304 Å line. The persistent presence of the Fe XVIII 974 Å line is not easily related to any special feature crossing the UVCS slit. We suggest to interpret this behavior in terms of the reconnection events which lead to the formation of loops observed in the EIT He II 304Å line.

Key words: CMEs; UV spectroscopy.

1. INTRODUCTION.

SOHO EIT and LASCO images of the solar corona, complemented by spectroscopic data from CDS, SUMER and UVCS, have provided a comprehensive view of Coronal Mass Ejections (CMEs), which, however, are still far from being completely understood. In particular, UVCS has observed more than two hundred CMEs, with different characteristics. During CMEs, most of the times UVCS detected low temperature lines (see [1], [2], [3], [4]): lines from ions forming at high temperatures ($T \geq 5 \times 10^6$ K) being only sporadically observed (see [5]). Hot material might originate either as cool prominence plasma rapidly heated to high temperatures, or as hot active region material. *In situ* observations by ACE revealed high Fe charge state to be associated with interplanetary CMEs (see [6]). It is crucial to ascertain the origin of this hot plasma which (see [5]) may be the signature of current sheets developing during reconnection processes following the CME event.
In this work we analyse CME data acquired during the SOHO-Sun-Ulysses quadrature (see [7], [8]) of November 2002, with the purpose of providing further information on this issue. To this end we examine UVCS spectra that cover a broad range of lines, from the cool C III ($T \approx 8 \times 10^4$ K) to the hot Fe XVIII ($T \approx 6 \times 10^6$ K) ions, and try to interpret their behavior in the framework of the CME event. In the next section we describe the CME scenario of 26/27 November 2002, on the basis of EIT and LASCO images. Section 3 describes the UVCS data and give a semi-qualitative interpretation of UVCS observations. A short discussion of our results concludes the paper.

2. CORONAL MORPHOLOGY.

In this section we give a description of the coronal morphology on November 26 – 27, 2002, during our UVCS observations, from other experiments. Because the UVCS slit was set at a latitude of 27° N, we concentrate only on the North-West quadrant.

2.1. SOHO/LASCO observations.

At the time of UVCS observations, LASCO movies show the presence of two coronal streamers at a latitude, respectively, of ≈ 10° N (hereafter streamer 1) and ≈ 50° N (hereafter streamer 2). Starting from about 15:30 UT on November 26, a fairly slow, wide and bright loop front moves outwards and disrupts the equatorial streamer 1 (see Fig.1). Meanwhile streamer 2 shows an intense activity with many jets

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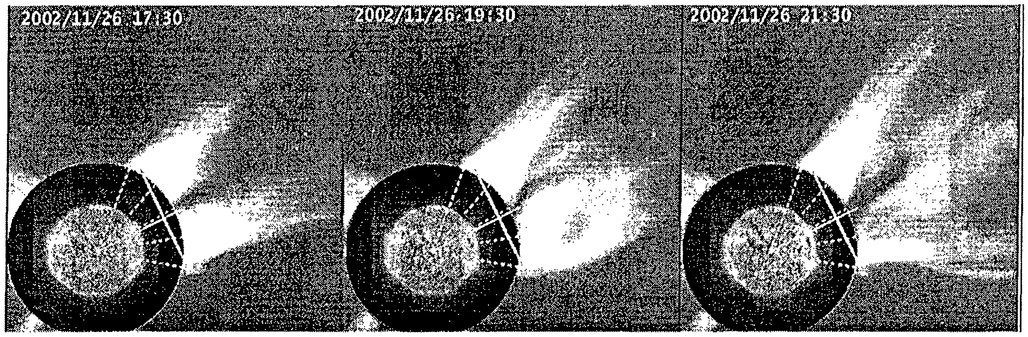

Figure 1. A panel showing the white-light coronal activity in the North-West quadrant over the 17:30 – 21:30 time interval on November 26, 2002, as seen by LASCO C2 coronagraph and the EIT 304 Å images for the solar disk scaled to the LASCO images. In the figure we plot the position of the UVCS slit, the radial through the slit (solid line) and the radials at a latitude of 10° *S*, 10° *N*, 30° *N*, 50° *N and* 70° *N (dotted lines).*

and prolonged outflows in the radial direction, possibly linked to the CME observed in streamer 1.
From LASCO movie we evaluate a radial velocity of the plasma, at the center of the bright loop, of about 120 Km/s. In order to evaluate plasma motion along the line of sight (LOS) direction we compute for the strongest lines detected by UVCS (*i.e.* the O VI and Si XII doublets and the Fe XVIII line) the first momentum $\lambda_0 = \int \lambda I(\lambda) d\lambda / \int I(\lambda) d\lambda$ (where $I(\lambda)$ is the intensity line profile and the integrals are made over the line spectral ranges) and look for any λ_0 Doppler shift. However, within our spectral resolution (see section 3), we find no evidence for plasma motion along the LOS. We conclude that plasma motion occurs principally in the plane of the sky.

2.2. SOHO/EIT and MSO observations.

EIT He II 304 Å images show in the NW quadrant two active regions (USAF/NOAA 10197 and 10199; hereafter ARs) close to the limb of the Sun at a latitude respectively of 25° N and 28° N (data from the Mees Solar Observatory); their position (see Fig.1) matches the Southward edge of streamer 2. The He II 304 Å images reveal a very complicate loop configuration, with plasma flowing along the AR field lines and many plasma jets not directly related with the loop activity. In particular from 18:30 to 20:30 UT on November 26 a big jet extends beyond the limb of the Sun from a latitude of ~ 30° at an angle of about 20° with respect to the radial. This jet reaches the altitude of 1.7 $R_\odot$ at ~ 20:00 UT and we expect UVCS to sample this feature. This event is not related in time with the CME which seems to originate (three hours earlier) in the area of the erupting loops that overlie the most equatorial AR.

2.3. Ulysses observations.

In November/December 2002 Ulysses was at a distance of 4.3 AU. Using a constant velocity approximation we traced back the *in situ* events observed by Ulysses on December 2002 to the corresponding solar events. The 26 – 27 November 2002 CME that we are studying shows up as an higher proton velocity (which raises from about 400 to 470 Km/s) and rapid variations of plasma composition (ratios C6/C5, O7/O6 and Fe/O). Space limitations do not allow us an extensive description of *in situ* data; this will be done in a future paper.

3. UVCS OBSERVATIONS.

In this work we report on UVCS (Ultra Violet Coronograph Spectrometer) observations taken from 2002 November 26, 18:39 UT to November 27, 3:03 UT. The UVCS slit was set at a latitude of 27° N at an altitude of 1.7 $R_\odot$; the slit width was 100 μm. Our spectra cover a wavelength range that includes the O VI 1031.91 Å – 1037.61 Å, the Si XII 520.67 Å – 499.37 Å and the Si VIII 949.35 Å – 944.47 Å doublets and the Si IX 950.15 Å, the H $Ly\beta$ 1025.67 Å and $Ly\gamma$ 972.54 Å, the Fe X 1028.06 Å, Fe XVIII 974.86 Å, C III 977.02 Å and Ca XIV 943.61 Å lines. Data have a spectral binning of 0.1986 Å$/bin$ and a spatial resolution along the UVCS slit of 42 $arcsec/bin$. In order to derive the line intensities we summed over the line profile and subtracted an average background evaluated over a spectral interval near the line.
Each exposure time is 120 s: for the most intense lines such as the O VI or the Si XII doublets we averaged over two exposures, while for less intense lines from ions such as Ca XIV or Si IX we averaged over four exposures and three spatial bins. Two dimensional plots of the intensity evolution with time and along the UVCS slit have been made for both high and low temperature lines. Because each spectral line intensity shows a specific behaviour, we give now a brief description of the behaviour of lines from ions with different temperature of maximum formation.

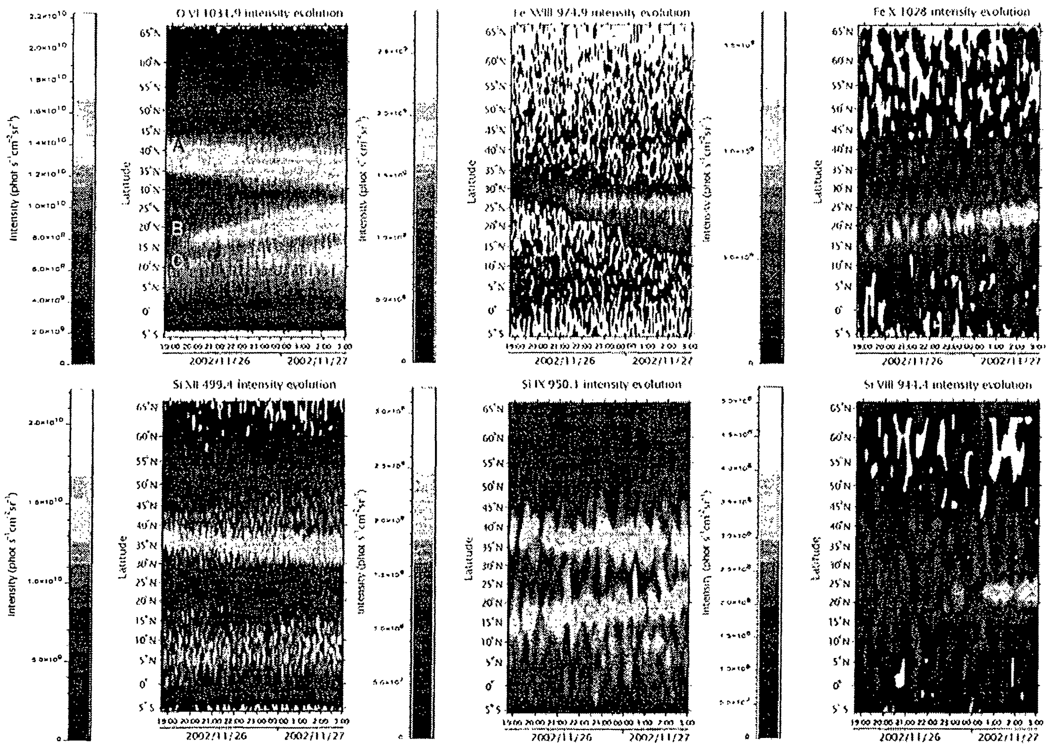

Figure 2. Intensity evolution along the UVCS slit for lines from ions with different temperature of maximum formation T_{max}. Top panels (from left to right): O VI *1031.91 Å, Fe* XVIII *974.86 Å, Fe* X *1028.06 Å. Bottom panels (from left to right): Si* XII *499.37 Å, Si* IX *950.15 Å, Si* VIII *944.47 Å. Features A, B and C (see text) are identified in the first panel of the top row.*

3.1. The O VI doublet lines.

In the O VI doublet lines ($\log T_{max} = 5.5$) we can identify three features (dubbed A, B and C, see Fig.2), along which the O VI intensity maximizes.
The most intense feature A is also the most stable with time: in the 7 hours and 44 minutes of observations its peak intensity doesn't show any variation with time and the peak position along the slit moves slowly equatorward only by 1 bin (*i.e.* 42 *arcsec*). The feature A position at a latitude of $\sim 37° N$ corresponds in the LASCO images to the southward edge of the streamer 2, the most stable with time. Starting at about 19:40 UT we can identify two additional features (see Fig.2) at a latitude of $17° N$ (feature B) and $12° N$ (feature C) both about 40 % less intense than the principal component A. If we compare the position of these features with the LASCO images, we associate B with the Southern part of the wide bright CME ejected from streamer 1, while feature C can be associated with the Northern edge of the surviving section of streamer 1. In the successive exposures B moves Northward and after 6 hours and 40 minutes the peak is shifted by 6°, while its intensity increases continuously being at the end of our observations about 70 % most intense than the feature A. On the contrary C doesn't change position along the slit and increases only by about 20 %.

3.2. The Si XII, Si IX and Si VIII lines.

The Si XII, Si IX and Si VIII ions have a temperature of maximum formation respectively of $\log T_{max} =$ 6.3, 6.0 and 5.9. Depending on the temperature of A, B and C, these lines may or may not show up in these features. Feature A is not emitting in the Si VIII line ($8.10 \cdot 10^7$ $phot/cm^2\, s\, sr$, averaging over all the exposures), while the Si IX and Si XII lines have an average emission respectively of $2.21 \cdot 10^8$ and $1.48 \cdot 10^{10}$ $phot/cm^2\, s\, sr$. The ratio between these intensities is independent of the elemental abundance and emission measure and allows us to evaluate the temperature of plasma, assuming ionization equilibrium (in this work we use emissivities predicted by the CHIANTI 4.02 code). Averaging data in Fig.2 along the UVCS slit over each feature and over time we get the temperatures of A, B and C (see Table 1): we observe a small difference in temperature between B (which seems to cool down) and the other two features A and B whose temperature seems to keep constant with time. Moreover we notice that, while the three features have very similar temperatures, their line intensities are very different: this may be ascribed to a difference in electron density N_e between A, B and C. To support quantitatively this conclusion we used the technique described in [9] to made an evaluation for plasma density in the

Feature A		Feature B		Feature C	
$\log T$	N_e	$\log T$	N_e	$\log T$	N_e
6.21	5.62	6.17	4.87	6.19	7.10
6.21	7.10	6.15	4.62	6.19	7.88
6.24	7.51	6.12	4.34	6.21	7.33

Table 1. Average values for $\log T$ and N_e ($10^7\,cm^{-3}$) in feature A, B and C (see text) between 18:39 – 21:33 (top), 21:33 – 00:26 and 00:26 – 03:03 UT.

three features (see Tab.1). This method is valid in case the plasma is stationary: in our case this approximation seems to be valid because of the high ratio of the 1032/1037 line intensity (R $\approx$ 3), which is indicative of very modest, if any, outflows.

3.3. The Fe X and Fe XVIII lines.

From the Fe X and Fe XVIII panels of Fig.2 we see that, while the intensity of the cool Fe X 1028 Å ($\log T_{max} = 6.0$) follows very well the pattern observed in O VI for feature B, the hotter Fe XVIII line intensity ($\log T_{max} = 6.8$) seems to be independent of any of these features. In particular the peak intensity of this line shifts by about 6° Southward (that is in the opposite direction than B) and increases by a factor 3.4. The emission of this line is concentrated between a latitude of $\sim 20^\circ N$ and $\sim 30^\circ N$ and is located at the Northern edge of the streamer blowout (see Fig.1). Because data don't show lines from other Fe ions and because Fe X and Fe XVIII form at very different temperatures, we can't apply the ratio technique for temperature evaluation. Therefore we can only make a qualitative discussion: where the Fe XVIII emission is highest there is no emission from Fe X 1028 Å while the Fe XV 481.45 Å line intensity ($\log T_{max} = 6.3$) is not greater than $\sim 5.0 \cdot 10^7$ $phot/cm^2\,s\,sr$. We conclude that $\log T \geq 6.8$.
A hight emission, decreasing with time, in the Fe XVIII line was also observed by [5], and interpreted in terms of a post – CME current sheet. In our data we observe the opposite behaviour because the Fe XVIII intensity increases over the time interval we examine. This behavior is puzzling: the Fe XVIII emission can be indicative of a current sheet because a post CME arcade can be seen in EIT observations from about 17:00 UT onwards in a position consistent with UVCS Fe XVIII observations. In this case, however, we need also to explain what causes an energy release which increases with time. This issue will be thoroughly investigated in a future work.

3.4. Lines from "cool" ions.

As we anticipated in section 2.2, UVCS samples a plasma jet clearly identifiable in the $Ly\beta$, $Ly\gamma$ and C III line intensities evolution with time. Over a time interval of only 26 minutes and over an area of 4′ 12″ along the UVCS slit the C III line brightens reaching a peak intensity of $1.35 \cdot 10^{10}$ $phot/cm^2\,s\,sr$ and later disappearing. The $Ly\beta$ and $Ly\gamma$ mimic the behavior of the C III line. The position and timing when this cold material appears in the UVCS slit match the position and time when the jet described in 2.2 and observed by EIT should reach the 1.7 radii level, thus confirming that what we are sampling is plasma at low temperature ($T \approx 8 \times 10^4$ K) ejected from the underlying chromosphere and not directly related to the CME activity.

4. CONCLUSIONS.

In this work we made a preliminary analysis of UVCS data for a post – CME event observed at the height of 1.7 $R_\odot$ in the North – West quadrant on 26/27 November 2002. By a qualitative study of LASCO and EIT movie we identifed two kind of solar activity: plasma jets from two ARs at the limb of the Sun and a complicate loop configuration over these ARs which possibly disrupts and reforms after the CME event. These phenomena have been related in space and time respectively with "cold" and "hot" emission lines observed in our data. We identified three features as areas where the intensity of some lines representative of typical temperature ranges maximizes and evaluated plasma temperatures in these features. It turns out that plasma is cooling in the feature B related with the Southern part of the bright loop front observed by LASCO.
Another feature (related with the Northern part of the CME) is observed in the hot Fe XVIII line, requiring temperatures of about $logT \geq 6.8$ and possibly a continuous plasma heating. The behavior of this line leads us to postulate the presence in a post – CME event of an energy source probably related with reconnection processes occurring after the CME, when the magnetic field closes back and loops re-form. We plan to extend our analysis to a longer time interval to get additional information on the pattern and time evolution of the Fe XVIII line and eventually build a more complete scenario of post-CME processes. To better understand this phenomen and how the Fe XVIII emission is really related to the current sheet it will be necessary to study the evolution in our data on the following hours, that in this preliminary study we have not analized.

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