The Nature and Origin of Moving Solar Radio Bursts Associated with Coronal Mass Ejections

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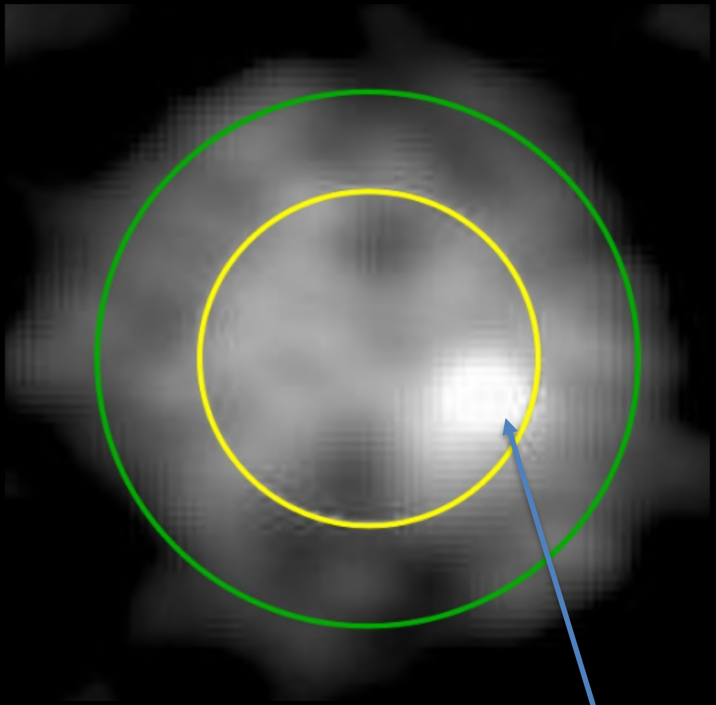
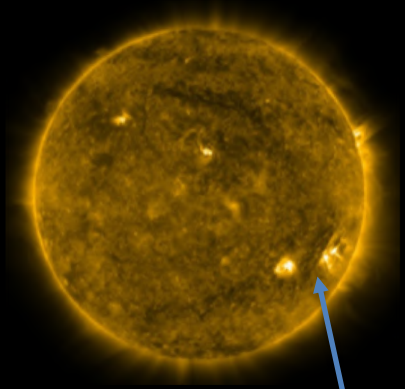
The Sun at Radio Wavelengths



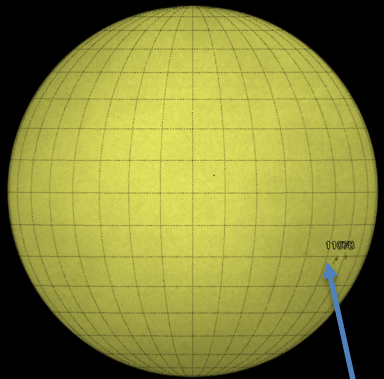
LOFAR 135 MHz
(Credit: G. Mann, AIP)

Radio Burst above
Active Region



Extreme Ultraviolet

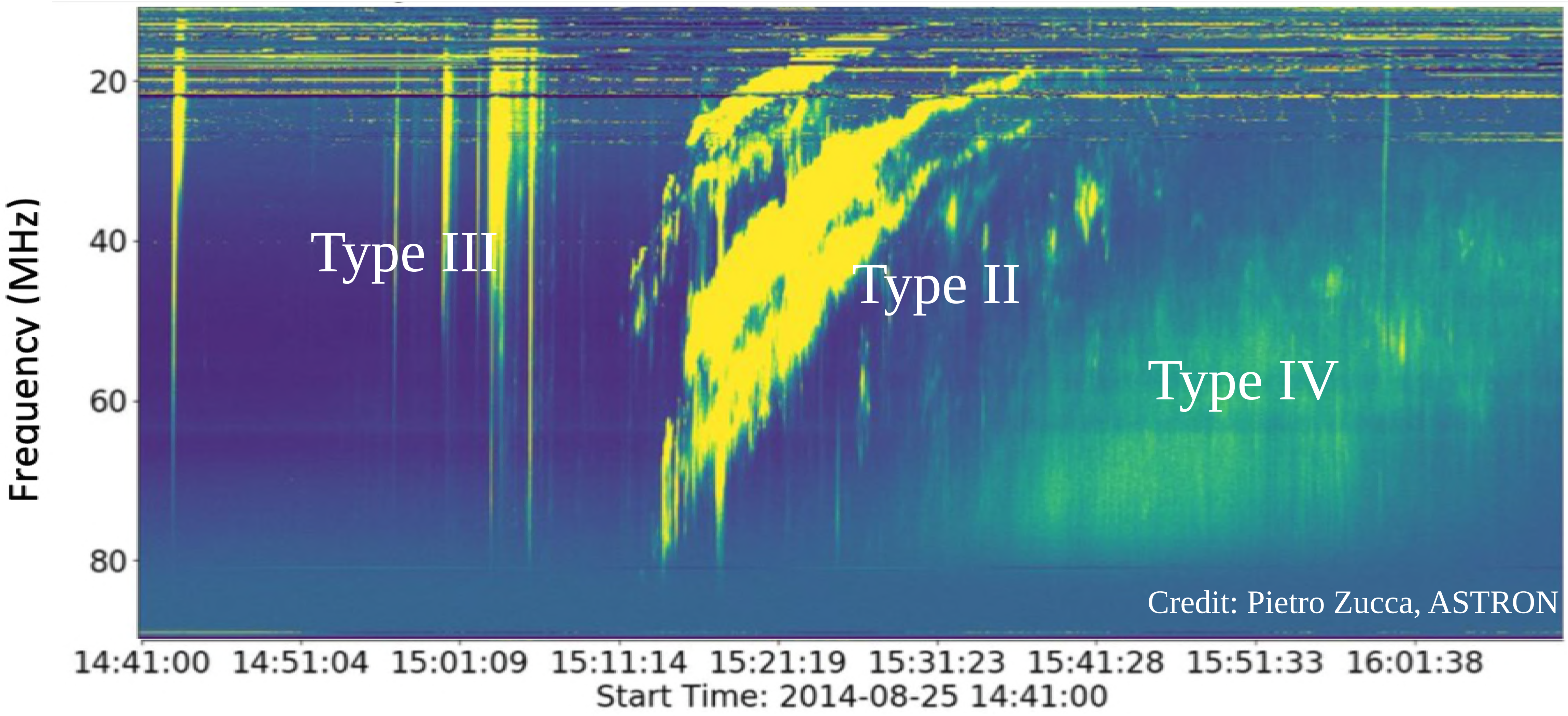
Active Region



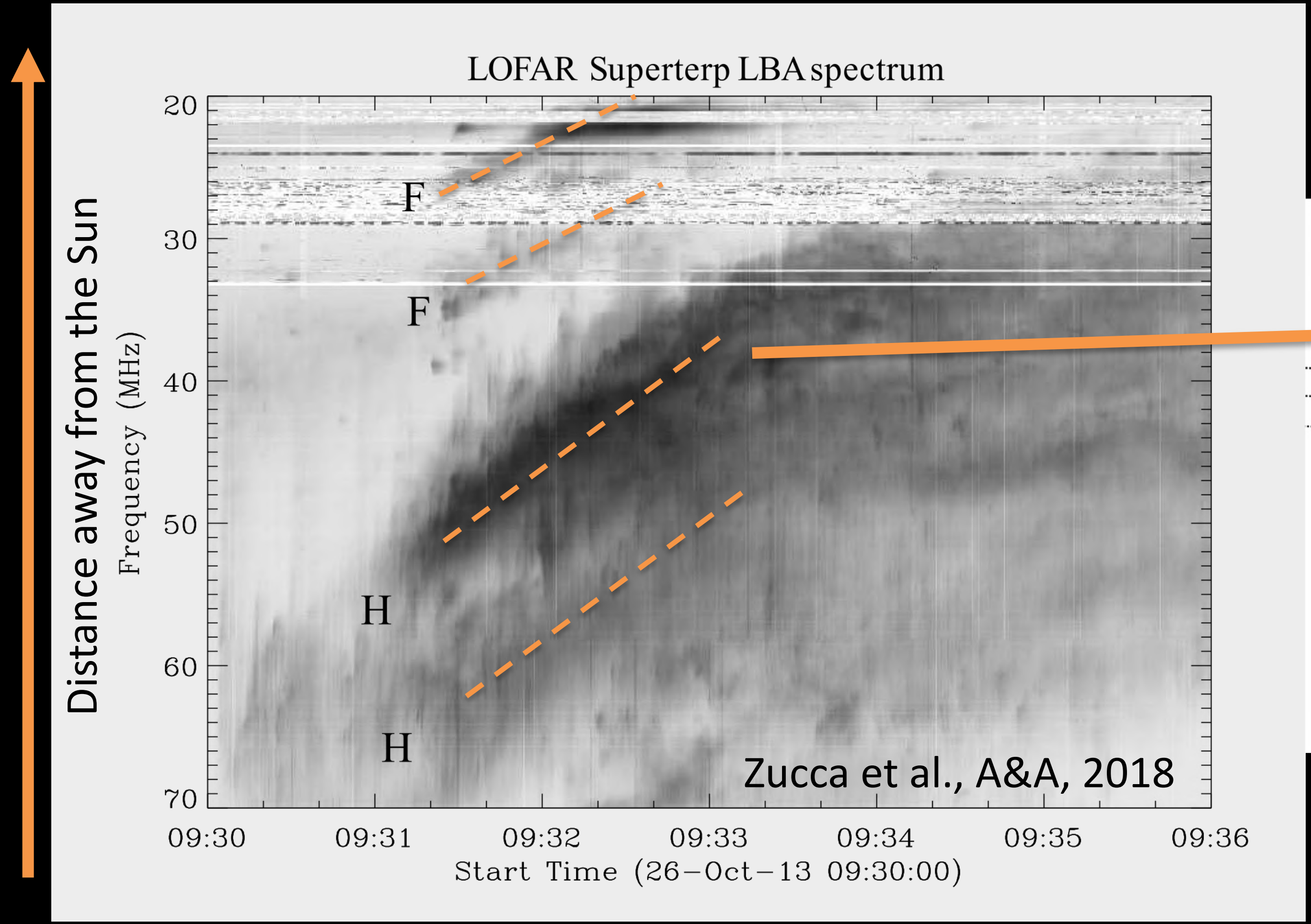
Visible

Sunspots

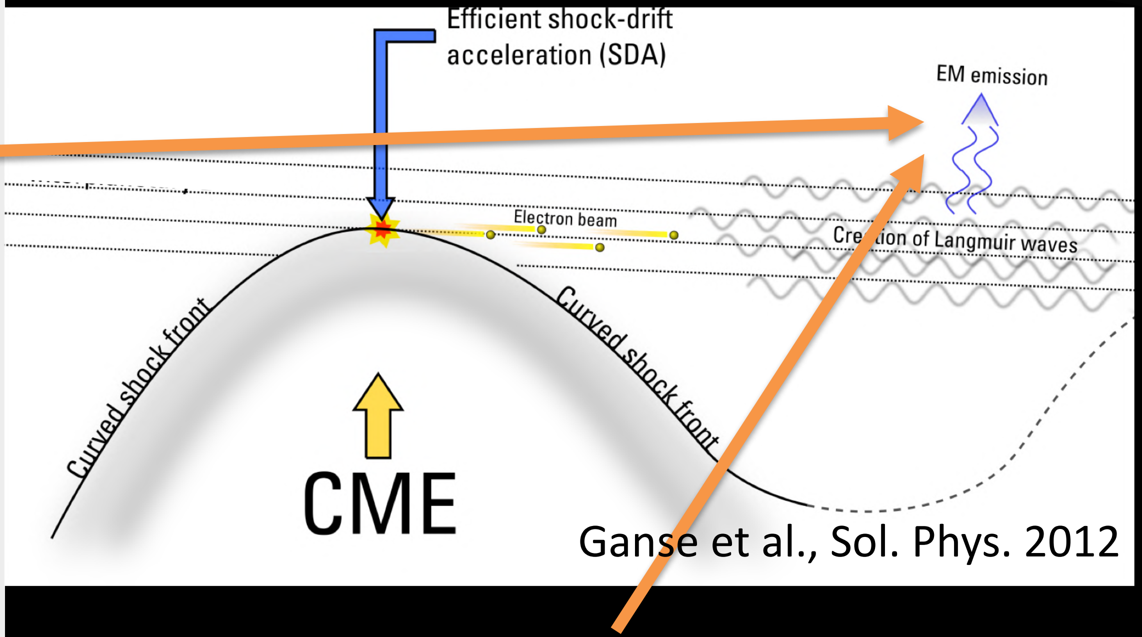
Radio bursts associated with Coronal Mass Ejections (CMEs)



CMEs and Type II Radio Bursts



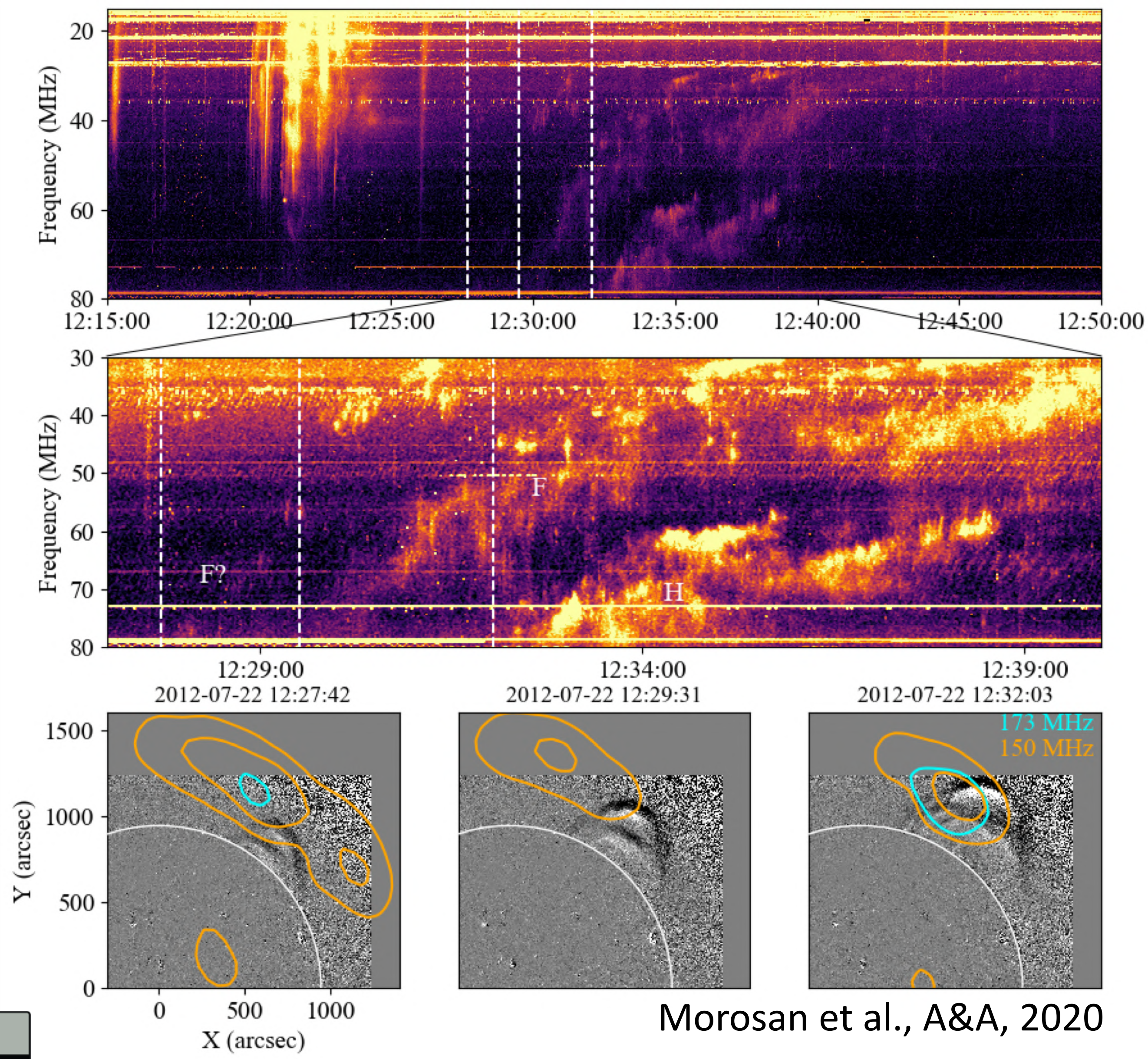
How do shocks accelerate electrons in the corona?



$$f = nf_p = 9000\sqrt{n_e}\ \text{(Hz)}$$

Type IIs are signatures of shock-accelerated electrons.

CMEs and Type II Radio Bursts



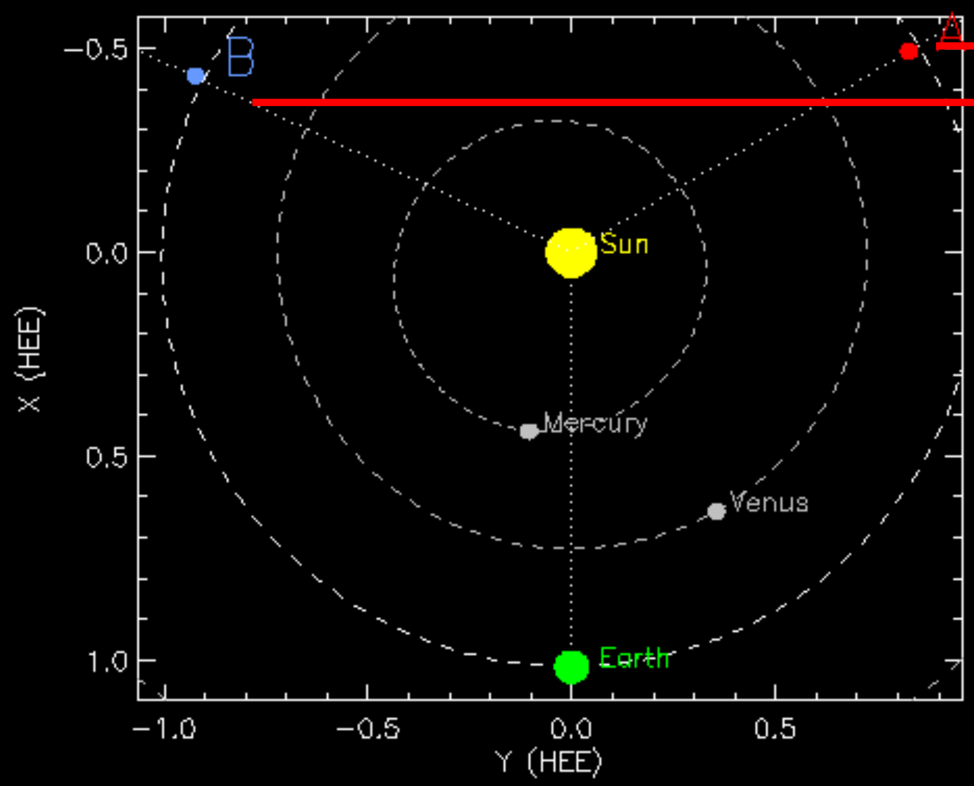
Morosan et al., A&A, 2020

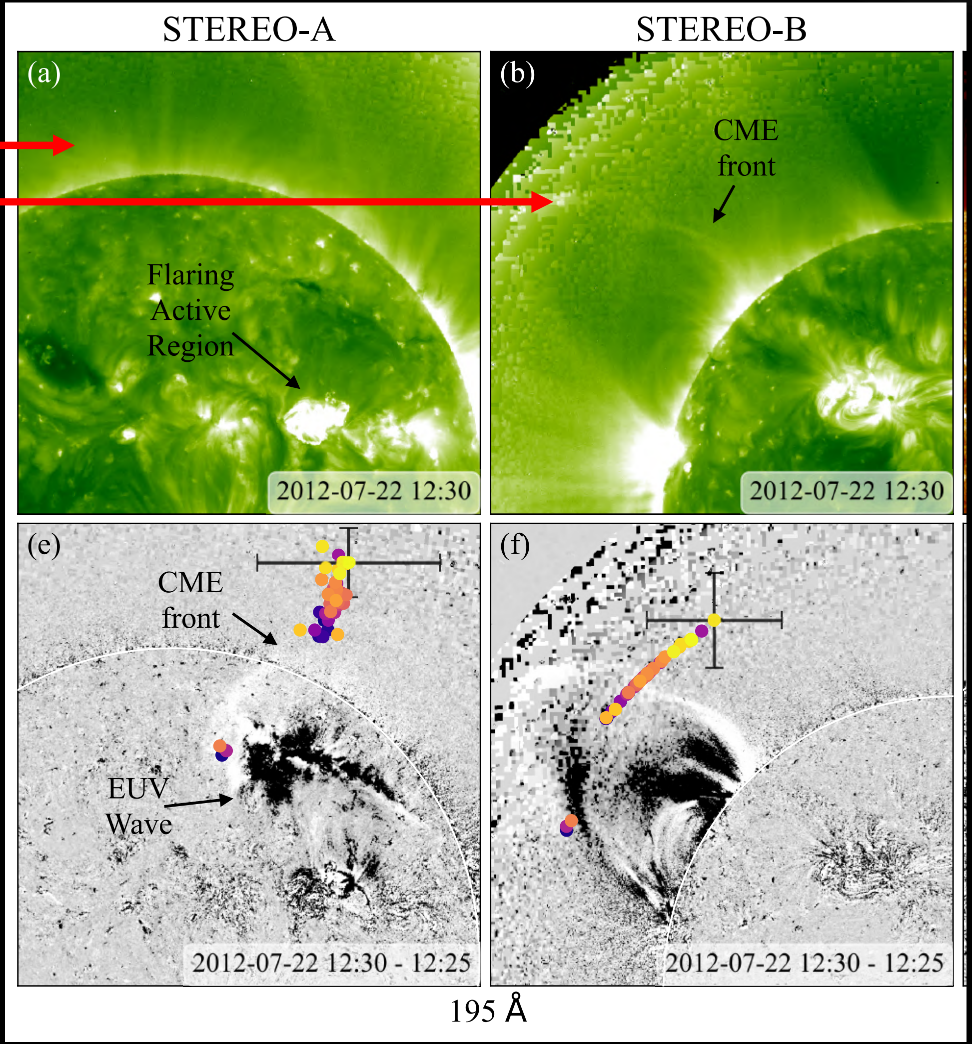
Faint Type II radio burst associated with a behind the limb eruption.

CME associated with a large radio source most most likely composed of multiple types of radio bursts.

CMEs and Type II Radio Bursts

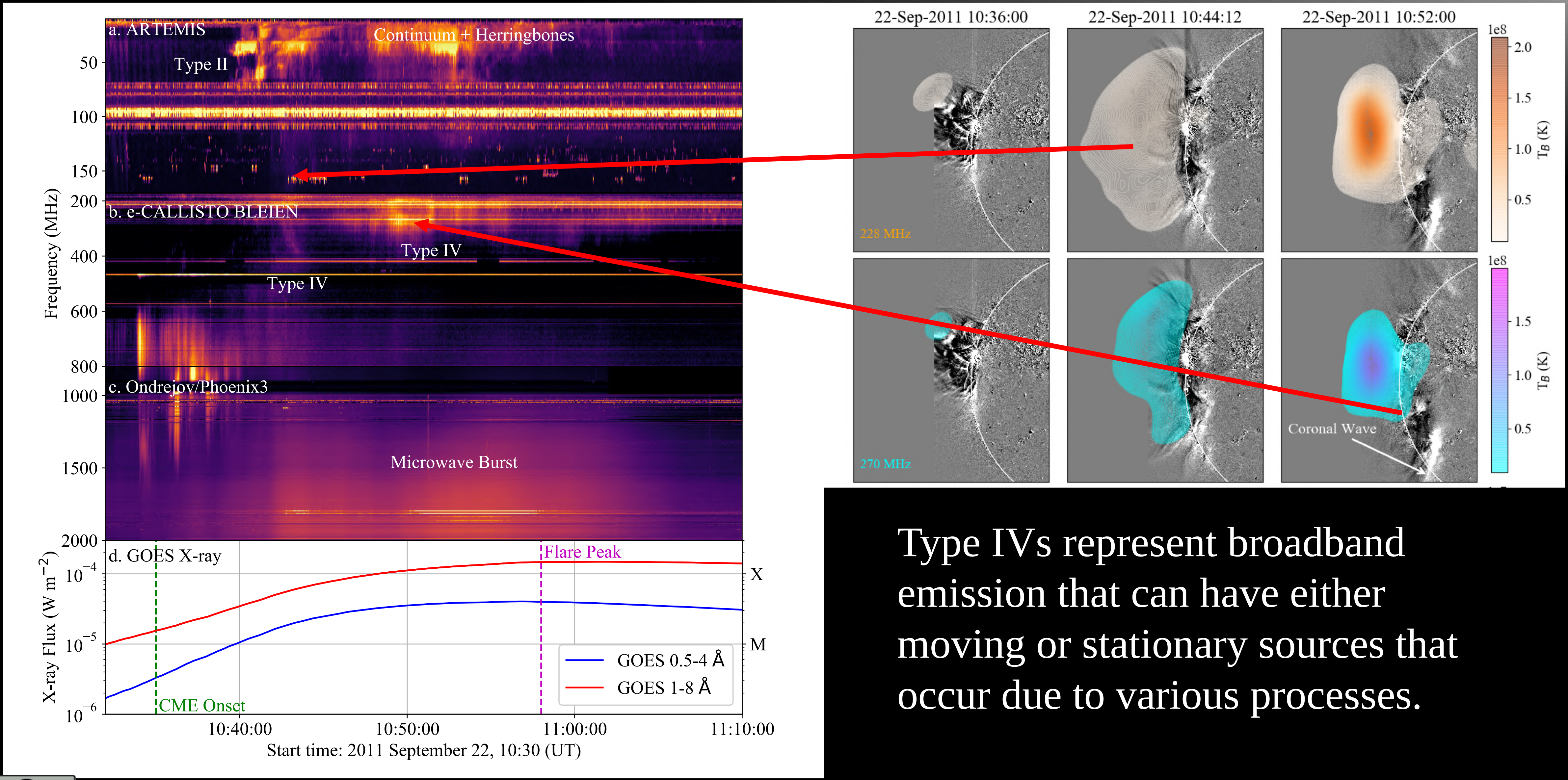
Perspectives from other spacecraft around the Sun can help reconstruct the radio emission location with respect to the CME.





Morosan et al., A&A, 2020

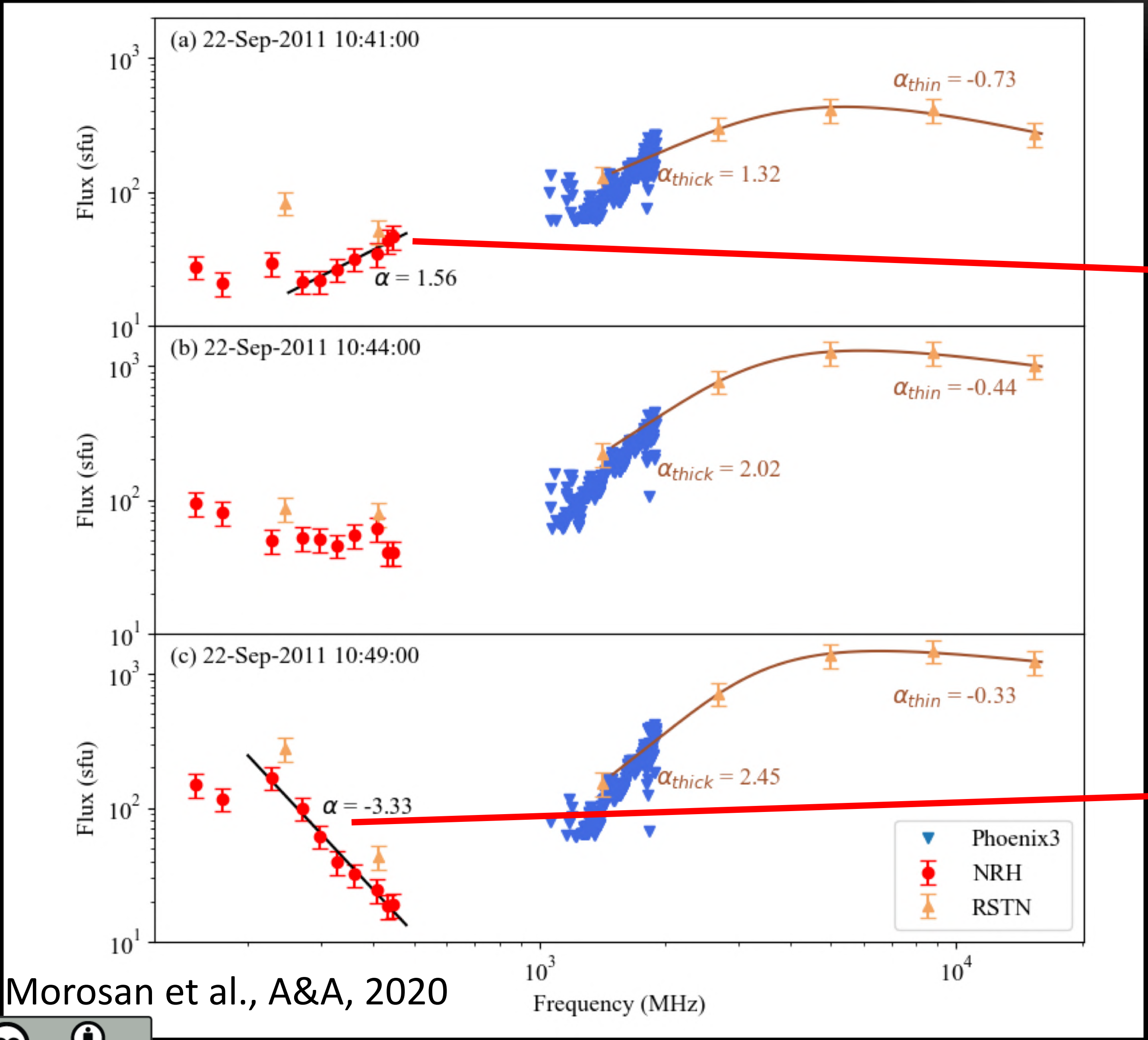
CMEs and Type IV Radio Bursts



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

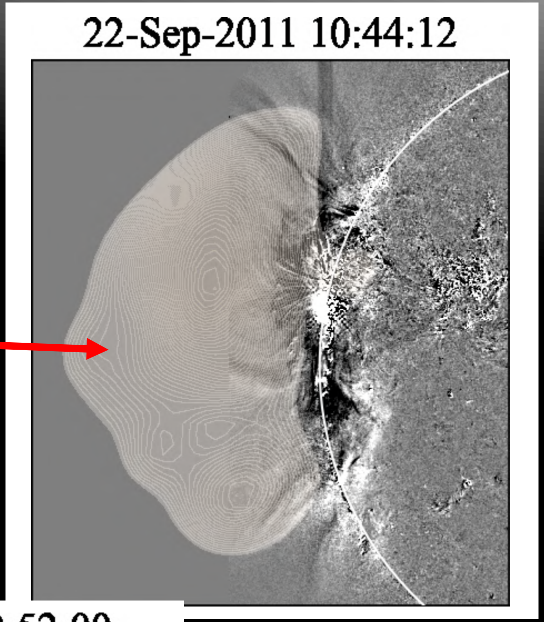
Morosan et al., A&A, 2020

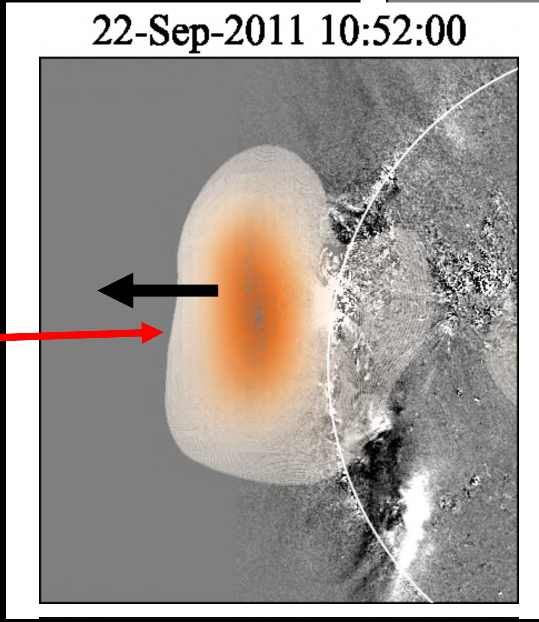
CMEs and Type IV Radio Bursts



Morosan et al., A&A, 2020

Large stationary radio source → Positive spectral index **α**

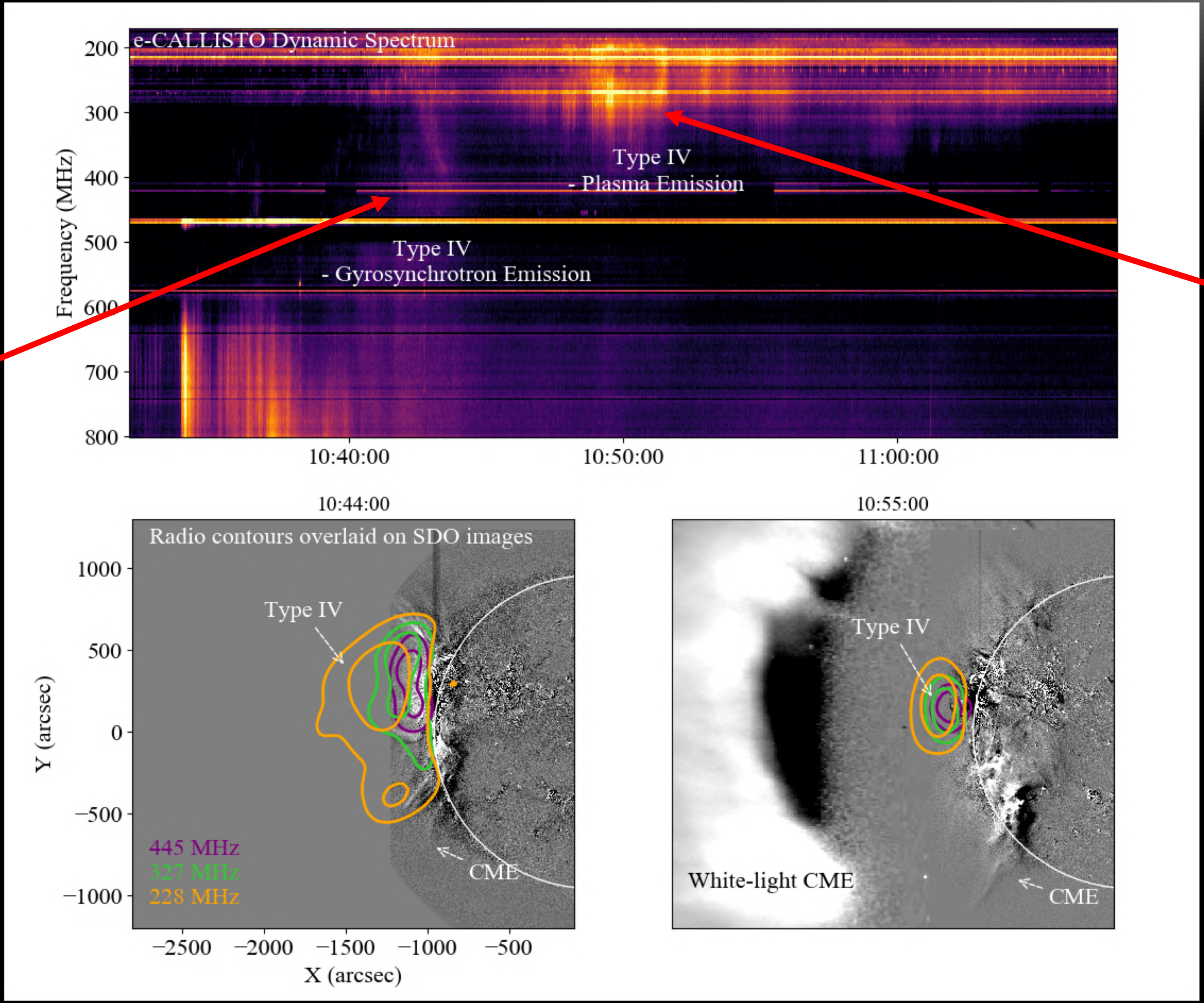




Smaller compact moving radio source → Negative spectral index **α**

CMEs and Type IV Radio Bursts

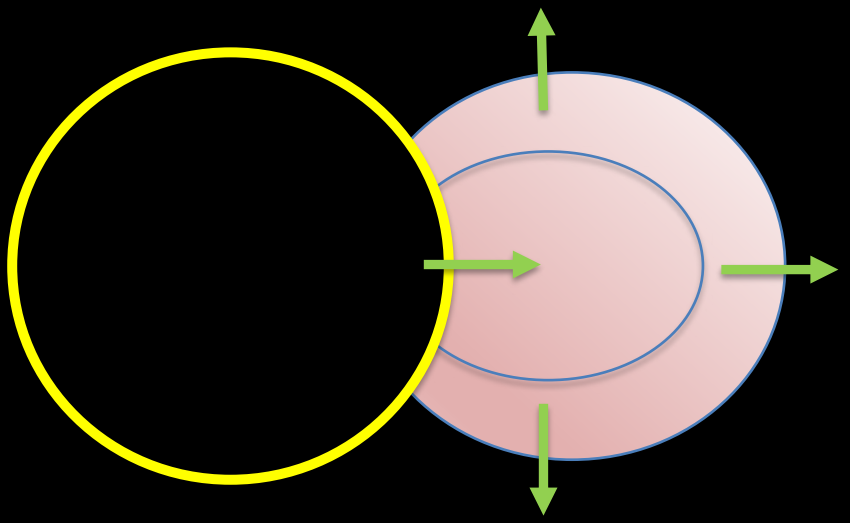
Gyro-synchrotron emission



Coherent emission: Plasma emission or electron-cyclotron maser emission

CMEs and Associated Radio Bursts

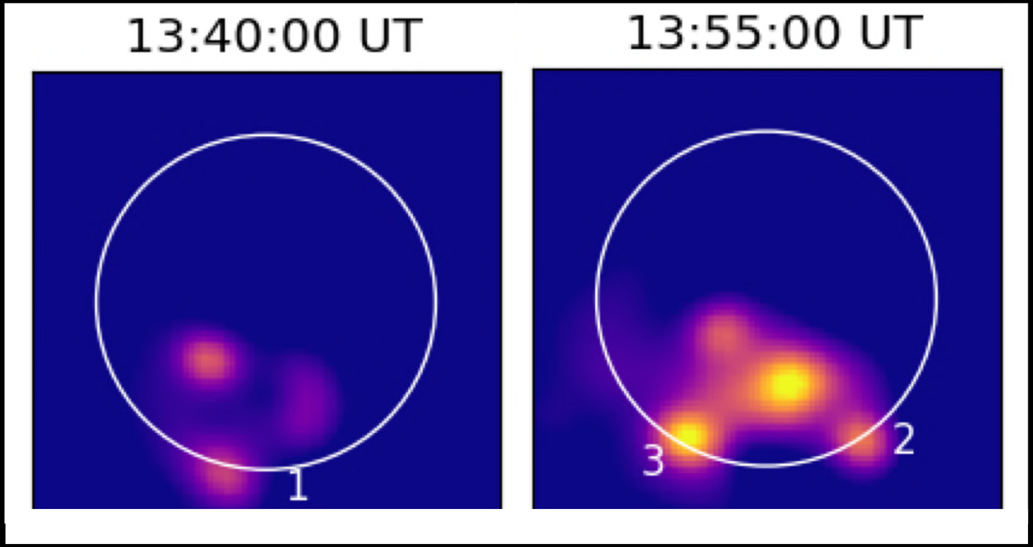
- Type IIs, Type IVs, herringbones can show a propagation path in the direction of the CME expansion → electrons can be accelerated at numerous locations during an eruption
- Why not investigate CMEs and moving radio bursts in 3D?



CMEs and Moving Radio Bursts

The 14 June 2012 CME and Moving Radio Sources

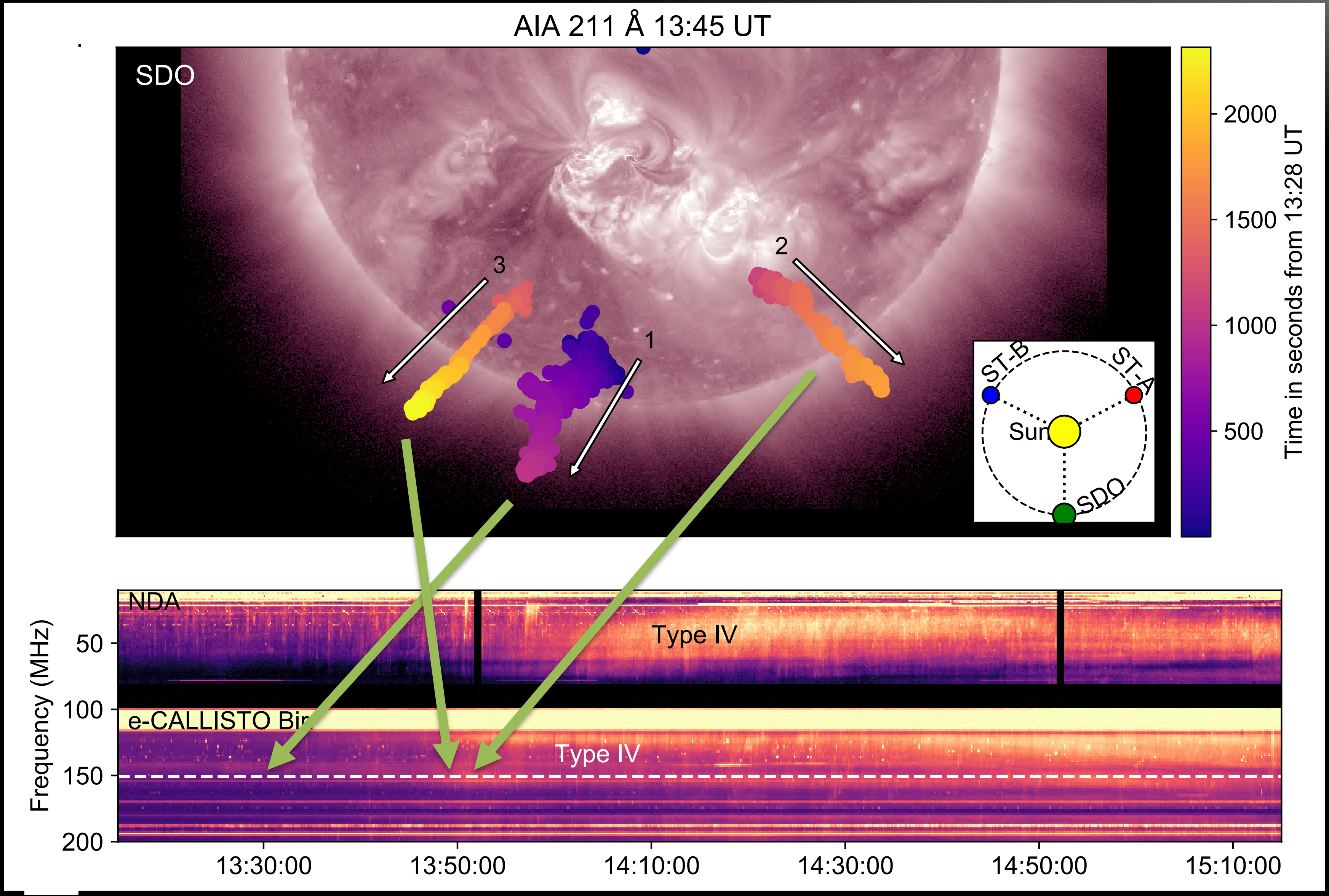
Three moving radio sources observed with the Nançay Radioheliograph (NRH)



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

→ fundamental plasma emission

Observations of Moving Radio Sources

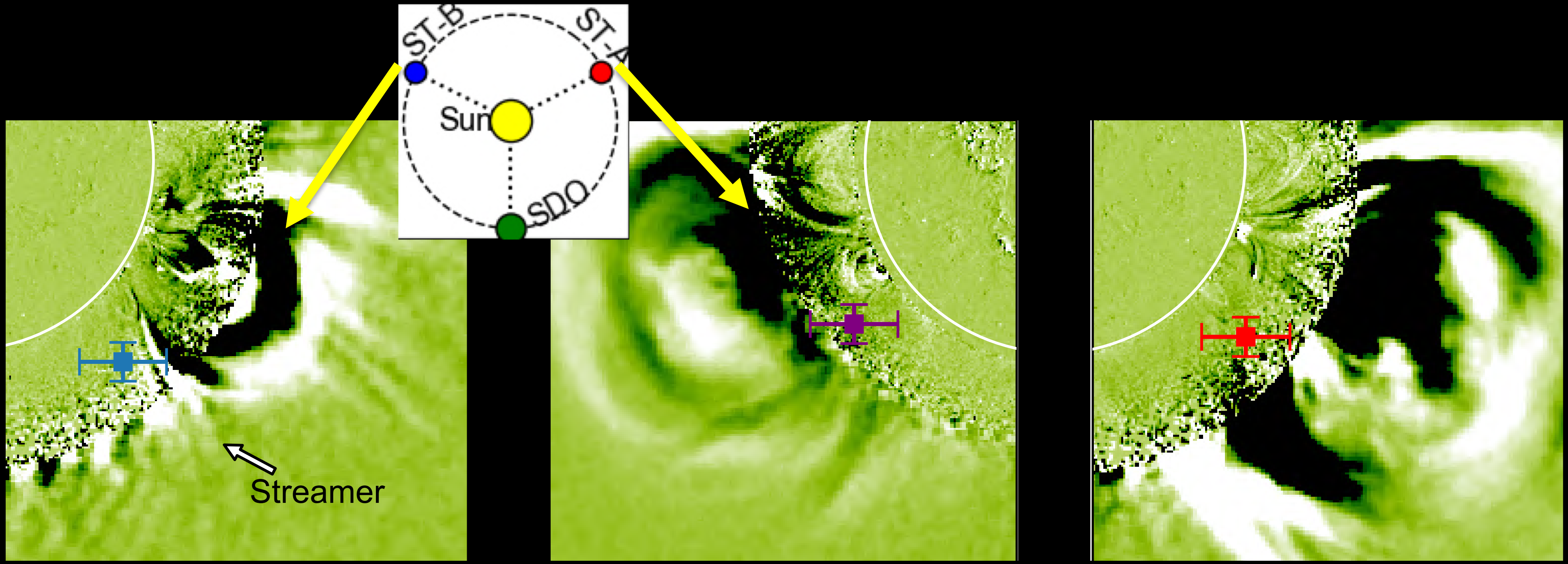


Nancay Decametric Array

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

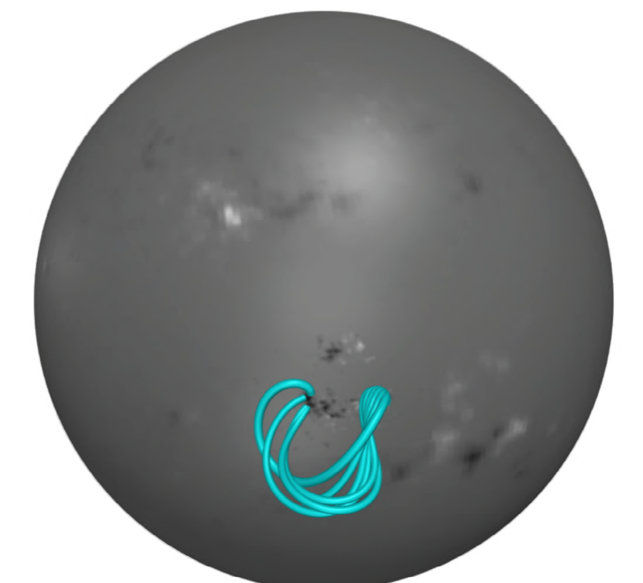


Morosan et al., A&A, 2020

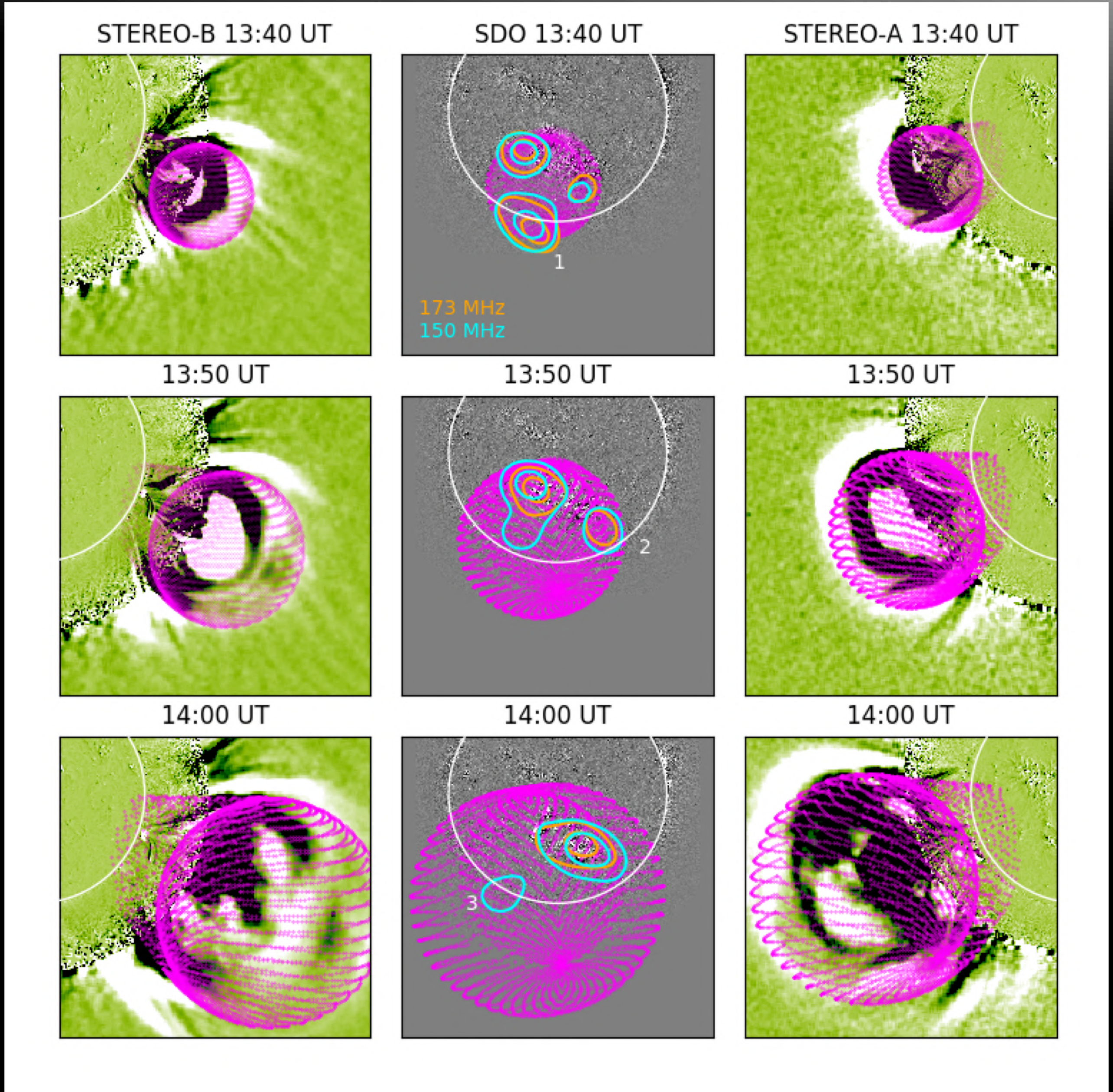
Location of Radio Sources and CME – 3D Picture

Using STEREO, NRH and GONG/HMI magnetograms:

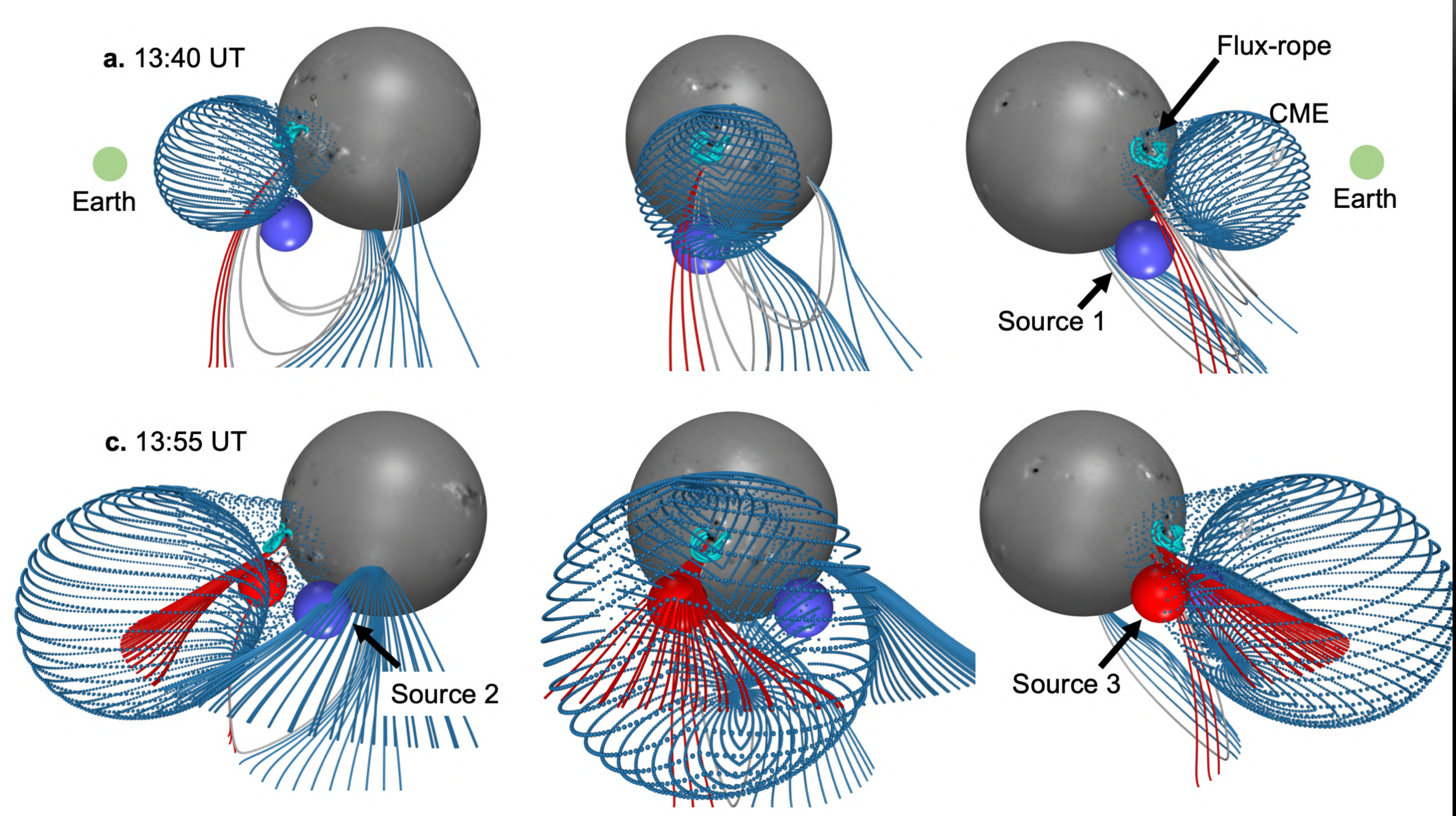
- 3D model of CME
- 3D radio burst location
- 3D open field regions
- 3D pre-eruptive flux rope



Pomoell et al., Sol. Phys., 2019



Location of Radio Sources and CME – 3D Picture

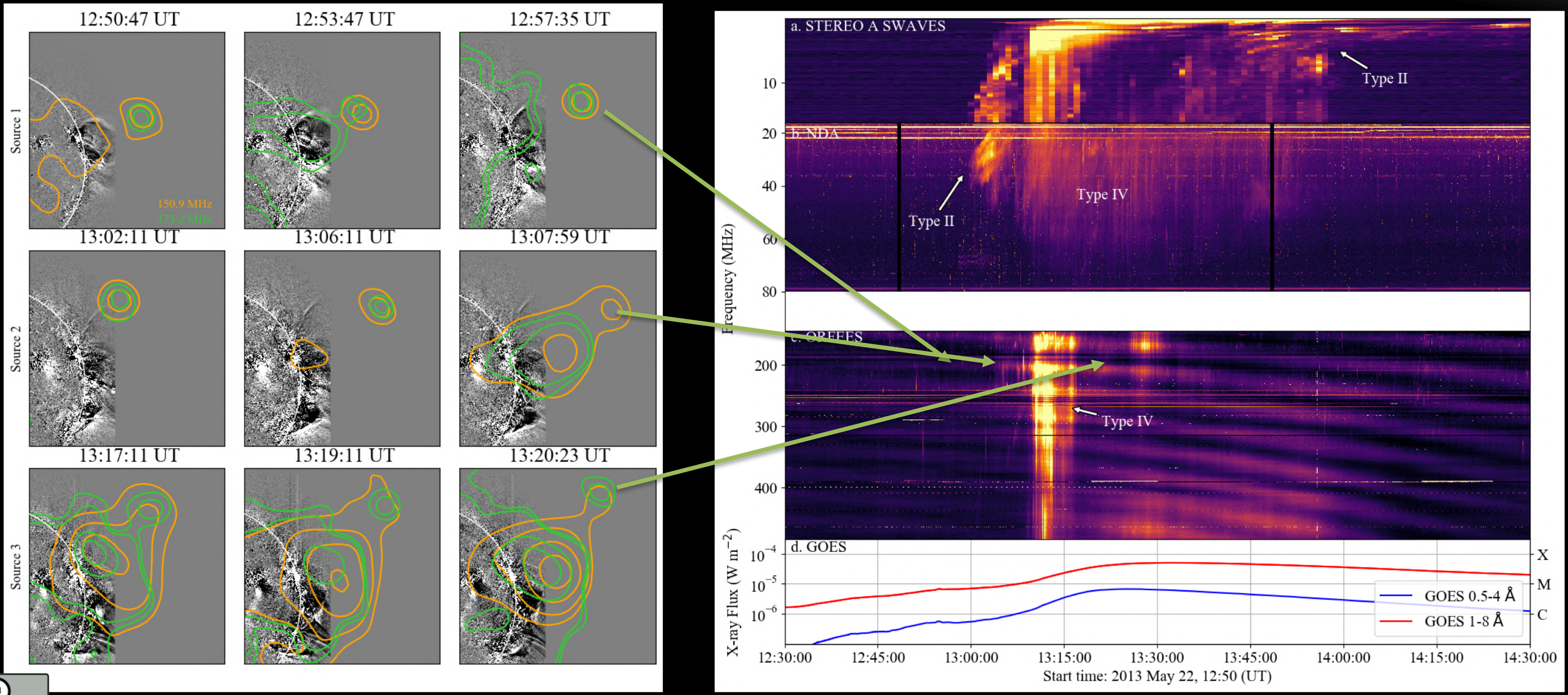


Morosan et al., A&A, 2020

CMEs and Moving Radio Bursts

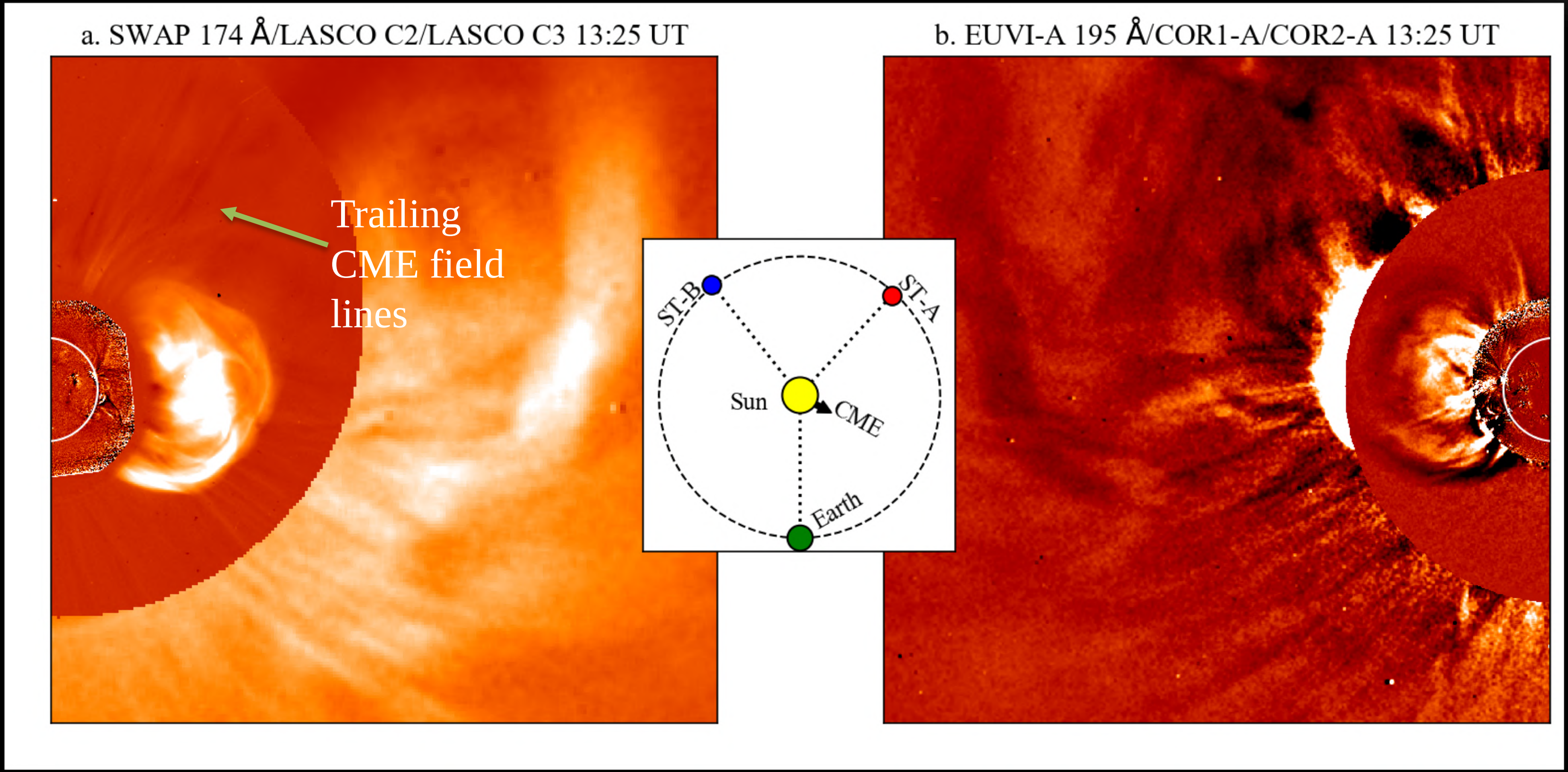
The 22 May 2013 CME and Moving Radio Sources

SDO/Earth Perspective with overlaid NRH Radio Contours



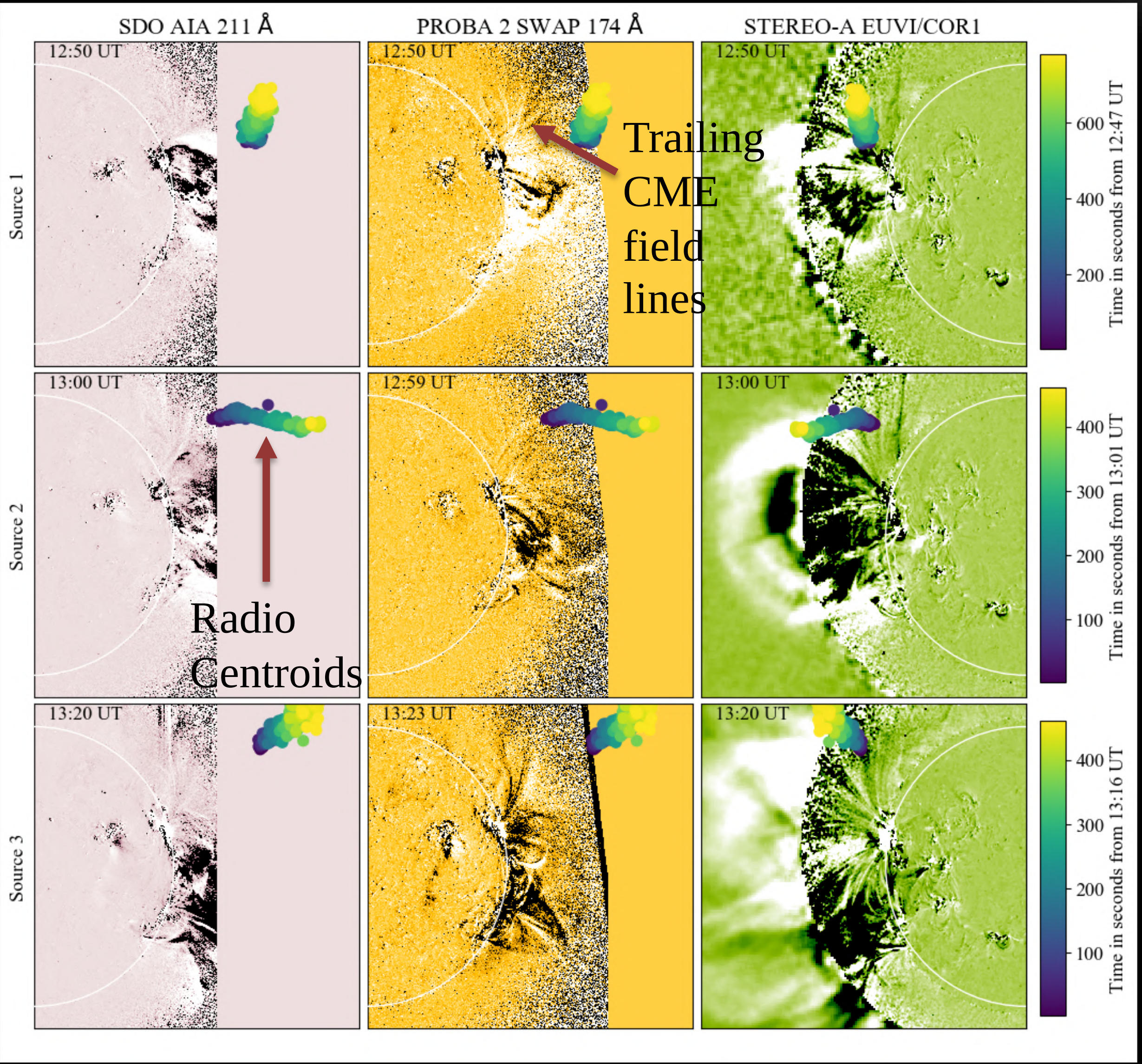
CMEs and Moving Radio Bursts

The 22 May 2013 CME and Moving Radio Sources

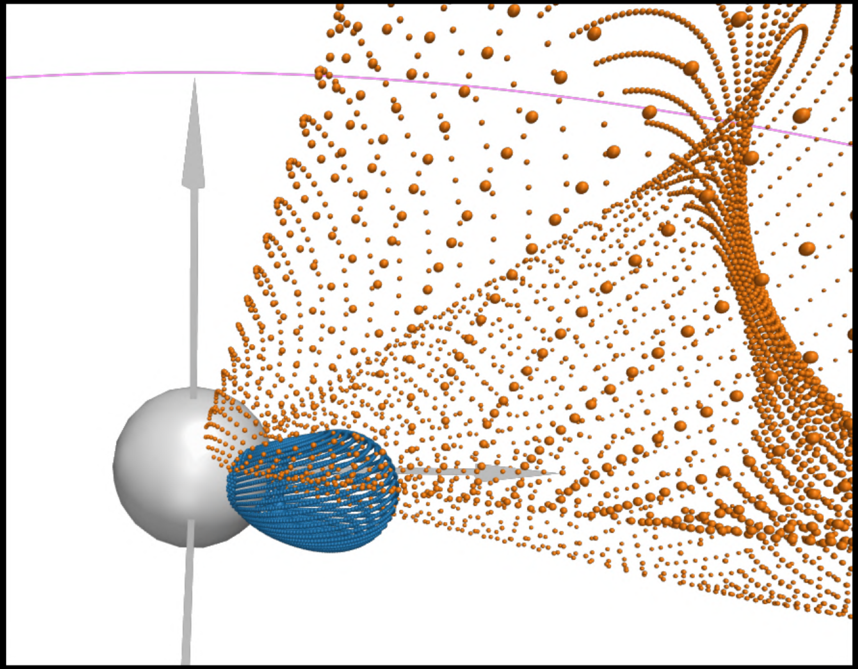


The CME is expanding inside an earlier CME
→ Lots of trailing features and magnetic field lines from the previous CME

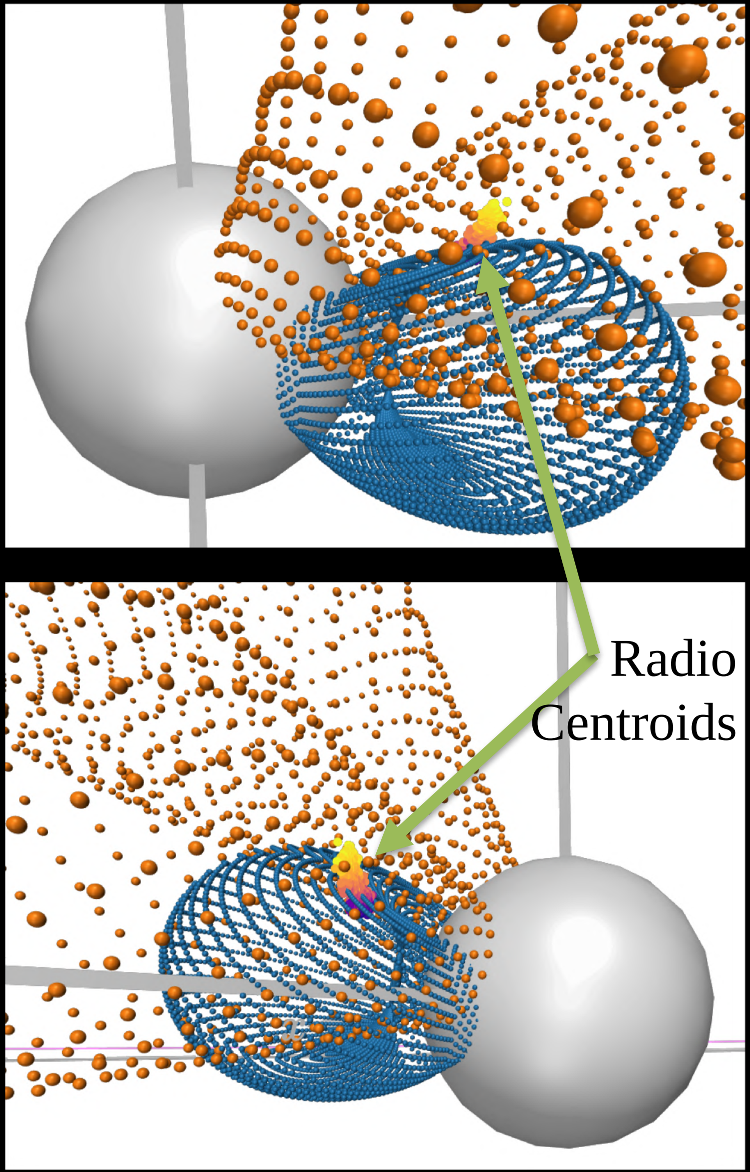
CMEs and Moving Radio Bursts



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



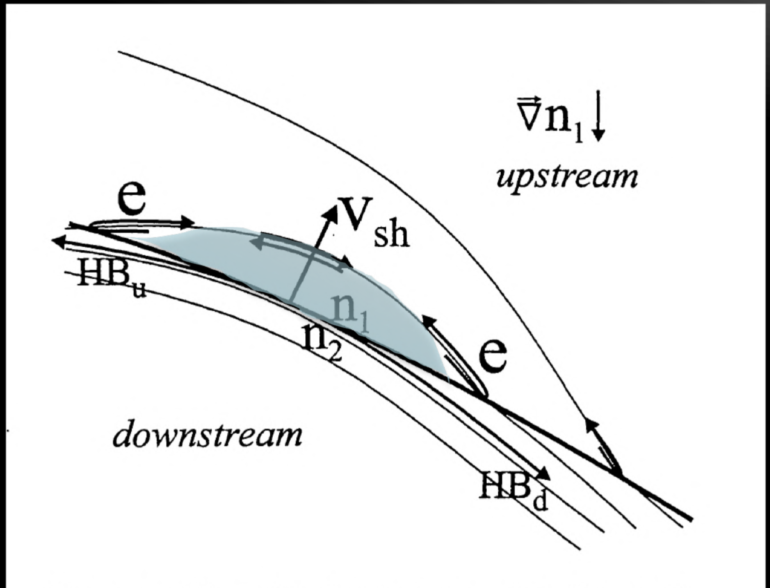


Figure 3. *The collapsing trap geometry. The particles are trapped in the shaded region. The magnetic field lines at the intersection with the shock front form two approaching magnetic mirrors as the front advances (indicated by velocity vector v_{sh}). In each reflection electrons (e) are accelerated.*

Magdalenić et al., 2002

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

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:
  - why are electrons accelerated only at specific locations since CME shocks are large scale structures?
  - where do Type IV emitting electrons come from?
  - 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 electrions even farther out from the Sun through radio observations