Multiple shocks generated by the 2024 May 14 coronal mass ejection

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Context

On 14 May 2024, a fast coronal mass ejection (CME) erupted from active region (AR) 13680 on the solar northeast limb, triggering a series of type II radio bursts. This event, part of a sequence of intense solar activity between 10–14 May 2024, also produced global auroral displays, an M4.5-class flare, and a preceding X8.7-class flare.

Methods

We combined white-light imaging from the SOHO/LASCO C2-C3 instruments and extreme ultraviolet (EUV) imaging from the GOES/SUVI instrument with ground-based low-frequency radio observations from the Irish station (I-LOFAR, 10–240 MHz) to track the CME and its associated shocks. Height–time profiles were derived along 13 slits, and radio source heights were estimated using various electron density models. Coronal conditions were modeled using Potential Field Source Surface (PFSS) and Magneto-hydrodynamic Algorithm outside a Sphere (MAS/FORWARD) reconstructions to map Alfvén speed distributions and magnetic field configurations.

Key Results

- Four type II radio bursts were detected over ~15 minutes (Fig. 1), showing fine structures (band splitting, herringbones, and spectral fragmentation).
- Shock speeds ranged from ∼443–2075 km s^{-1}, with drift rates of –361 to –78 kHz s^{-1}, indicating super-Alfvénic shocks ($M_A \approx 3.2–3.6$).
- Bursts were triggered at different coronal heights, typically 18 min after CME onset, and were likely produced at the CME shoulders near the flanks (Fig. 2), where low Alfvén speeds and open magnetic field lines facilitated shock formation.
- The CME exhibited overexpansion, with lateral speeds exceeding radial propagation early on before stabilizing in the outer corona.

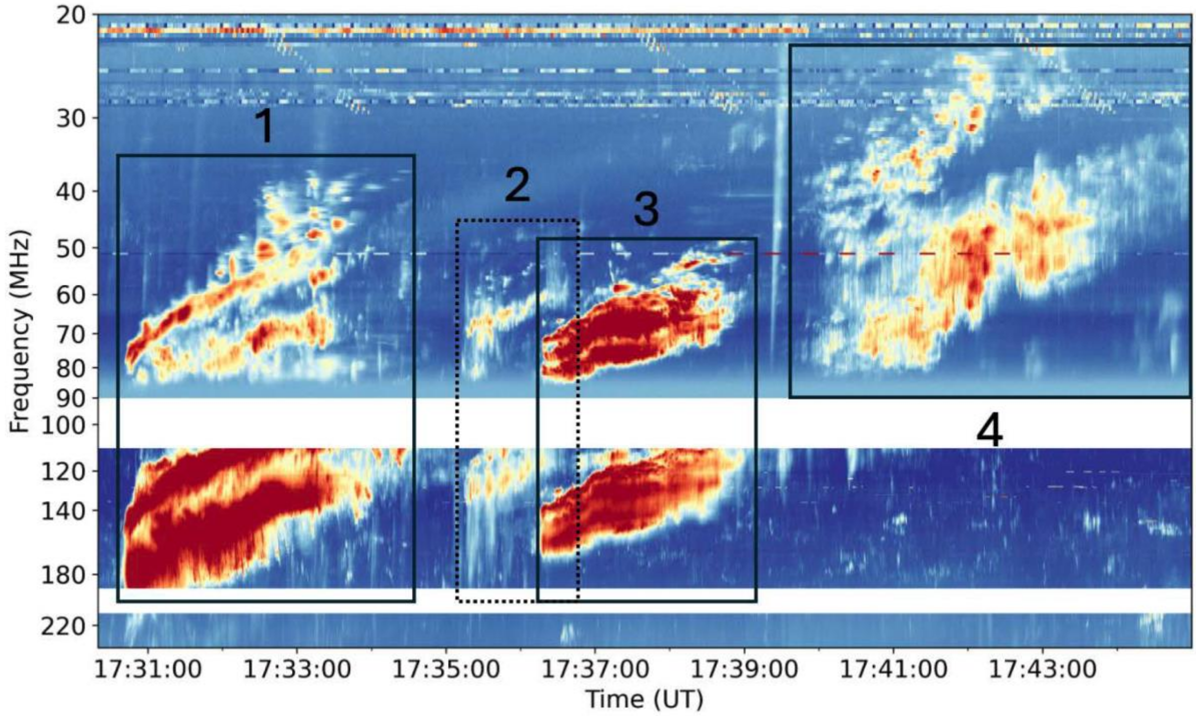

Fig. 1: I-LOFAR dynamic spectrum from 17:30 UT to 17:48 UT, covering 20 to 240 MHz, showing emission associated with the second CME. Each burst exhibits unique spectral features, including band-splitting, herringbones, spectral gaps, and fine structures.

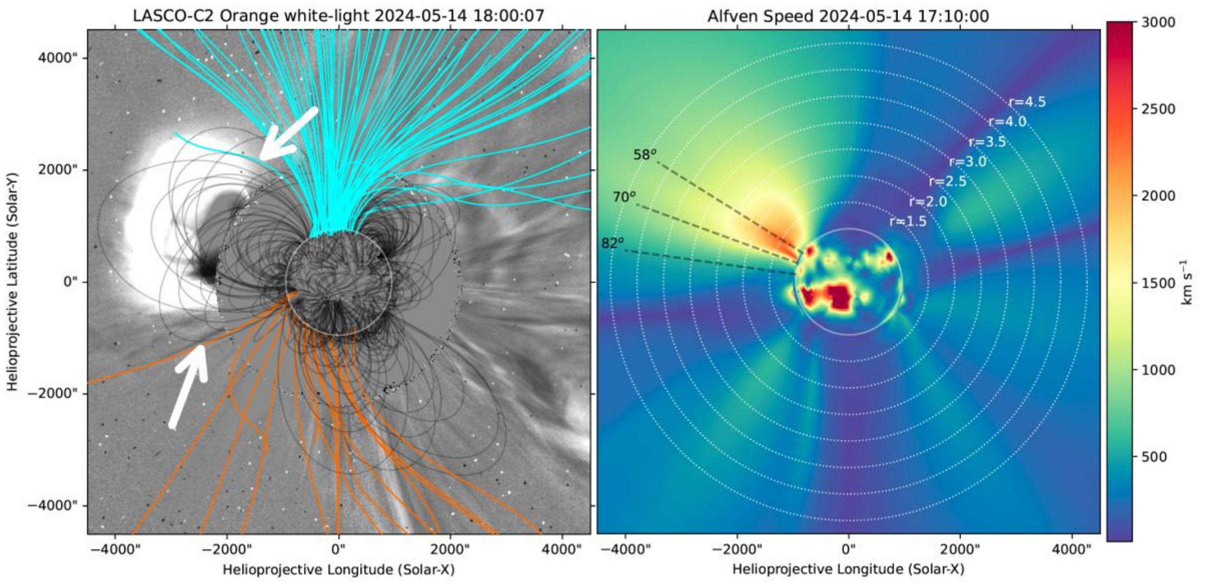

Fig. 2: Left: Running ratio image shows the PFSS model on top of the EUV wave in LASCO C2. The cyan and red lines are north and south magnetic polarities, respectively. Meanwhile, the yellow lines are closed field lines. For better contrast, we used black for the closed field lines in the LASCO C2 image. Right: FORWARD maps showing pre-eruption coronal conditions at 17:10 UT. The white circle denotes the solar limb, the same FOV as LASCO C2, with dotted circles representing different radial distances in solar radii

Conclusions

This study highlights the complex relationship between CME-driven shocks and type II radio bursts. The findings emphasize the role of coronal structure and Alfvén speed distribution in determining where and when shocks produce radio emission. Our results support the need for continuous, multi-wavelength solar monitoring and improved density models to constrain shock dynamics and enhance space weather forecasting.