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A study of a long duration B9 flare-CME event and associated shock

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Abstract

We present and discuss here the observations of a small long duration GOES B-class flare associated with a quiescent filament eruption, a global EUV wave and a CME on 2011 May 11. The event was well observed by the Solar Dynamics Observatory (SDO), GONG Hα, STEREO and Culgoora spectrograph. As the filament erupted, ahead of the filament we observed the propagation of EIT wave fronts, as well as two flare ribbons on both sides of the polarity inversion line (PIL) on the solar surface. The observations show the co-existence of two types of EUV waves, i.e., a fast and a slow one. A type II radio burst with up to the third harmonic component was also associated with this event. The evolution of photospheric magnetic field showed flux emergence and cancellation at the filament site before its eruption.

Keywords: EUV waves; Filaments; Magnetic field; Magnetic reconnection; Coronal mass ejections (CMEs)

1. Introduction

Solar flares are the most energetic phenomenon near the solar surface and occasionally they are accompanied by filament (or prominence) eruptions and coronal mass ejections (CMEs) (Chen, 2011; Fletcher et al., 2011; Joshi et al., 2012; Benz, 2017). The association of filament eruptions with solar flares varies from small GOES B-class flares to very large GOES X-class flares. Filaments are dense cool plasma materials suspended in the hot corona (Parenti, 2014). They are often visible **at** chromospheric and coronal heights. Observations indicate that they are along the polarity inversion line (PIL). The processes related to the flare occurrence, the formation of flare ribbons, and the eruption of filament are well explained by standard CSHKP model (Carmichael, 1964; Sturrock, 1966; Hirayama, 1974; Kopp and Pneuman, 1976).

Sometimes solar flares along with erupting filaments are accompanied by globally propagating waves, known as extreme ultraviolet (EUV) waves. EUV waves were first observed by the Extreme Ultraviolet Imaging Telescope (EIT, Delaboudinière et al. (1995)) on-board the SOHO spacecraft, and were thus historically named as EIT waves (Thompson et al., 1999, 2000). These EUV waves can propagate to long distances on the solar disk with a speed of about 170–350 km s^{-1} (Thompson et al., 1999). Now, with the high cadence SDO data, our knowledge on EUV waves is enhanced considerably. EIT waves were initially considered as the coronal counterpart of high speed Chromospheric Moreton waves (Moreton, 1960), although it was also noticed that the EIT wave speeds are several times smaller than those of Moreton waves.. Later on,

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Warmuth et al. (2004) and Vršnak et al. (2016) explained that the difference in the velocities can be attributed to the deceleration of coronal waves.

The interpretations for the EUV waves include wave and non-wave models. The wave models interpret EUV waves as fast-mode MHD waves (Thompson et al., 2000; Wang, 2000). The observations like reflection, refraction, transmission seem to support the wave nature of EUV waves (Olmedo et al., 2012). The discovery of stationary fronts (Delannée and Aulanier, 1999) of EUV waves challenged the wave nature of EUV waves. Later on several other models have been proposed which include the magnetic field-line stretching model (Chen et al., 2002, 2005), the successive reconnection model (Attrill et al., 2007), the slow-mode wave model (Wills-Davey et al., 2007; Wang et al., 2009), and the current shell model (Delannée et al., 2008). The magnetic field line stretching model further proposed that there should be a fast-mode wave ahead of the slow EUV wave. It is believed in the above discussed observations and models that the slow wave stops at the magnetic quasi-separatrix layers (QSLs) and forms stationary fronts. However, very recently Chandra et al. (2016) found the observation of stationary fronts associated with the fast component of EUV waves and their location also lies at the QSLs. Encouraged by this observational finding, Chen et al. (2016) did a numerical simulation of the interaction of a fast mode MHD wave and a magnetic QSL. Their numerical results showed that the fast-mode MHD wave does generate a stationary front once passing through a magnetic QSL. Their study suggested that some part of this fast-mode wave is converted to a slow mode wave which gets trapped and forms a stationary front. Recently, this type of stationary waves is confirmed by the studies of Yuan et al. (2016), Srivastava et al. (2016), Zong and Dai (2017).

Solar flares, filament eruptions, and EUV waves are sometimes associated with type II radio bursts. Type II radio bursts are the signature of shock waves propagating in the corona. Type II radio bursts are slowly drifting radio emission from high to low frequencies (Wild and McCready, 1950). Both the EUV waves and type II radio bursts are often associated with CMEs. These type II radio bursts are believed to be triggered by either a CME (Cliver et al., 1999; Gopalswamy et al., 2001) or by a blast wave which gets created by a flare (Uchida, 1974; Hudson and Warmuth, 2004). It is difficult to determine whether a shock is ignited by a CME or a flare. Vasanth et al. (2011) studied the characteristics of type II radio bursts associated with flares and CMEs and concluded that some parts of the high frequency shocks are initiated by flares, whereas low frequency type II bursts are related to the shocks driven by CMEs. Also, Gopalswamy (1999) did a study of type II radio bursts and CMEs and suggested that at the height of minimum Alfvén speed a type II radio burst starts and the end time will depend on the relative variation of the CME speed and the Alfvén speed of the background corona.

The aim of this paper is to study the flare, filament eruption and their association with EUV waves, CME and type II radio bursts on 2011 May 11. The paper is organized as follows: Section 2 describes the observations and in Section 3, we present the analysis and results of the study. Finally in Section 4, we summarize our study.

2. Observations

For the current study, we used the data from the following sources:

- **SDO/AIA and HMI data:** The Atmospheric Imaging Assembly (AIA, (Lemen et al., 2012)) on board Solar Dynamic Observatory (SDO, Pesnell et al. (2012)) observes the full Sun with different filters in EUV and UV spectral lines. The cadence is 12 s and the pixel size is 0.6 arcsec. For this study, we used the AIA 171 Å, 193 Å, 211 Å, and 335 Å data. In order investigate the magnetic causes of the filament eruption and the associated flare, we used the data from the Heliospheric Magnetic Images (HMI, (Scherrer et al., 2012)) observations. HMI observes the photospheric magnetic field of the Sun with a cadence of 45 s and spatial resolution 1″ (i.e., the pixel size is 0.5″).
- **NSO/GONG data:** For the chromospheric observations of the filament eruption and flare, we used the Hα data from the National Solar Observatory (NSO)/ Global Oscillation Network Group (GONG, (Harvey et al., 2011)) instrument. GONG observes the full Sun in Hα with a cadence of 1 min. The spatial resolution of the GONG data is 2″ (i.e., the pixel size is 1″).
- **STEREO, LASCO, and Radio spectrograph data:** To look into the associated CME with the filament eruption, we used the COR1, COR2 (Kaiser et al., 2008) and LASCO (Brueckner et al., 1995) CME data. For the radio analysis, we used the Culgoora spectrograph data.

3. Analysis and results

3.1. Overview of the event and EUV wave

On 2011 May 11 the filament under study was located between the active regions *NOAA 11207* and *NOAA 11205* at *N20W60* on the solar disk. Earlier, this filament eruption was studied by Chandra et al. (2016) and Grechnev et al. (2015) analyzed the same event and came to the conclusion that the shock was impulsively excited by the erupting filament, which was a flux-rope progenitor, and not by the flare. The shock appeared when the CME was not yet formed. Chandra et al. (2016) reported that the eruption was associated with two global EUV waves, which were predicted by Chen et al. (2002). In their study, apart from the traditional stationary EUV front which

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