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Spatially resolved observations of a coronal type II radio burst with multiple lanes

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Abstract

Relative dynamics of the radio sources of the metric type II burst with three emission lanes and coronal mass ejection (CME) occurred in the lower corona ($r \lesssim 1.5R_\odot$) during the SOL2011-02-16T14:19 event is studied. The observational data of the Nancay Radioheliograph (NRH) and the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) are used. These observations are also supplemented by the data sets obtained with the STEREO-A and -B, RHESSI, and GOES spacecraft, as well as with the ground-based solar radio spectrometers. It is found that the sources of the radio burst were located ahead of the expanding CME and had a complex spatial structure. The first and the second lanes were both emitted from the "magnetic funnel" — a bundle of open magnetic field lines separated the south and north systems of magnetic loops of the active region. Due to the projection effect and limited angular resolution of the NRH it is not possible to determine, whether the spatial locations of the radio sources of the two first emission lanes differed or not. It is argued that the observations support the hypothesis that the radio sources of the first and second lanes could be emitted respectively ahead of and behind a front of the same weak (the Alfvén Mach number $M_A \approx 1.1$–1.2), fast mode, quasi-parallel piston MHD shock wave. However, the third lane of the burst was definitely emitted from a different place. Its radio sources were situated ahead of the north-west part of the CME propagated through the north system of magnetic loops. This indicates clearly that different emission lanes of the same type II burst can be a result of propagation of different parts of a single CME through regions with different physical conditions (geometries and plasma densities) in the lower corona.

Keywords: Solar flare; Coronal mass ejection; Shock wave; Type II radio burst

1. Introduction

Coronal type II radio bursts usually represent two parallel bright emission lanes on the solar radio spectrograms with a frequency ratio of around 2 and slowly drifting (typically with $|df/dt| \approx 0.1 - 1.0$ MHz/s) from high to low frequencies in the decimeter/meter/decameter wavelength ranges. It is generally accepted that this radio emission is a result of plasma wave excitation at fronts of magneto-hydrodynamics (MHD) shock waves propagating through the corona from low to high altitudes (e.g., Zhelezniakov (1969), Zaitsev (1966), Wild and Smerd (1972), Nelson et al. (1985), Mann et al. (1995), Aurass (1996), Gopalswamy (1998), Pick and Vilmer (2008), Cairns (2009)). The lower and higher frequency lanes are interpreted respectively as emissions at the fundamental and at the second harmonic of local plasma frequency. Despite long-term active study, the debate on the origin of the coronal shock waves is still ongoing (e.g., see discussions in Cliver et al. (1999), Cho et al. (2005), Gopalswamy (2006), Cho et al. (2008), Vrsnak and Cliver (2008), Magdalenic et al. (2010), Grechnev et al. (2011), Nindos

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et al. (2011), Cho et al. (2013) and references therein). It is not yet clear whether the coronal shocks are excited by flares, by coronal mass ejections (CMEs) or by both these objects.

Sometimes a splitting of the main emission lanes of the type II bursts, both at the fundamental and harmonic frequencies, on two additional sub-lanes is observed. There is no consensus on this phenomenon yet. One of the possibilities is that the band-splitting is a result of simultaneous radio emission from the downstream and upstream regions of a shock (Smerd et al., 1974, 1975; Nelson and Robinson, 1975; Vrsnak et al., 2001). This hypothesis has recently found clear observational confirmation (Zimovets et al., 2012; Zucca et al., 2014). However, other possible interpretations can not be ruled out, since the statistics of the spatially resolved observations of the splitted type II bursts is extremely poor. For example, the splitting can be due to the fact that two different parts of a single shock propagate simultaneously in coronal regions with different physical conditions (e.g., McLean (1967), Holman and Pesses (1983), Schmidt and Cairns (2012)). Some recent observations support the notion that the CME nose and the CME-streamer interaction at the CME flank are two main regions, where the type II burst emission can be generated (Cho et al., 2008; Mancuso and Avetta, 2009; Cho et al., 2011). Another possibility is that two shocks, e.g. a blast shock caused by a flare and a piston shock driven by a CME, simultaneously propagate in the corona with similar speeds (e.g., Eselevich et al. (2013)).

Moreover, some type II bursts have more than two separate emission lanes, “which are neither harmonically related nor consistent with simple band splitting” (Nelson et al., 1985). As well as with the split-band effect, there is no generally accepted mechanism explaining the multiple-lane structuring of the type II bursts. Two of the most probable scenarios are that several disturbances (and shocks) simultaneously propagate in the corona or different parts of a single, possibly non-planar, extended shock interact with different coronal structures at the same time (e.g., Cairns (2009)). A number of spatially resolved observations of the type II bursts with multiple lanes were very restricted and spatial resolution of these observations were mainly insufficient to draw reliable conclusions (Weiss, 1963; Stewart, 1977; Robinson and Sheridan, 1982; Vrsnak et al., 2006). More detailed, new observations are required to make progress in this problem.

The goal of this work is to partially fill this gap by presenting an analysis of the spatially resolved observations of one particular metric type II radio burst with three quasi-parallel lanes of emission detected both at the fundamental and at the second harmonic of the plasma frequency. This type II burst occured in the NOAA active region 11158 on 16 February 2011 in close association with the M1.6 class flare (SOL2011-02-16T14:19) and the CME observed in the EUV range in the lower corona ($r \lesssim 1.5R_\odot$). Analysis of the relative dynamics of the CME and the radio sources of the first (in time) emission lane of this type II burst is reported by Eselevich et al. (2015). Spectroscopic analysis of the EUV-wave in this event was presented by Harra et al. (2011) and Veronig et al. (2011). Here we mainly concentrate on analysis of the spatial location of the radio sources of all three emission lanes of the type II burst relative to each other, to the CME and to the EUV-wave in the lower corona.

2. Instruments and data

We use radio spectrograms obtained with: (1) the CALLISTO spectrometer[1] (Benz et al., 2009) at the Bleien Observatory (Switzerland); (2) the spectrometer at the San Vito Solar Observatory (Italy), which is a part of the Solar Radio Telescope Network (RSTN); (3) the ARTEMIS IV ASG solar radio spectrograph[2] (Greece) (Kontogeorgos et al., 2006). The frequency ranges of these spectrograms are 175–870, 25–180, and 20–650 MHz respectively. Their time resolutions are 0.25, 3, and 5 s respectively. Also, we use 1-s time profiles of solar radio flux detected by the San Vito radio telescope (RSTN) at 8 fixed standard frequencies: 245, 410, 610, 1415, 2695, 4995, 8800 and 15,400 MHz.

To investigate spatial location and dynamics of the radio sources in the studied event we use observations made by the Nancay Radioheliograph (NRH; Kerdraon and Delouis (1997)) with the moderate time cadence of 1 s, which is sufficient for our purposes. On 16 February 2011, the NRH operated at all ten available frequencies (from 150.9 MHz to 445.0 MHz). The type II burst was observed by the NRH at six frequencies: 327.0, 298.7, 270.6, 228.0, 173.2, and 150.9 MHz. The NRH beam was highly asymmetric during the time interval under consideration. It was more extended in the east–west direction than in the south–north one. The beam size (full width at half maximum) at six mentioned frequencies along the east–west direction was 100″, 109″, 121″, 143″, 188″, 216″ and 33″, 36″, 39″, 47″, 61″, 71″ along the south–north direction respectively. The NRH’s field of view was 2° × 2°. The standard technique within the Solar Soft Ware[3] is used to synthesize time series of the 2D radio intensity maps of 128 pixels × 128 pixels with the pixel size of ≈ 30″ for each NRH frequency. The observed radio sources are fitted with the 2D elliptical Gaussian. This gives us quantitative information about positions of the centroids of the radio sources in the image plane at each time and at each given frequency.

Morphology of the active region and dynamics of the CME in the lower corona ($r \lesssim 1.5R_\odot$) is studied with the use of the EUV observations made by the Atmospheric Imaging Assembly (AIA; Lemen et al. (2012)) onboard the Solar Dynamics Observatory (SDO). The very initial phase of the CME is best seen in the 131 Å channel, while

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[1] <http://www.e-callisto.org>.

[2] <http://artemis-iv.phys.uoa.gr//>.

[3] <http://www.lmsal.com/solarsoft/>.