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The Sun at Radio Wavelengths

LOFAR 135 MHz
(Credit: G. Mann, AIP)

Radio Burst above Active Region

Extreme Ultraviolet

Active Region

Visible

Sunspots
Radio bursts associated with Coronal Mass Ejections (CMEs)

Credit: Pietro Zucca, ASTRON
CMEs and Type II Radio Bursts

How do shocks accelerate electrons in the corona?

Type IIs are signatures of shock-accelerated electrons.

\[ f = n f_p = 9000 \sqrt{n_e} \text{ (Hz)} \]
Faint Type II radio burst associated with a CME associated with a large radio source most likely composed of multiple types of radio bursts.

CMEs and Type II Radio Bursts

Morosan et al., A&A, 2020
CMEs and Type II Radio Bursts

Perspectives from other spacecraft around the Sun can help reconstruct the radio emission location with respect to the CME.

Morosan et al., A&A, 2020
CMEs and Type IV Radio Bursts

Type IVs represent broadband emission that can have either moving or stationary sources that occur due to various processes.

Morosan et al., A&A, 2020
CMEs and Type IV Radio Bursts

Morosan et al., A&A, 2020

Large stationary radio source \(\rightarrow\) Positive spectral index \(\alpha\)

Smaller compact moving radio source \(\rightarrow\) Negative spectral index \(\alpha\)
CMEs and Type IV Radio Bursts

Gyro-synchrotron emission

Coherent emission: Plasma emission or electron-cyclotron maser emission
CMEs and Associated Radio Bursts

- Type IIIs, Type IVs, herringbones can show a propagation path in the direction of the CME expansion → electrons can be accelerated at numerous locations during an eruption
- Why not investigate CMEs and moving radio bursts in 3D?
CMEs and Moving Radio Bursts
The 14 June 2012 CME and Moving Radio Sources

Three moving radio sources observed with the Nançay Radioheliograph (NRH)

- Moving radio sources are bursty, narrowband, highly polarised, with steep spectral indices

→ fundamental plasma emission
Observations of Moving Radio Sources

Nancay Decametric Array
e-Callisto Birr
Location of Radio Sources and CME – 2D Picture

- Radio bursts centroids can be projected onto the STEREO perspectives using an electron density model of the solar corona to estimate the z-coordinate of the centroid.

Morosan et al., A&A, 2020
Location of Radio Sources and CME – 3D Picture

Using STEREO, NRH and GONG/HMI magnetograms:
- 3D model of CME
- 3D radio burst location
- 3D open field regions
- 3D pre-eruptive flux rope

Location of Radio Sources and CME – 3D Picture

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Morosan et al., A&A, 2020
CMEs and Moving Radio Bursts

The 22 May 2013 CME and Moving Radio Sources

SDO/Earth Perspective with overlaid NRH Radio Contours
CMEs and Moving Radio Bursts

The 22 May 2013 CME and Moving Radio Sources

The CME is expanding inside an earlier CME

➔ Lots of trailing features and magnetic field lines from the previous CME

a. SWAP 174 Å/LASCO C2/LASCO C3 13:25 UT

b. EUVI-A 195 Å/COR1-A/COR2-A 13:25 UT

Trailing CME field lines
CMEs and Moving Radio Bursts

Moving radio bursts occur at the northern CME flank where the CME expands into the trailing material of an earlier CME:
CMEs and Moving Radio Bursts

Possible acceleration mechanism: collapsing traps formed by the CME shock/CME field lines intersecting the non-radial trailing field lines from the earlier CME.

Magdalenić et al., 2002

Radio Centroids

Figure 3. The collapsing trap geometry. The particles are trapped in the shaded region. The magnetic field lines at the intersection with the shock front form two approaching magnetic mirrors as the front advances (indicated by velocity vector \( v_{sh} \)). In each reflection electrons \( (e) \) are accelerated.
Summary and Future Work

• Radio observations are great tools to determine the particle acceleration locations during solar eruptions.

• But, there are still many unanswered questions:
  o why are electrons accelerated only at specific locations since CME shocks are large scale structures?
  o where do Type IV emitting electrons come from?
  o what is the link between in situ electrons at L1 and electrons generating Type II and Type IV emission at the Sun?

  → Future ground-based radio observations combined with Parker Solar Probe and Solar Orbiter could find the link between in situ observed particles and observed moving radio bursts

  → Cubesats could track fast electrons even farther out from the Sun through radio observations