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SOHO OBSERVATIONS OF A CME-DRIVEN SHOCK AND EIT WAVES

Durgesh Tripathi[*1] **and Nour-Eddine Raouafi**[2]

[1]*Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge, CB30WA, UK*
[2]*National Solar Observatory, Tucson, University of Arizona, USA*

ABSTRACT

We report on observations of a CME-driven shock wave on March 5 2000 from different instruments (EIT, LASCO and UVCS) on board the SOlar and Heliospheric Observatory (SOHO). The CME lift-off took place at about 16:12 UT and reached the LASCO/C2 field of view (FOV) at 17:06 UT with a speed (projected in the plane of sky) of about 860 km s^{-1}. On-disk waves are also observed in the EIT difference images. Moreover, enhancement in intensities and widths of the O VI lines providing signatures of plasma heating are also observed based on the UVCS data suggesting the presence of a driven shock wave propagating in front of the CME. Interestingly, visual evidence for the shock wave is shown based on the propagation of the kink along a streamer where no CME material is present to cause such an effect. The preliminary results on the relationship of different phenomena observed by the different instruments on SOHO are presented.

Key words: Sun, Corona, CME, EIT-wave, Shock.

1. INTRODUCTION

The evidence of coronal mass ejection (CME) driven shock waves in white-light coronagraphic images were first reported by Hundhausen (1987) and Sime and Hundhausen (1987). They proposed that deflections in the remote streamers are due to the shock waves associated with CMEs propagating with super Alfvenic speeds in the corona. Based on the Large Angle Spectrometric Coronagraph (LASCO; Brueckner et al. 1995) observations of CMEs with speed higher than 600 km s^{-1}, Sheeley et al. (2000) showed a number of cases where propagation of a kink in streamers was seen along with the associated CME. The first direct observation of a shock in the LASCO images has been reported by Vourlidas et al. (2003).

The CME associated shock waves have been observed based on the UltraViolet Coronagraph Spectrometer (UVCS; Kohl et al. 1995). Intensity enhancement of lines formed at high temperatures and line broadening (namely of O VI, Si XII, etc.) are interpreted as signature of plasma heating most likely due to shock waves (e.g. Raouafi et al. 2004).

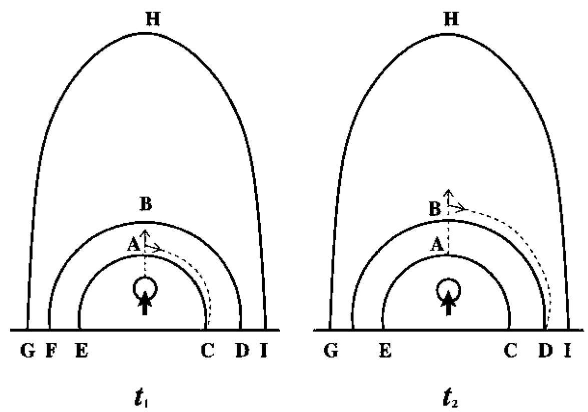

Figure 1. Schematic illustration of propagating perturbation due to opening of the field lines and the erupting flux rope. The perturbation which is induced at the top, is transferred to the footpoint of each magnetic field line creating successive wave fronts known as EIT wave from point C to point D at two different times. (Adopted from Chen et al. 2005).

The EIT waves were first detected by Thompson et al. (1998). These waves observed by the measurements taken by the Extreme-ultraviolet Imaging Telescope (EIT; Delaboudinère et al. 1995) and thus the name "EIT waves". These waves were thought to be coronal counterpart of the chromospheric Moreton waves which are seen during flares. The Moreton waves are interpreted as the propagating fast mode shock waves (Uchida et al. 1968). Since the detection of EIT waves, the relation problem of the different phenomena (CME-driven shock waves, $H\alpha$ Moreton waves and EIT waves) has become at the forefront. Recently, based on MHD simulations, Chen et al. (2005) provided a complete picture of association between above noted phenomena. According to Chen et al. (2005), there are types of existing coronal waves associated with a CME. A piston-driven shock wave straddle the CME, the legs of which are the coronal counterpart of the $H\alpha$ Moreton wave. Simultaneously, a slow moving wave with bright front appears and recognized as EIT waves. Figure 1 displays a schematic diagram for a gen-

[*]E-Mail: d.tripathi@damtp.cam.ac.uk

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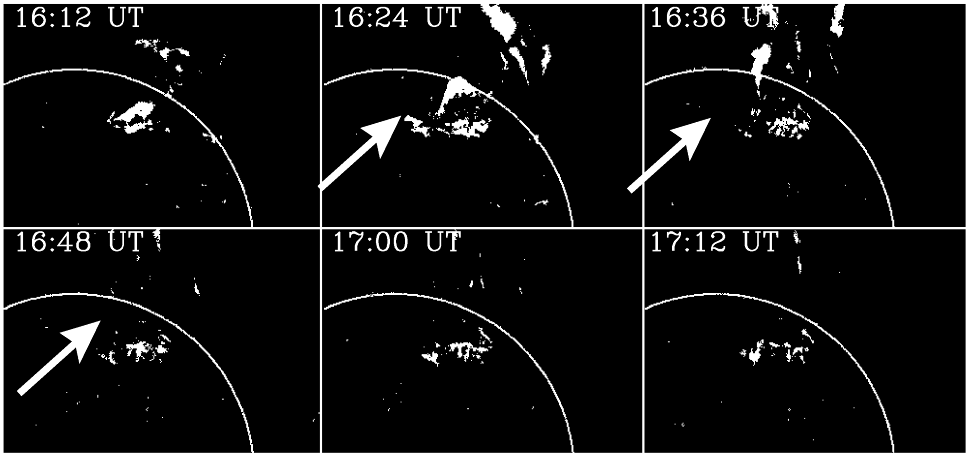

Figure 2. Sequence of running difference images taken by EIT at 195 Å showing an erupting prominence and associated EIT wave. In all the images, north points upward and west towards the right. The arrows indicate the propagating EIT-wave front.

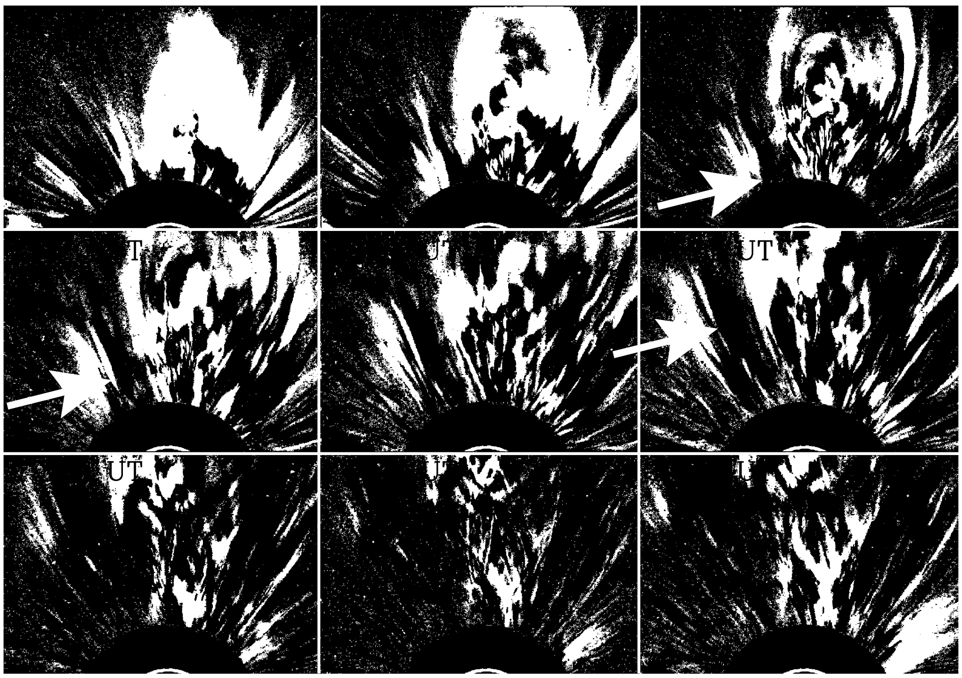

Figure 3. Sequence of running difference images taken by LASCO/C2. The CME was first seen in the LASCO/C2 field of view at 17:06 UT. The arrows mark the kink in the streamer. In all the images north point upwards and west towards the right. The gray disk in the bottom represents the occulting disk and the white arc marks the solar limb.

eration of an opening related perturbation at the top and its propagation towards the foot point, providing the complete view of the shock wave and EIT wave.

In the present paper, we study the correlation of the different phenomena using images recorded by EIT, LASCO and spectral observations performed by UVCS. The results presented here are preliminary and more detailed study will be published in a subsequent paper.

2. OBSERVATIONS

2.1. EIT observations: EIT wave

EIT observes the solar corona in four different wavelength channels. Solar images at 195 Å are recorded regularly and are, thus, used for the present study. Figure 2 displays the running difference of EIT images. The time of each second image in the difference is marked on the top-left corner of the corresponding panel. The location of the erupting filament and propagating EIT wave are marked by arrows on the different panels in Figure 2. The erupting filament and the associated CME are studied in detail by Tripathi et al. (2006). The EIT wave first appeared at 16:12 UT and propagated outward respective to the eruption location having a semi circular front. The wave is seen propagating predominantly northwards. The EIT wave stepped at the boundary of the coronal hole which was located north-east from the eruption location and not seen in the running difference images presented in the Figure 2.

2.2. LASCO Observations of CME and streamer deflection

LASCO observes the solar corona in white-light and is comprised of three coronagraphs: C1, C2 and C3. C1 is

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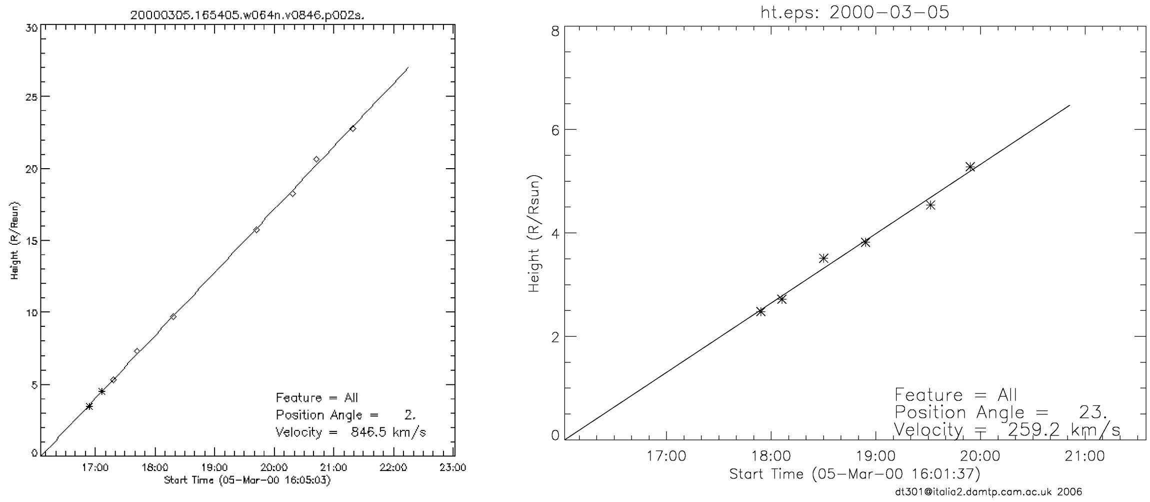

Figure 4. Left Panel: Height-time diagram of the CME based the LASCO/C2 and C3 observations. Right Panel: height-time diagram for the propagating kink along the streamer beside the CME.

not operational since 1998. The C2 telescope has a field-of-view (FOV) ranging from $\sim 2.0\ R_\odot$ to $\sim 6.0\ R_\odot$ and C3 observes from $\sim 4.0\ R_\odot$ to $\sim 30.0\ R_\odot$. Figure 3 displays the running difference images of the CME taken by LASCO/C2 on March 5, 2000. The CME first appears in the LASCO/C2 FOV at 16:54 UT and propagate into the outer corona with a speed of about 860 km s^{-1} (see left panel in Figure 4) with a three part structure at a position angle of 2 degrees. Note that the speed and the position angle of the CME are taken from the CME catalog (http://cdaw.gsfc.nasa.gov/CME_list/). The speed of the CME was measured based on the observations taken by LASCO/C2 and C3. At about 17:30 UT, a kink in the streamer located westward from the CME location and marked with an arrow in Figure 3. With the evolving CME, the streamer is deflected more towards south which yields information on the propagation path of the kink (projected on the plane of the sky). In between the propagating CME and the streamer, there was no visible CME material which could cause such a deflection in the streamer. The latter suggests that there is some wave propagating in the flank of the CME which deflects the streamer. Interestingly, the deflection which is seen in the form of kink is also propagating outwards. The speed of the wave was about 260 km s^{-1}. The latter could be greater taking into account the geometry of the propagating kink and that of the streamer.

2.3. UVCS observation of intensity enhancement and line broadening

The UVCS slit was centered at 2.5 $R_\odot$ from Sun center at a position angle of 355° counter clockwise from the north pole. The spectral coverage included mainly the O VI doublet lines and much weaker other lines. The observation sequence started at 15:58 UT and ended at 20:12 UT and is composed of 80 exposures with exposure time of 180 seconds each. This time interval covers the time evolution of the CME event of March 5, 2000. In the present paper, we concentrate on the thirty first exposures. Lots of spectral evolution is observed in the rest of the sequence but it is not described here.

Figure 5 display the averages of four UVCS exposure sets (top-left: 1-15, top-right: 16-20, bottom-left: 21-24 and bottom-right: 25-27) showing the O VI doublet lines. The top-left panel shows the O VI profiles before the CME material reaches the UVCS slit. The top-right panel shows an intensity enhancement and broadening of the two lines. The change in the O VI profiles is observed mainly in the wings. The O VI profiles are then formed of two components: one narrow that is similar to the profiles shown in the top-left panel and a broader one that reflects the emission of hotter plasma. In the following exposures shown in the bottom panels the emission in the O VI lines is enhanced and confined in a small section near the center of the slit. The profiles are broader than before. This suggests that some heating mechanism of the plasma is taking place. This is likely to be due to a shock wave propagating in front of the erupted CME. A simple time computation suggests that the sock wave has reached the UVCS slit after 16:45 and the heated gas emission lasted till about 17:20 UT, where emission in colder lines is observed. Extra broadening in the O VI lines is noticeable even after the CME cold material has reached UVCS FOV.

3. SUMMARY

Combined observation data sets from different instruments on board of the spacecraft SOHO reveal signatures of waves propagating on the solar disk and also in the solar corona caused by the CME event of March 5, 2000. The CME lift-off took place around 16:12 UT in the north-west quadrant of the solar disk (near the north pole). An EIT wave is observed propagating to-

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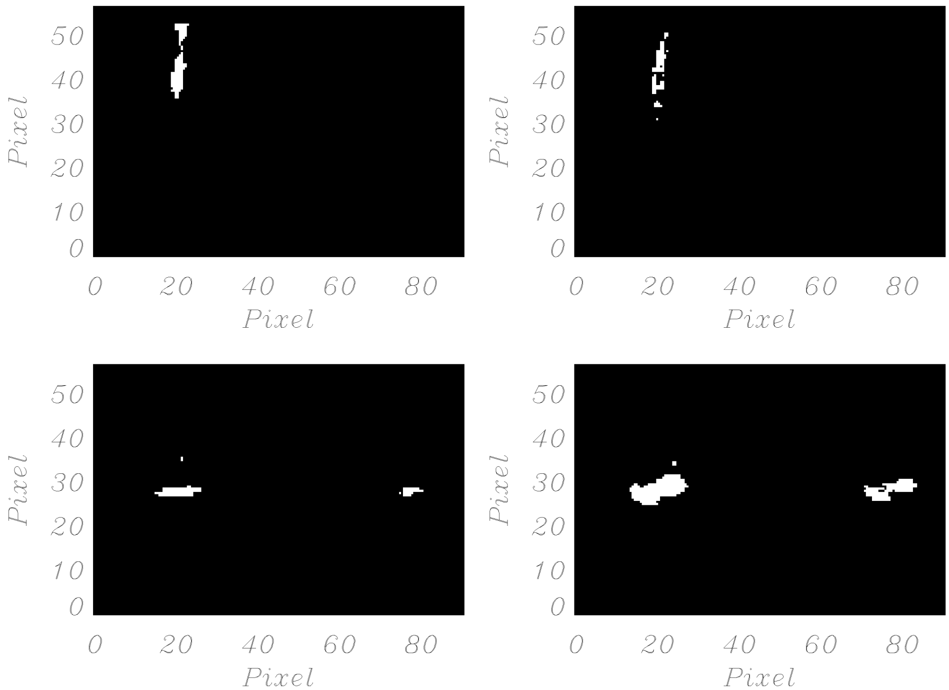

Figure 5. Average of four UVCS exposure sets showing the O VI lines before (top-left panel) and after the eruption event has reached the UVCS slit centered at 2.5 $R_{\odot}$ (top-right and bottom panel). The angular position of the slit is 355° counter clockwise (CCW). The intensity enhancement and excess broadening in the O VI lines are likely the signature of heating mechanisms of the plasma. The heating could be generated by a shock wave propagating in front of the CME.

ward north-east direction in the difference of EIT 195 Å images. A deflection in a streamer belt located on the north-east quadrant of the solar disk is also observed in the LASCO/C2 images. No CME material is present at that location and the shape change of the streamer seems to be due to a wave front propagating outward. It is detected first around 17:30 UT. However, with the cadence of LASCO/C2 images we are not able to determine accurately the timing of this event. Broadening in the O VI lines accompanied by an intensity enhancement is observed in the UVCS spectra at 2.5 $R_{\odot}$ from Sun center. The intensity enhancement and line broadening are observed starting from about 16:45 UT till after 17:20 UT. This is likely the signature of the CME-driven shock wave. Note that the CME speed projected on the plane of the sky is high enough to generate such a wave.

The timing of the O VI broadening is comparable to that of the streamer deflection observed in LASCO/C2 images at about 17:30 UT. This is supported also by the geometry of the two events. The EIT wave observed earlier was propagating in the same direction as the deflection of the streamer. Hence a probable connection between the two events is likely probable. This will be studied in details in a future publication.

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