

Analysis of a CME and EUV waves associated with a solar flare on 13 February 2011

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Resumen / El 13 de febrero de 2011 se produce una fulguración M6.6 originada en la región activa 11158, la cual está asociada a una eyección coronal de masa y ondas EUV. Utilizamos datos de diferentes instrumentos tales como el “H-alpha Solar Telescope for Argentina”, el “Helioseismic and Magnetic Imager” y el “Atmospheric Imaging Assembly”, los dos últimos a bordo del “Solar Dynamic Observatory”. Se estudia la evolución de las ondas EUV y se presenta el posible escenario que dio origen a las mismas.

Abstract / On 13 February 2011 a M6.6 flare occurred in active region 11158 associated with a coronal mass ejection and EUV waves. We analyse these events using observations from the ground, H-alpha Solar Telescope for Argentina, and space, Helioseismic and Magnetic Imager and Atmospheric Imaging Assembly, both onboard the *Solar Dynamics Observatory*. We study the evolution of EUV waves and present a possible scenario for their origin.

Keywords / Sun: chromosphere — Sun: flares — Sun: corona — Sun: coronal mass ejections (CMEs)

1. Introduction

Impulsive releases of large amounts of energy in flares are frequently accompanied by coronal mass ejections (CME) disturbances and wave-like features propagating in the solar corona. The physical processes that underlie these events as a whole are still unclear due to the complex mechanisms involved. In general, the coronal propagating disturbances that follow a CME cannot be properly identified due to the line-of-sight overlap of different features, such as real MHD waves or those derived from the magnetic coronal reconfiguration. With the aim of contributing to the understanding of some of these aspects, we analyse a CME and EUV waves associated to the M6.6 flare in the active region (AR) 11158, which occurred on 13 February 2011. We use ground-based observations from the H-alpha Solar Telescope for Argentina (HASTA), and space observations of the Helioseismic and Magnetic Imager (HMI) and the Atmospheric Imaging Assembly (AIA), onboard the *Solar Dynamics Observatory* (SDO).

2. The flare and the magnetic evolution

The flare was observed in the chromosphere with HASTA (Bagalá et al., 1999; Francile et al., 2008). Fig. 1 shows the H α light curve of the whole active region overlapped to the GOES 15 X-Ray measurements in both XS (0.05–0.4 nm) and XL (0.1–0.8 nm) bands. The curves are normalised by dividing by their maxi-

mum. The maximum of GOES XS band occurs at 17:36 UT with a $2.15 \text{ E-5 W m}^{-2}$ flux (M6.6 class). The H α maximum occurs 14 s later, preceding the XL band peak at 17:38 UT. We define the flare onset time as the peak of the derivative of the H α light curve as done in Francile et al. (2016), i.e. 17:32 UT.

Fig. 2 shows the evolution of AR 11158 from 10 to 13 February 2011 as observed with HMI/SDO at 17:01 UT on each day. We identify two small bipoles that approached as they emerged. On 13 February the AR displayed a quadrupolar magnetic field configuration. We presume that the observed flux emergence, which is usually accompanied by shearing motions, probably led to the interaction of the structures anchored to the approaching bipoles with the consequent energy release that originated the M6.6 flare and CME ejection.

3. EUV waves and CME

After the flare initiation and CME disruption, coronal EUV waves were visible. We obtained running-difference images in the AIA 193 Å band. To analyse the temporal and spatial evolution of the waves we applied the intensity profile technique (Vršnak et al., 2002) to these images. The intensity profiles were computed along angular sectors traced every 5° departing from the point where the flare intensity was strongest (S20E04), which we call the radiant point (RP). The seventy two sectors were numbered in a counterclockwise direction from 0 to 71 as observed in Fig. 3.

Flare, CME, and EUV waves on 13 February 2011

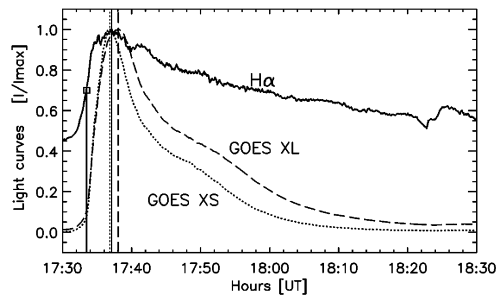


Figure 1: Flare light curve obtained from HASTA. Overimposed the GOES 15 X-Ray XS and XL bands in dotted and dashed lines, respectively. The square indicates the peak of the derivative of $H\alpha$.

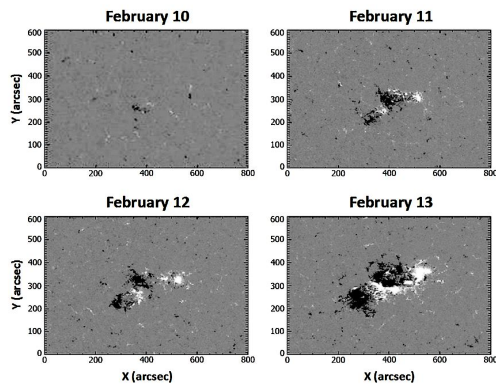


Figure 2: Magnetic evolution of AR 11158. The images correspond to HMI/SDO taken at 17:01 UT on each day. <https://sdo.gsfc.nasa.gov/data/aiahmi/>

To investigate the evolution of the wave event in different angular sectors, we apply a stack plot procedure as done in Francile et al. (2016). Distance-time (DT) maps are shown for sectors 26 to 57 in Fig. 4. The abscissas are in seconds while the ordinates are the plane of sky distance measured from the RP.

The first appearance of a EUV disturbance is observed as a sharp, well-defined, and slowly decelerating line between sectors 29 to 51, denoted with red arrows in some of the central panels. This disturbance resembles an S-type EIT wave or a shock wavefront, which originated at the flare and CME onset. It can also be driven by the CME bubble as discussed by Patsourakos & Vourlidas (2012). The green arrows in Fig. 4 denote a second propagating disturbance, which is more blurred and exhibit a higher decelerating path, detaching from the sharp front at ≈ 100 Mm from the RP. The blue arrows indicate a thin and sharp third EUV disturbance that appears not connected to the others.

We estimate the kinematic parameters of the first appearing sharp wavefront (pointed by a red arrow in Fig. 4) by fitting linear and quadratic curves for sectors 26–51 in the time interval 17:32 to 17:37 UT. The results are shown in Table 1. A nearly homogeneous speed, with a mean of 446.7 km s^{-1} , is derived from the linear

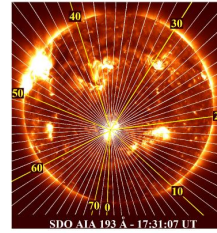


Figure 3: Sector tracing performed on SDO/AIA 193 Å band images. The 5° wide sectors are centred at the RP, starting from the solar South Pole.

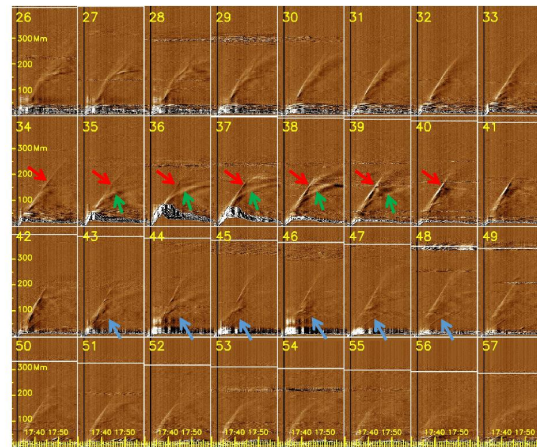


Figure 4: Stack plots, sectors 26 to 57. The red, green, and blue arrows indicate different EUV propagating perturbations.

fittings. A predominance of negative accelerations, with a mean of -0.112 km s^{-2} , results from the quadratic fittings. We also calculate the speeds extrapolated to the flare onset time (17:32 UT) and 5 min later. These values show high dispersion, with a mean of 512 km s^{-1} at the onset of the flare and a decay to approximately 478 km s^{-1} 5 minutes later.

The CME was observed by the Large Angle and Spectroscopic Coronagraph (LASCO) onboard the *Solar and Heliospheric Observatory* (SOHO) (see Fig. 5, left). According to the CDAW SOHO/LASCO CME Catalog*, the event associated with the EUV wave was a poor partial halo as seen from Earth. The height-time points measured as projected in the plane of the sky are shown in Fig. 6. A linear fit indicates a mean speed of 373 km s^{-1} . The measured points can also be fitted to a quadratic curve, which gives as a result an acceleration of 0.024 km s^{-2} and implies a speed of 517 km s^{-1} at the height of the last measured point. These speed values do not necessarily correspond to the propagation speed of the CME, but rather to its expansion speed, given the vantage point of SOHO. From the perspective of the *Solar Terrestrial Relations Observatory* (STEREO**), the CME appears in the field of view of COR1 at 17:45 UT

*https://cdaw.gsfc.nasa.gov/CME_list

**<https://stereo-ssc.nascom.nasa.gov>

Table 1: Kinematic parameters obtained for the first sharp front (red arrows).

Sector	Speed (mean) km s^{-1}	Accel. km s^{-2}	Speed (t flare) km s^{-1}	Speed (t flare + 5min) km s^{-1}
26	520.1	-0.096	584.4	555.7
27	490.9	-0.378	744.2	630.9
28	508.8	-0.659	903.0	705.4
29	477.2	-0.392	730.7	613.1
30	410.8	-0.246	590.5	516.7
31	431.2	-0.353	667.5	561.8
32	425.2	-0.264	608.8	529.5
33	506.4	0.397	278.5	397.6
34	397.3	-0.072	452.4	430.8
35	455.5	0.270	296.8	377.9
36	410.1	0.247	265.1	339.3
37	430.6	-0.056	462.1	445.3
38	429.6	-0.176	516.1	463.2
39	421.9	-0.077	459.6	436.5
40	427.4	-0.097	478.3	449.3
41	450.0	-0.149	526.4	481.8
42	468.0	0.205	369.9	431.4
43	446.9	-0.066	479.4	459.5
44	545.4	0.275	400.4	483.0
45	513.3	-0.186	628.8	573.1
46	501.8	-0.277	687.7	604.5
47	488.2	0.048	459.6	473.9
48	471.4	0.129	397.3	435.9
49	440.9	0.058	412.9	430.5
50	446.4	0.087	397.2	423.5
51	423.0	-0.030	438.3	429.4
52	409.3	-0.034	426.2	415.9
53	382.0	-0.184	474.3	419.2
54	323.0	-0.538	586.8	425.4
55	413.7	-0.005	415.8	414.4
56	453.2	-0.303	572.7	481.9
57	374.5	-0.658	665.7	468.2
Mean	446.7	-0.112	511.8	478.3

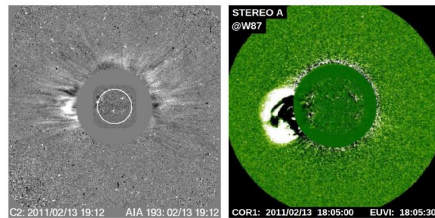


Figure 5: Appearance of the CME. Left: Composite SOHO/LASCO C2 and SDO/AIA 193 Å images at 19:12 UT. Right: Composite STEREO COR1 and EUVI images at 18:05 UT. The SOHO/LASCO image is courtesy of NASA and ESA, SDO and STEREO images are courtesy of NASA. Image processing and labelling courtesy of CDAW Data Center (<https://cdaw.gsfc.nasa.gov>).

(see COR1-A in Fig. 5, right). In the FOV of COR2, the CME is detected as an unstructured event, without exhibiting signatures of a three-part or flux rope structure. Given that by the time of the event the twin S/C were 180° apart, and that the event originates close to central meridian, the views of *STEREO* A and B are almost identical, but flipped.

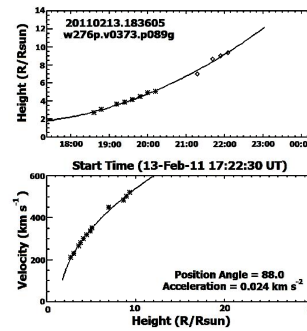


Figure 6: Quadratic fit to the height-time points and velocity of the CME, both measured projected in the plane of the sky.

4. Discussion and Conclusions

Our analysis by sectors of the first EUV wavefront indicates an almost homogeneous angular behaviour. We determine a mean speed of 447 km s^{-1} and a mean acceleration of -0.112 km s^{-2} . This wavefront has the characteristics of an MHD fast magnetosonic shock of the blast type, i.e. a shock originated by a short lived 3D piston. This 3D piston can be associated with a pressure pulse (flare origin) or with the initial acceleration of the CME (see the discussion in Francile et al., 2016). From our analysis it is not possible to discern the origin of the EUV shock.

The green arrows in Fig. 4 denote a second and slow propagating disturbance. Probably it is not a real wave because it could be originated by the outskirt of the first EUV front which interacts with the lower and denser coronal layers close to solar surface while it expands (Francile et al., 2016). The third EUV disturbance (blue arrows in Fig. 4) is probably the trace of a real MHD wave since it exhibits a well defined and thin front. We measure a mean speed of 204.8 km s^{-1} and an acceleration of -0.043 km s^{-2} , which suggest that it can be of the slow magnetosonic type and, probably, in a shock regime. Fast and slow magnetosonic shock waves are compressional waves, which could explain the observed enhancing of the EUV emissions. Existence of multiple EUV waves has been reported in several cases, see Warmuth (2015) and references therein. From the analysis of the kinematic evolution of the CME it is not possible to infer a clear relation between its expansion speed with the measured EUV waves. As a future work we intend to do a deeper analysis of this event and to extend our study to the events on the following days, i.e. 14 and 15 February 2011.

References

- Bagalá L. G., et al., 1999, in *Magnetic Fields and Solar Processes*, p. 469
- Francile C., et al., 2008, *BAAA*, 51, 339
- Francile C., et al., 2016, *Sol. Phys.*, 291, 3217
- Patsourakos S., Vourlidas A., 2012, *Sol. Phys.*, 281, 187
- Vršnak B., et al., 2002, *A&A*, 394, 299
- Warmuth A., 2015, *Living Reviews in Solar Physics*, 12, 3