Overexpansion-dominated coronal mass ejection formation and induced radio bursts

B. T. Wang\textsuperscript{1,2}, X. Cheng\textsuperscript{1,2,3}, H. Q. Song\textsuperscript{4}, M. D. Ding\textsuperscript{1,2}

\textsuperscript{1} School of Astronomy and Space Science, Nanjing University, Nanjing 210023, People’s Republic of China e-mail: xincheng@nju.edu.cn
\textsuperscript{2} Key Laboratory of Modern Astronomy and Astrophysics (Nanjing University), Ministry of Education, Nanjing 210093, People’s Republic of China
\textsuperscript{3} Max Planck Institute for Solar System Research, Göttingen, 37077, Germany
\textsuperscript{4} Shandong Provincial Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, and Institute of Space Sciences, Shandong University, Weihai, Shandong 264209, Peoples Republic of China

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ABSTRACT

\textbf{Aims.} Coronal mass ejections (CMEs) are the most fascinating explosions in the Solar System. Their formation is still not fully understood, however.

\textbf{Methods.} We investigated a well-observed CME on 2021 May 7 that showed a typical three-component structure and was continuously observed from 0 to 3 R\textsubscript{\odot} by a combination of SDO/AIA (0–1.3 R\textsubscript{\odot}), PROBA2/SWAP (0–1.7 R\textsubscript{\odot}), and MLSO/K-Cor (1.05–3 R\textsubscript{\odot}). Furthermore, we compared the morphological discrepancy between the CME white-light bright core and the extreme-UV (EUV) blob. We finally explored the origin of various radio bursts that are closely related to the interaction of the CME overexpansion with a nearby streamer.

\textbf{Results.} An interesting finding is that the height increases of the CME leading front and of the bright core are dominated by the overexpansion during the CME formation. The aspect ratios of the CME bubble and bright core, quantifying the overexpansion, are found to decrease as the SO/STIX 4–10 keV and GOES 1–8 Å soft X-ray flux of the associated flare increases near the peaks. This indicates that the flare reconnection plays an important role in the first overexpansion. The CME bubble even undergoes a second overexpansion, although it is relatively weak, which is closely related to the compression with a nearby streamer and likely arises from an ideal magnetohydrodynamics process. Moreover, the CME EUV blob is found to be relatively lower and wider than the CME white-light bright core, which may correspond to the bottom part of the growing CME flux rope. The interaction between the CME and the streamer leads to two type II radio bursts, one that is drifting normally and another that is stationary, which are speculated to be induced by two different sources of the CME-driven shock front. The bidirectional electrons shown in series of C-shaped type III bursts suggest that the interchange reconnection is also involved during the interaction of the CME and streamer.

\textbf{Key words.} Sun: corona – Sun: coronal mass ejections (CMEs) – Sun: flares

1. Introduction

Coronal mass ejections (CMEs) are the most fascinating solar activities in the solar corona and are able to release a large amount of magnetized plasma to the interplanetary space. If propagating towards the Earth, they may cause severe space weather events, leading to the destruction of space- and ground-based electronic devices (Gosling 1993; Webb et al. 1994).

White-light coronagraph data reveal that CMEs often exhibit a typical three-component structure: a leading front, a dark cavity, and an embedded bright core (Illing & Hundhausen 1986). The CME leading front is usually explained as the plasma that piles up ahead of the erupting magnetic structure. The dark cavity and bright core are interpreted as magnetic flux rope (MFR) and cold prominence (filament) matter that is suspended in the magnetic dips of the MFR, respectively. Nevertheless, white-light data are incapable of disclosing the early dynamics of CMEs, in particular, the formation of CMEs. Taking advantage of extreme-UV (EUV) multiple-wavelength imaging data, Zhang et al. (2012) and Cheng et al. (2013) found that the pre-eruptive configuration of CMEs first appears as a channel-like high-temperature MFR structure. After it is triggered, it quickly evolves toward the CME cavity and drives the formation of the CME leading front at the same time (Cheng et al. 2014). Moreover, the CMEs can also present a three-component structure in the EUV passbands, very similar to what is observed in white-light data (e.g., Song et al. 2019b).

The kinematic evolution of CMEs is closely coupled with the variation in the soft X-ray emission of associated flares (Cheng et al. 2020). Zhang et al. (2001, 2004) studied the temporal evolution of the velocity of flare-associated CMEs and found that it can be divided into three phases: a slow rise phase and an impulsive acceleration phase, followed by a propagation phase of constant speed. The three evolution phases correspond well to the three phases of the soft X-ray flux of associated flares: a pre-flare phase, a rise phase, and a decay phase, respectively (also see Zhang et al. 2001; Marićić et al. 2007). Moreover, some studies revealed that the acceleration of CMEs coincides very well with the hard X-ray flux of associated flares (Wang et al. 2003; Qiu et al. 2004; Jing et al. 2005; Temmer et al. 2008, 2010). These results strongly support the so-called standard flare model, in which CMEs and associated flares are thought to be two manifestations of the same physical process, that is, reconnection.
coupled disruption of the coronal magnetic field (Lin & Forbes 2000; Priest & Forbes 2002).

In addition to radial propagation, CMEs also present a lateral expansion, which could play a more important role in the CME formation. In the outer corona, it is found that the expansion of CMEs tends to be self-similar, that is, it expands radially and laterally at the same rate (Schwenn et al. 2005). In the inner corona, however, CMEs will undergo strong lateral overexpansion, in which the CME width grows faster than the height of the CME centroid (Patsourakos et al. 2010a,b; Cheng et al. 2013). This strong overexpansion is even able to excite a CME shock wave ahead of the CME leading front if the velocity exceeds the local Alfvén speed (Veronig et al. 2008; Temmer et al. 2009; Patsourakos et al. 2010a; Veronig et al. 2010; Cheng et al. 2012).

With appropriate conditions, the CME-driven shock wave can accelerate local electrons, which then give rise to type II solar radio bursts (Krucker et al. 1999; Klassen et al. 2002; Simnett et al. 2002). In radio dynamical spectrographs, type II bursts appear as a narrow band that drifts toward lower frequency, showing the evolution of the CME shock toward the region of lower density (Wild & McCready 1950). On the other hand, type III radio bursts, presenting an extremely fast frequency-drifting rate, appear more frequently in radio spectrographs. They are mostly argued to be caused by energetic electrons that are accelerated by associated flares and then propagate along open magnetic field lines. Some type III bursts even exhibit reversed drifting features, which are thought to be caused by electrons moving toward the lower atmosphere (van Driel-Gesztelyi et al. 2008).

Although much progress has been achieved in the study of the early CME evolution, it is still far from fully understood how the different structures of CMEs are formed. One of the main restrictions is the lack of observations that are capable of continuously and routinely tracking CMEs from the solar limb to 3 R_⊙. In this paper, we investigate a well-observed limb CME that took place on 2021 May 07 and was observed continuously from 0 to 3 R_⊙ by a combination of EUV and white-light images. In particular, we pay more attention to the CME overexpansion and to various radio bursts it induced. In Section 2 we introduce the instruments. In Section 3 we present the methods and main results. This is followed by a summary and discussions in Section 4.

2. Instruments

The Atmospheric Imaging Assembly (AIA; Lemen et al. 2012) on board the Solar Dynamics Observatory (SDO) provides EUV
and SWAP 174 Å passbands, the erupting bubble caused the ex-
keV. In addition, the combination of solar radio dynamic spec-
combination detector and Image Processing (SWAP; Bougeret et al. 2020) network spectrometer at the BIR station.

calibrated. The Sun Watcher using Active Pixel Sys-
space observatory (MLS0) observes the coronal polarization
100 MHz was obtained from Wind/Waves (Bougeret et al. 1995) and from the e-CALLISTO (Benz et al. 2009) network spectrometer at the BIR station.

temporal resolution is 11 arcsecs and the temporal candence is 15
s. In this paper, we mainly used the data from MLS0/K-Cor and
AIA data at 131 Å and 211 Å passbands with a temporal
candence of 60 s and 36 s, respectively. The K-Cor data we used
were well calibrated. The Sun Watcher using Active Pixel Sys-
tem detector and Image Processing (SWAP; Seaton et al. 2013)
on board the PRoject for Onboard Autonomy 2 (PROBA2) were
also used as a supplement. The X-Ray Sensor (XRS; Chamber-
lin et al. 2009) on board the Geostationary Operational Environ-
mental Satellite-R (GOES-R) provided the soft X-ray 1–8 Å flux
of associated flare, and the Spectrometer Telescope for Imaging
X-rays (STIX; Krucker et al. 2020) on board Solar Orbiter (SO)
observed the hard X-ray flux at the energy band from 4 to 150
keV. In addition, the combination of solar radio dynamic spectra
of 20 kHz to 100 MHz was obtained from Wind/Waves
and MLso/K-Cor. The bright core was first observed at
18:56 UT. Similar to the erupting EUV high-temperature blob,
it also propagated in a significantly nonradial direction before
19:11 UT. Nevertheless, we did not detect the rotation of the
bright core, which was detected for the EUV blob. The CME
leading front first appeared at ~18:59 UT and propagated almost
radially. Its top boundary can be identified clearly before
19:11 UT. The bright core appeared earlier than the leading
front in the K-Cor FOV, mainly because in the early phase of the
eruption, not enough plasma was accumulated at the CME front,
which was thus invisible. Moreover, we find that the CME front
was asymmetrical: its northern part seemed to be strongly com-
pressed by a nearby streamer. Their interaction even gave rise
to complicated radio bursts, which are discussed in Section 3.4.
Unfortunately, the shock wave for the current event may be too
weak to be clearly visible at the EUV and white-light bands.

3. Observation

3.1. Event overview

On 2021 May 7, a limb CME in active region (AR) NOAA 12822
was observed simultaneously by SDO, PROBA2, and MLso. It
originated from the eruption of a high-temperature blob, which
was also called the CME core in the EUV passbands (Song et al.
2019a), as shown in the AIA 131 Å passband (the red blob in
Figure 1a–1c). After its appearance (~18:50 UT), the blob started
to grow. At 18:57 UT, it seemed to rotate in a counterclock-
wise direction, presenting a channel-like feature very similar to
the hot-channel MFR that is detected for face-on events (e.g.,
Zhang et al. 2012; Cheng et al. 2013, 2014). In the AIA 211 Å
and SWAP 174 Å passbands, the erupting bubble caused the ex-
pansion of the overlying fields and the accumulation of plasma,
which quickly formed a bright leading front followed by a dark
cavity (Figure 1d–1e). The front and core structures of the CME
As seen in the EUV passbands (Figure 1b and 1c) are very similar
to what is usually observed in the white-light band (e.g., Figure
3 and Figure 11 in Veronig et al. 2018).

Figure 2 shows the early evolution of the white-light CME
captured by MLso/K-Cor. The bright core was first observed at
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3.2. Kinematics of the CME bright core and dark cavity

To quantify the expansion and propagation of the different struc-
tures of the CME, we first defined the height of the CME (Hr)
as the radial distance from the highest point of the bright front
(yellow asterisk in Figure 2) to the solar limb that is independ-
ent of the CME position angle, and the CME width (Dr) as the
maximum arc length of the CME bubble relative to the he-
liocenter (solid red line in Figure 2). Because the CME bright
core propagated nonradially at the early stage, the definitions
of its height and width are different from those of the CME bub-
ble. The height (Hr) is the distance from the top of the CME
bright core (yellow cross in Figures 1 and 2) to the source region
white point in Figures 1 and 2). The width (Dr) is the arc length
(solid cyan line in Figure 2) in the direction perpendicular to its

Fig. 2. K-Cor images of 2021 May 07 CME. The dashed cyan line shows the eruption direction of the bright core. The white point and yellow cross in panel (b) have the same meaning as in Figure 1b. The solid red line represents the width of the bright core. The dashed red line shows part of a circle with a center at the solar center, which is tangent to the CME leading front, while the yellow asterisk marks its position. The solid red line shows the width of the CME bubble. Purple arrows mark the positions of the interaction between the CME front and streamer. (An animation of this figure is available.)

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propagation direction (dashed cyan line in Fig. 2). All the above parameters were measured manually five times.

Before we performed measurements, we processed the AIA images by the IDL routine *aia_rfilter.pro* in SSW package to enhance the coronal structures above the limb, that is, by summing a number of EUV images acquired at consecutive times to increase the signal-to-noise ratio. The off-limb corona was divided into concentric rings. The corona structures in different rings were scaled based on parameters including the ring radius, average brightness, and intensity relative to the neighboring rings. For white-light coronagraph K-Cor data, the normalized radially graded filter (NRGF; Morgan et al. 2006, 2012) was used, which scales the corona structure by the mean brightness and its standard deviation at different heights. Because the CME leading front in the EUV images is not sharp enough, only the K-Cor data were used to quantify the front parameters.

The MFR at the AIA 131 Å passband is found to be observed partially face-on, which makes it difficult to justify the cross section of the MFR; thus the core width was also derived from K-Cor data. For each parameter, we repeated the measurement five times and obtained the average value. The standard deviation was considered as the corresponding uncertainty. Then, through calculating the first-order numerical differential of height-time and width-time data by the IDL routine *deriv.pro*, we derived the eruption and expansion velocities of the CME bubble, called $V_{Hf}$ and $V_{Df}$, respectively. For the CME bright core, the eruption and expansion velocities ($V_{Hc}$ and $V_{Dc}$) were also derived similarly.

Moreover, we defined the aspect ratio to identify the overexpansion, which is the height of the CME (core) centroid divided by its half-width. For simplicity, we used $H_f - 0.5D_f$ and $H_c - 0.5D_c$ to denote the height of the CME and core centroids, respectively. The aspect ratios were then derived by $r_f = (2H_f - D_f)/D_f$ and $r_c = (2H_c - D_c)/D_c$ for the CME bubble and the core, respectively. To further reveal the temporal relation between the CME overexpansion and the flare energy release, the lower energy part (4-10 keV) of the STIX hard X-ray flux was used in addition to

Fig. 3. Early temporal evolution of the CME bubble and bright core in the radial and lateral directions. (a) Temporal evolution of the height and width of the CME bubble. (b) Temporal evolution of the radial and expansion velocities. The vertical bars denote their uncertainties. The STIX 4-10 keV and GOES 1-8 Å fluxes are also plotted in green and blue, respectively. The two vertical dashed lines mark their peaks. (c) The aspect ratio of the CME bubble. Panels (d)–(f) are similar to panels (a)–(c), but show the CME bright core. The black dots connected by solid and dashed lines are the measurements from the EUV blob and white-light bright core, respectively.
the GOES 1-8 Å soft X-ray flux. This is mainly produced by the bremsstrahlung of thermal electrons.

Figure 3 shows the early temporal evolution of the CME bubble (panels a–c) and bright core (panels d–f) in the radial and lateral directions. The width and height of the CME bubble are plotted in Figure 3(a) as a function of time, according to which the width of the CME bubble is larger than its height during the observation period. Figure 3(b) shows the evolutions of the radial and lateral velocities overlapped with the STIX 4-10 keV and GOES 1-8 Å flux curves. They both increase continuously before 19:08 UT. After this, the radial velocity tends to be constant at 600-700 km s\(^{-1}\), while the lateral velocity still quickly increases from \(\sim 600 \text{ km s}^{-1}\) up to \(\sim 1000 \text{ km s}^{-1}\) within 2 minutes. In Figure 3(c), the aspect ratio clearly shows two decrease phases. The first phase takes place near the flare peak time, that is, the impulsive energy release of the flare revealed by STIX 4-10 keV flux. This agrees well with the finding of Cheng et al. (2013). However, after an increase phase, the aspect ratio decreases again (after 19:08 UT), even though the flare has already evolved into the decay phase. The results show that the height increment of the CME leading front in the early phase comes mostly from its expansion.

The bright core of the CME that appears as the EUV high-temperature blob was tracked continuously to 0.3 \(R_\odot\). After this, it appeared at the white-light band and was captured by the K-Cor from 0.2 to 0.7 \(R_\odot\). The temporal evolutions of its height and width are presented in Figure 3(d) and that of the corresponding velocities in Figure 3(e). The eruption velocity of the bright core gradually increases to over 500 km s\(^{-1}\) near the flare peak (19:02 UT) and is then constant in the flare decay phase. The expansion velocity of the bright core also reaches its maximum near the flare peak and subsequently starts to decrease, which obviously differs from that for the CME bubble. The aspect ratio of the bright core rapidly decreases in the time period of 18:58 UT-19:01 UT. Similar to the CME bubble, the minimum aspect ratio is found to roughly correspond to the peak of the STIX 4-10 keV flux. This indicates that the CME bright core also experienced a strong lateral expansion, but only during the main energy release process of the flare. The aspect ratios of the CME bubble and bright core are greatly different, mainly because their widths are obviously distinct but the centroid heights are similar.

### 3.3. EUV MFR and white-light bright core

The overlapped FOV of the AIA and K-Cor allows us to explore the evolution of the different EUV structures of the CME toward the white-light structures. Here, we mainly focus on the evolution of the erupting high-temperature blob. Figure 4 shows that the EUV blob seems to be wider but lower than the white-light bright core at the same moment (Figure 4(c) and 4(d)). Here,
we determine the boundary of the bright core by performing the threshold segmentation on the original data (Figure 4b). We set the threshold to be 40% of the maximum brightness. In order to check the influence of the threshold, we also changed the threshold within 20% and find that it does not affect our conclusion qualitatively.

Figure 4c and 4d show the temporal evolution of the height and width of the EUV blob and that for the white-light bright core, respectively, during the time period of 18:57 UT–19:02 UT. The discrepancy in height between the two structures is over 10 Mm, similar to the discrepancy in width. We used the same method to measure the height and width of the EUV blob and white-light core as in Figure 3. The discrepancy mainly arises from the fact that the visibility of the EUV MFR structure is not only related to the density, but also the temperature, while that of the white-light structure only relies on the density.

Furthermore, for this particular event, we do not observe an erupting filament, and thus the CME white-light bright core is likely contributed by the erupting flux rope as argued by Song et al. (2019a). However, during the flare, magnetic reconnection proceeds continuously, forming the poloidal flux that is added to and envelopes the erupting MFR. Meanwhile, due to the reconnection heating, the envelope layer of the flux rope should be much hotter than its inner part (e.g., Cheng et al. 2018). On the other hand, the density of the MFR drastically decreases as it erupts outward because of its overexpansion. We speculate that the entire MFR could be larger than both the observed EUV blob and white-light bright core. The discrepancy between the morphologies shown in the EUV and in white-light is mainly caused by their different responses to the density and temperature structures within the MFR. In addition, many other factors also influence the visibility of CME different structures, such as the projection effect and the deflection during the propagation.

3.4. Radio bursts caused by the CME overexpansion

As the CME expanded, it interacted with the streamer in the north and caused three types of radio bursts: a normal type II burst, a stationary type II burst, and a group of type III bursts with both normal and reversed parts, whose dynamic spectrographs are shown in Figure 5. Figure 5(b) shows that the normal type II burst consisted of one fundamental and one harmonic components, the latter of which started at 80 MHz at 19:08 UT and slowly drifted to 40 MHz at 19:15 UT with a drifting rate of 1 MHz/s (also see Figure 6). Moreover, the stationary type II burst also included fundamental and harmonic components, which appeared at 27 MHz and 55 MHz, respectively, and lasted for about 5 minutes. In Figure 5(c), the zoom-in dynamic spectrograph at the time period of 19:07 -19:09 UT clearly displays the reversed type III signals: a group of type III bursts started at about 30 MHz and then drifted toward the higher frequency of over 40 MHz. Figure 5(a) also shows signals toward ~100 kHz that lasted for more than 20 minutes. The positive and negative drifting type III bursts form a C-shape in the spectrum and are therefore called C-shaped type III bursts thereafter.

To reveal the origin of these radio bursts, we studied the interaction of the CME overexpansion with the northern streamer. Taking advantage of the density model, we first estimated the height of the source region of the drifting type II burst. The frequency was converted into the density based on the following formula:

\[ f_p = 8.98 \times 10^{-3} \sqrt{n_e}, \]  

where \( f_p \) and \( n_e \) represent the frequency (MHz) and the electron density (cm\(^{-3}\)), respectively. The plasma frequency is taken from the half of the first harmonic component because it appears more clearly than the fundamental one and thus can be used in measurements with a higher precision. The density model we used
Fig. 6. Properties and explanation of three types of radio bursts.
(a) Radio dynamic spectrograph representing a drifting and stationary type II radio burst. The white (black) points mark the harmonic (fundamental) frequency of the drifting type II burst and are used to estimate the heights of the source region. (b) Height-time profiles of the drifting type II burst source region derived from the model of Saito et al. (1977) (red) and of the interaction region between the CME and streamer estimated directly using the K-Cor data (black). The shaded region represents the possible initial height of the type III bursts. (c) Sketch interpreting the interaction between the CME shock and streamer. The green and blue curves are the opened and closed streamer magnetic field lines, the purple curves represent the CME-driven shock front, and the black curve is the streamer current sheet. The radio-emitting regions related to the type II bursts are marked $A_i$ and $B_i$.

Here is from Saito et al. (1977), which takes the following form:

$$n_e = 1.36 \times 10^6 r^{-2.14} + 1.68 \times 10^8 r^{-6.13},$$ (2)

where $r$ is in units of solar radii and $n_e$ is in units of cm$^{-3}$. Solving Equations (1) and (2) with a nonlinear least-squares method, we derived the height of the type II source region and its temporal evolution. The results are shown in Figure 6b, in which we also overplot the heights of the CME flank (where we determine the CME width in Figure 2) as the region of interaction with the streamer (the black triangles in Figure 6b). The two heights are very close to each other, indicating that the type II burst is most likely produced in the interaction regions in which the CME compresses the streamer.

The stationary type II burst may originate from a source different from the drifting type II burst. Aurass & Mann (2004) observed a zero-drifting type II burst and argued that it was caused by the interaction between a termination shock driven by the reconnection outflows and the flare loops. However, the frequency of the zero-drifting type II burst under study is clearly much lower than that observed by Aurass & Mann (2004). We speculate that this is also generated during the CME-driven shock that crosses the streamer. In Figure 6c we interpret the possible generation process of two type II bursts. It is likely that two sources of type II bursts are formed during the interaction of the CME-driven shock and streamer with one (A) moving outward and the other (B) just crossing the streamer, which generates the drifting and stationary type II bursts, respectively.

The type III radio burst is thought to be caused by energetic electrons that escape from the Sun along the open field lines. However, in addition to the normal type III burst, we also observe a group of reversed type III bursts, which had a starting frequency of $\sim 30$ MHz and then drifted toward the higher frequencies (Figure 5c), showing that energetic electrons propagate downward. Based on the density model, the initial height of the reversed type III bursts is estimated to be in the range of 1.45-1.61 $R_\odot$ (the gray region in Figure 6b), which is very close to the height at which the CME interacts with the streamer. Moreover, the reversed type III bursts mostly appeared near the onset time of the drifting type II burst. Thus, it is most likely that the interaction between the CME and streamer also involves interchange reconnection, which releases energetic electrons trapped in the erupting CME. These electrons move upward and downward, giving rise to positive-drifting and negative-drifting type III bursts, respectively.

4. Summary and discussions

We studied the formation and early dynamics of a CME on 2021 May 7. The CME occurred near the solar limb and was captured by SDO/AIA and MLSO/K-Cor simultaneously, thus allowing us to investigate the continuous evolution of the CME different
structures from 0 to 3 R⊙, by minimizing projection effects. An interesting finding is that this CME bubble underwent two overexpansion processes. The first overexpansion process occurred near the flare peak, similar to previous results (Patsourakos et al. 2010a; Cheng et al. 2013; Balmaceda et al. 2022), and the second occurred in the decay phase, when magnetic reconnection had greatly weakened.

Based on the standard flare model (Carmichael 1964; Sturrock 1966; Hirayama 1974; Kopp & Pneuman 1976), Patsourakos et al. (2010a) proposed two effects that probably cause the overexpansion. First, the reconnection in the flare current sheet underneath the MFR continuously adds additional poloidal flux to the erupting MFR, thus causing the MFR overexpansion. Second, an MHD process (called inverse pinch effect in Kliem et al. (2014)) is also capable of causing the overexpansion. As the MFR rises, the current decreases because of the flux conservation between the MFR and the photosphere. As a result, the poloidal flux decreases and a larger volume is required to compensate for the weaker fields, acting as the lateral overexpansion of the MFR. Based on the relation of the CME overexpansion to the flare, for the current event, the first and second overexpansion is attributed to the reconnection-dominated effect and the ideal MHD inverse pinch effect, respectively. Balmaceda et al. (2022) also interpreted the overexpansion of two bubble-like CMEs as caused by the reconnection process based on its simultaneity with the impulsive phase of the associated flare. Zhan et al. (2022) even found that the CME overexpansion extended to the high corona over 10 R⊙. However, different from our interpretation, they argued that flare reconnection was the unique mechanism to drive the overexpansion continuously.

Based on the overlapped FOV of AIA and K-Cor, we compared the morphological discrepancy between the white-light bright core and the EUV blob. The EUV blob is lower but wider than the bright core. In the context of standard flare model, a large quantity of heat flow is generated quickly by the flare reconnection and is then added to the MFR, thus resulting in the fast expansion of the MFR (Cheng et al. 2013; Veronig et al. 2018). However, the temperature of the MFR might be nonuniform. The lower part of the MFR is found to be much hotter than the upper part (Cheng et al. 2018; Ye et al. 2021); thus probably only part of the MFR is visible at the EUV high-temperature passbands. This means that the real CME MFR is more likely larger than the EUV blob, in particular when the hot MFR has cooled down, while for the white-light bright core, it merely corresponds to a part of the MFR where the plasma is dense.

The interaction of the expanding CME with the nearby streamer produced multiple radio bursts, including a typical and a stationary type II burst. We argue that the two type II bursts are generated at two sources simultaneously. They are thus most likely from the two different sources at the CME-driven shock front.

The interchange reconnection may take place at the beginning when the expanding CME interacts with the streamer. This is strongly supported by the appearance of a group of C-shaped type III bursts. In general, the formation of type III bursts needs two conditions, one of which is accelerated electrons, and the other is open flux. Nevertheless, the energetic electrons are mostly restricted within the close flux of the erupting CME unless the reconnection takes place between the CME flux and the background field so as to release restricted electrons (van Driel-Gesztelyi et al. 2008; Masson et al. 2013; Kou et al. 2020). The released electrons propagate upward and downward and then give rise to the C-shaped type III burst (van Driel-Gesztelyi et al. 2008; Halliras et al. 2011; Zheng et al. 2017).

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