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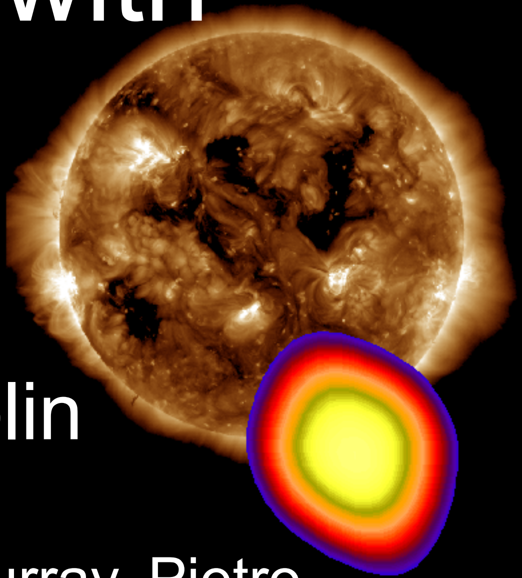
UNIVERSITY OF HELSINKI

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Imaging Radio Shock Signatures of Solar Coronal Mass Ejections with LOFAR



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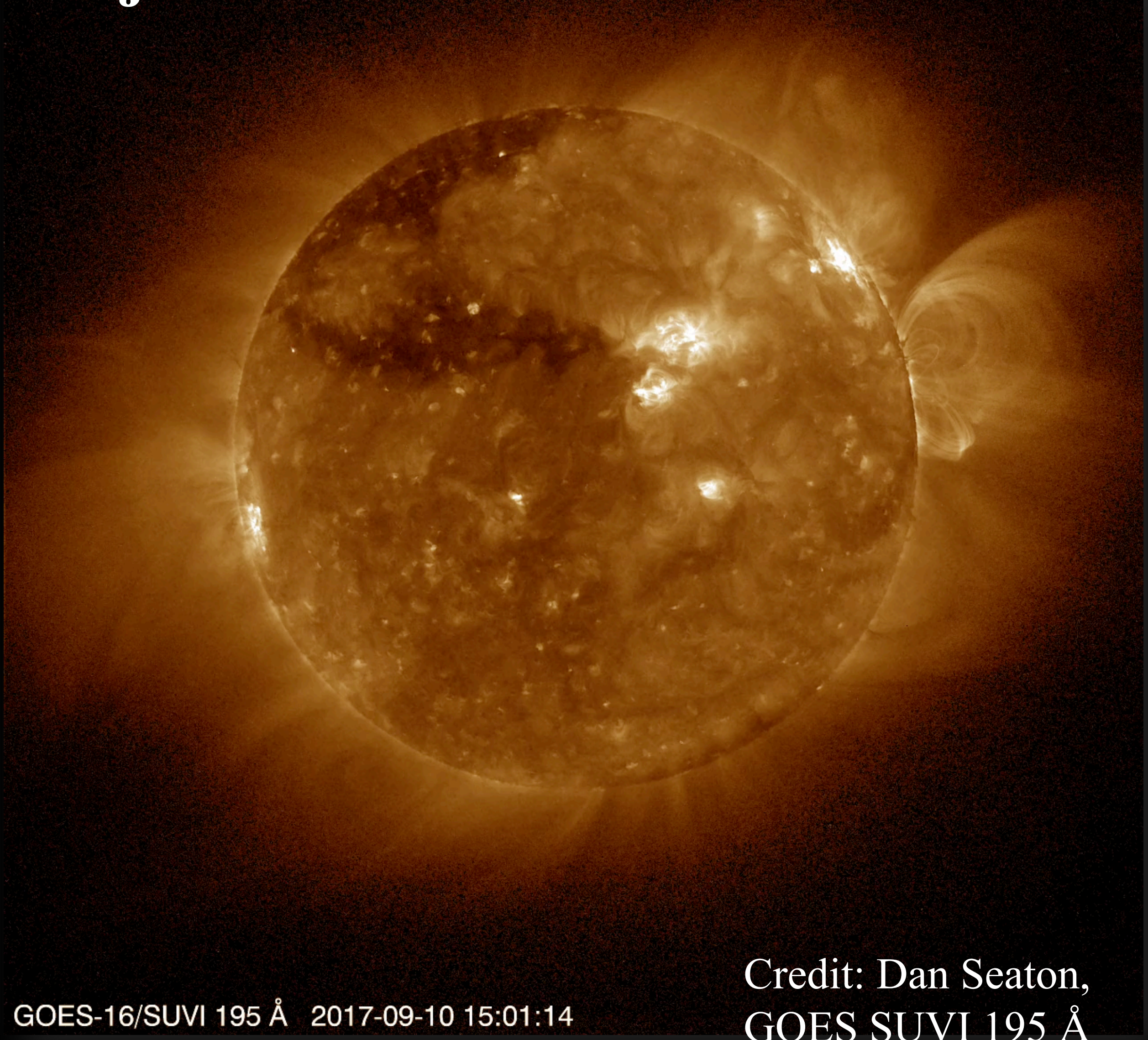
Dublin Institute of Advanced Studies, ASTRON, Leibniz-Institut für Astrophysik Potsdam, University of Turku

Solar Activity in September 2017 during LOFAR Observation Campaings

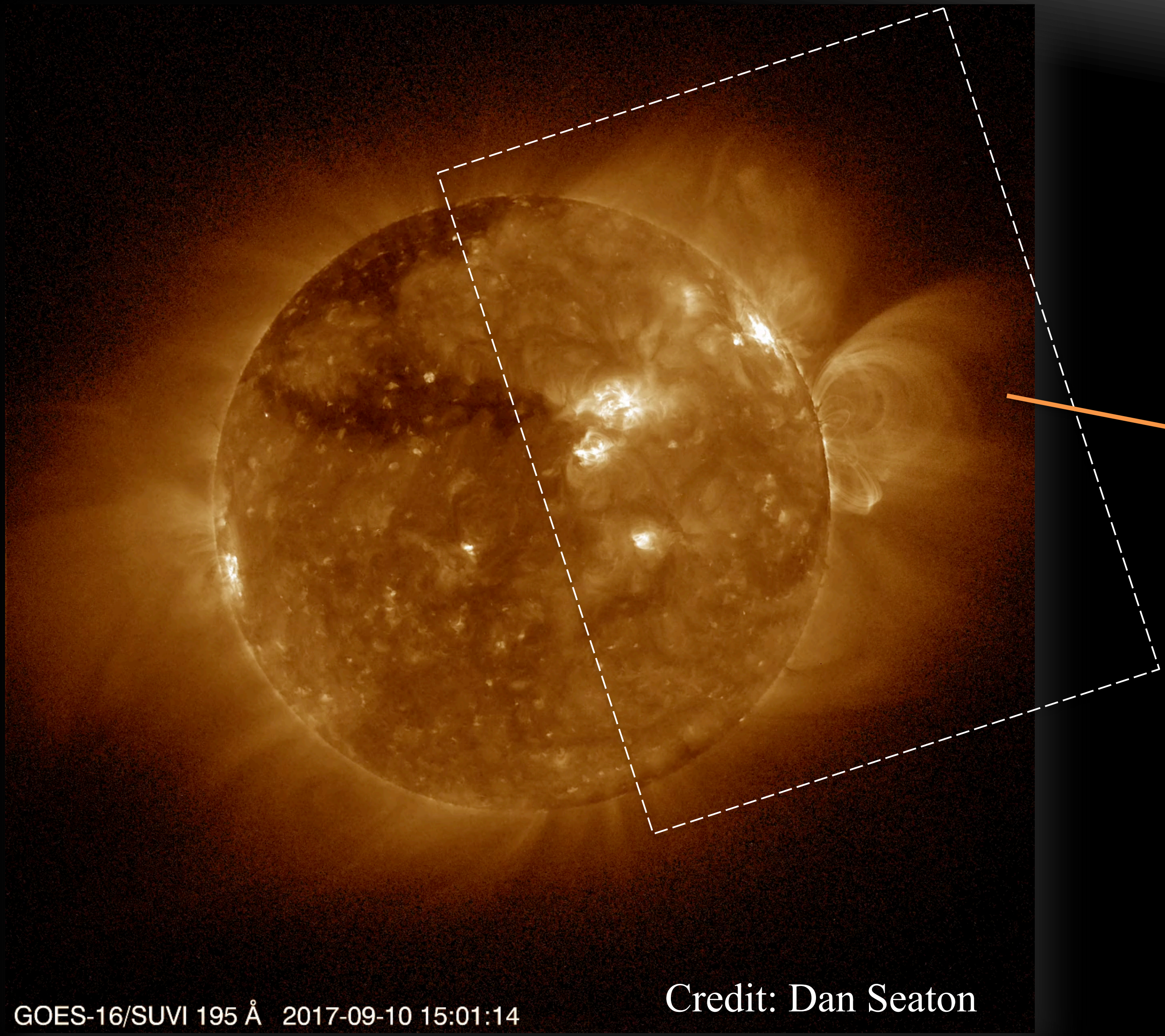
The 10 September 2017 Flare and Coronal Mass Ejection

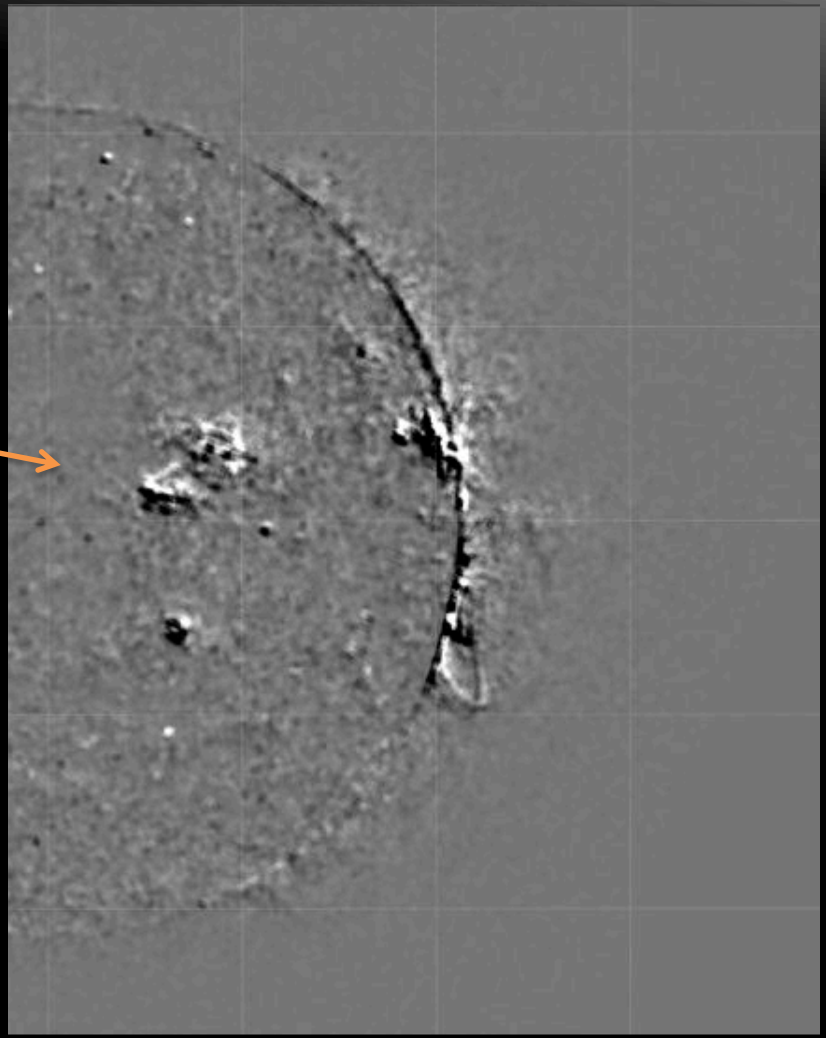


Credit: Dan Seaton,
GOES SUVI 195 Å

10 September 2017
– X8.2 Flare on the visible solar limb
– second largest flare of Solar Cycle 24
– accompanied by a very fast CME

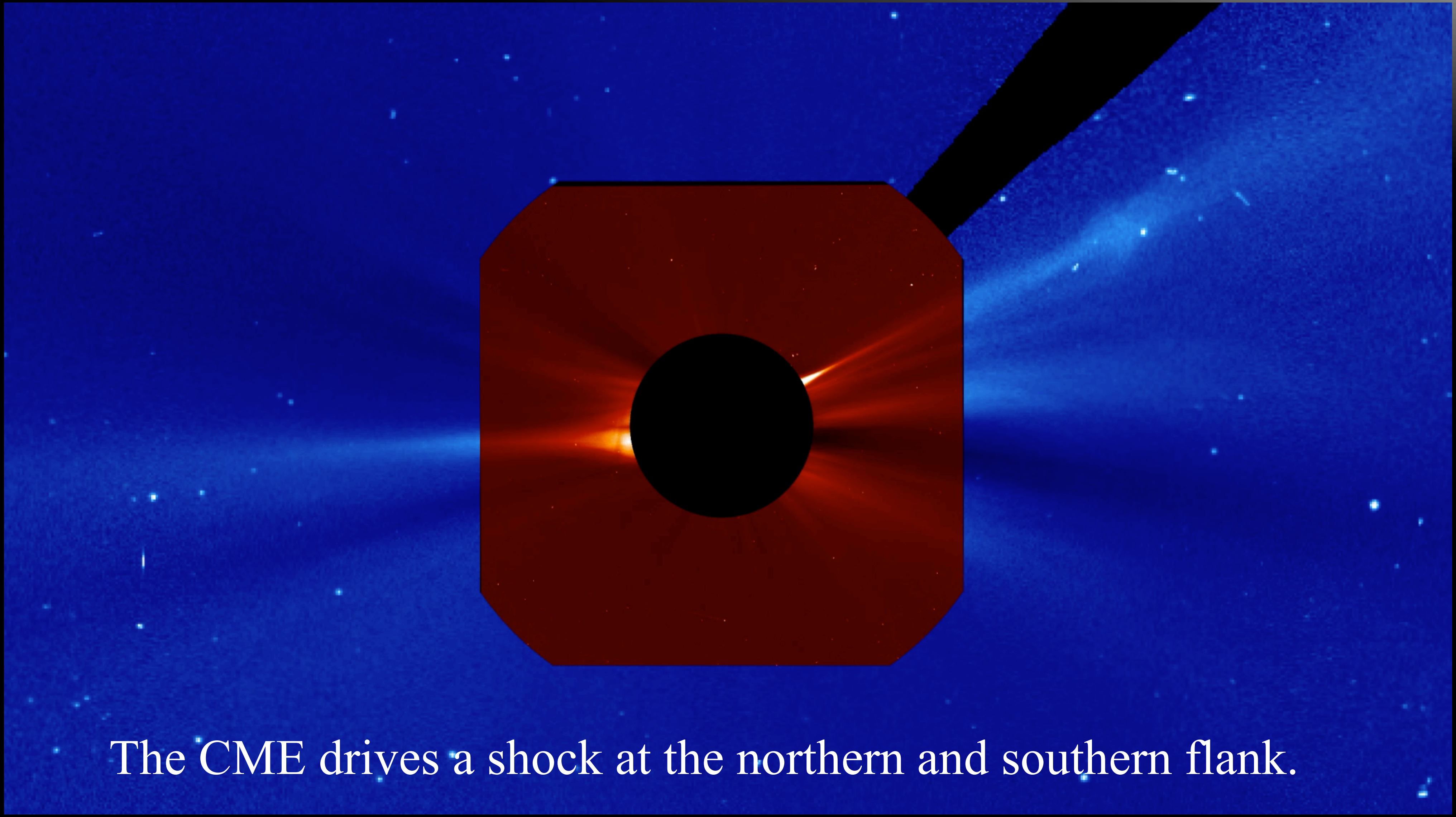
Observations of a Fast Coronal Mass Ejection (CME)



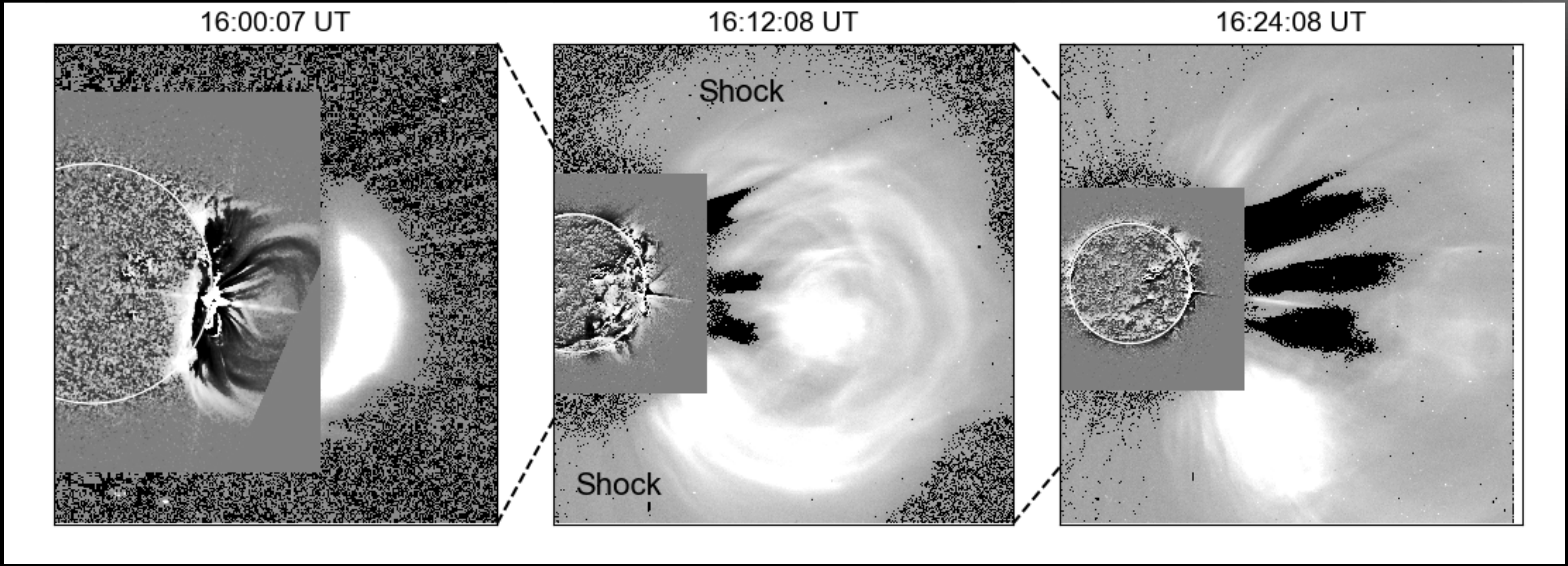


Very fast CME – 3000 km/s

Evolution of the 10 September 2017 CME



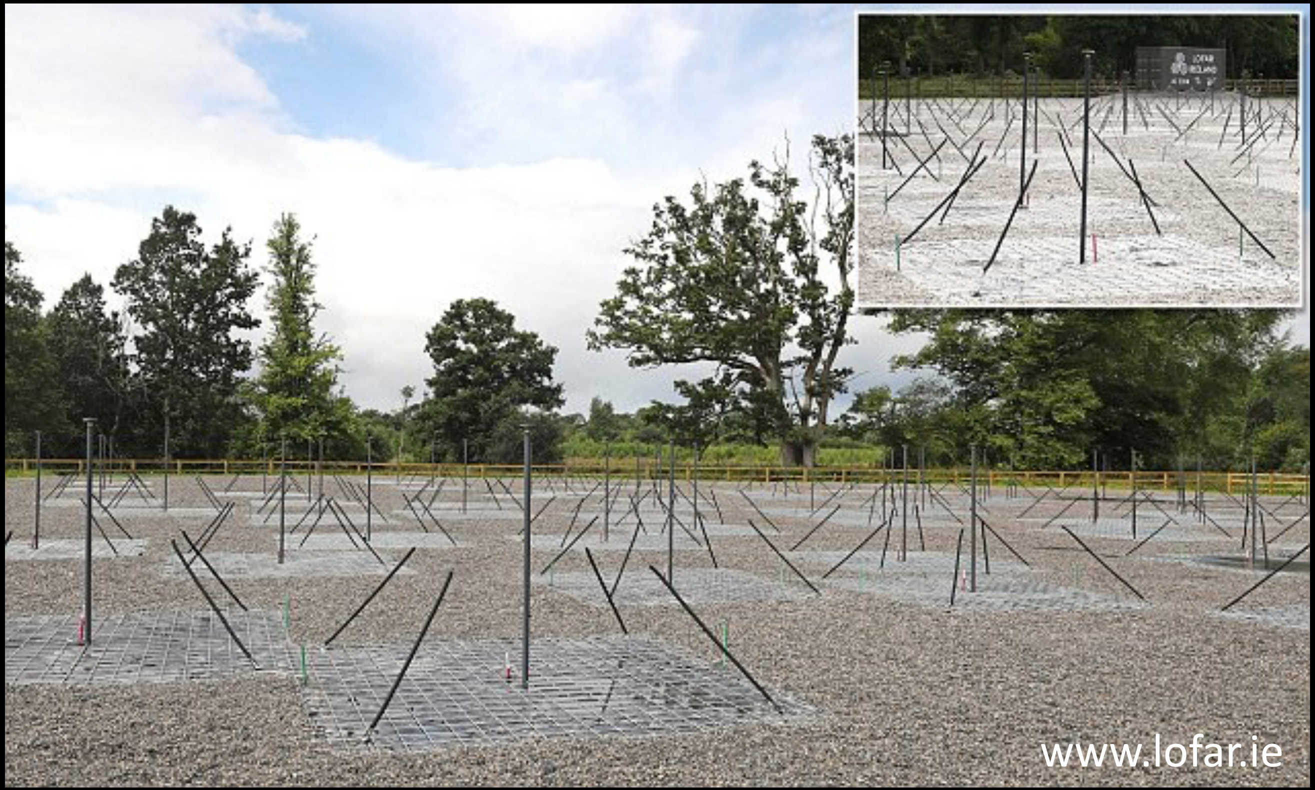
Evolution of the 10 September 2017 CME

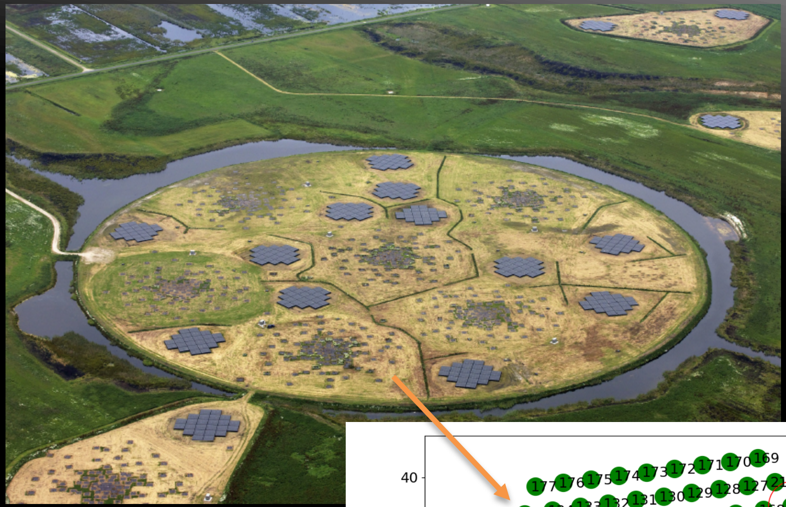


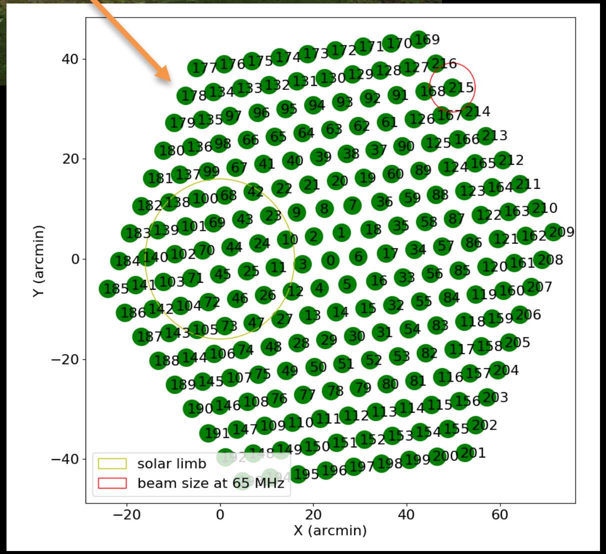
GOES-R SUVI + SOHO/LASCO

The CME drives a shock at the northern and southern flank.

LOFAR Core and I-LOFAR Observations

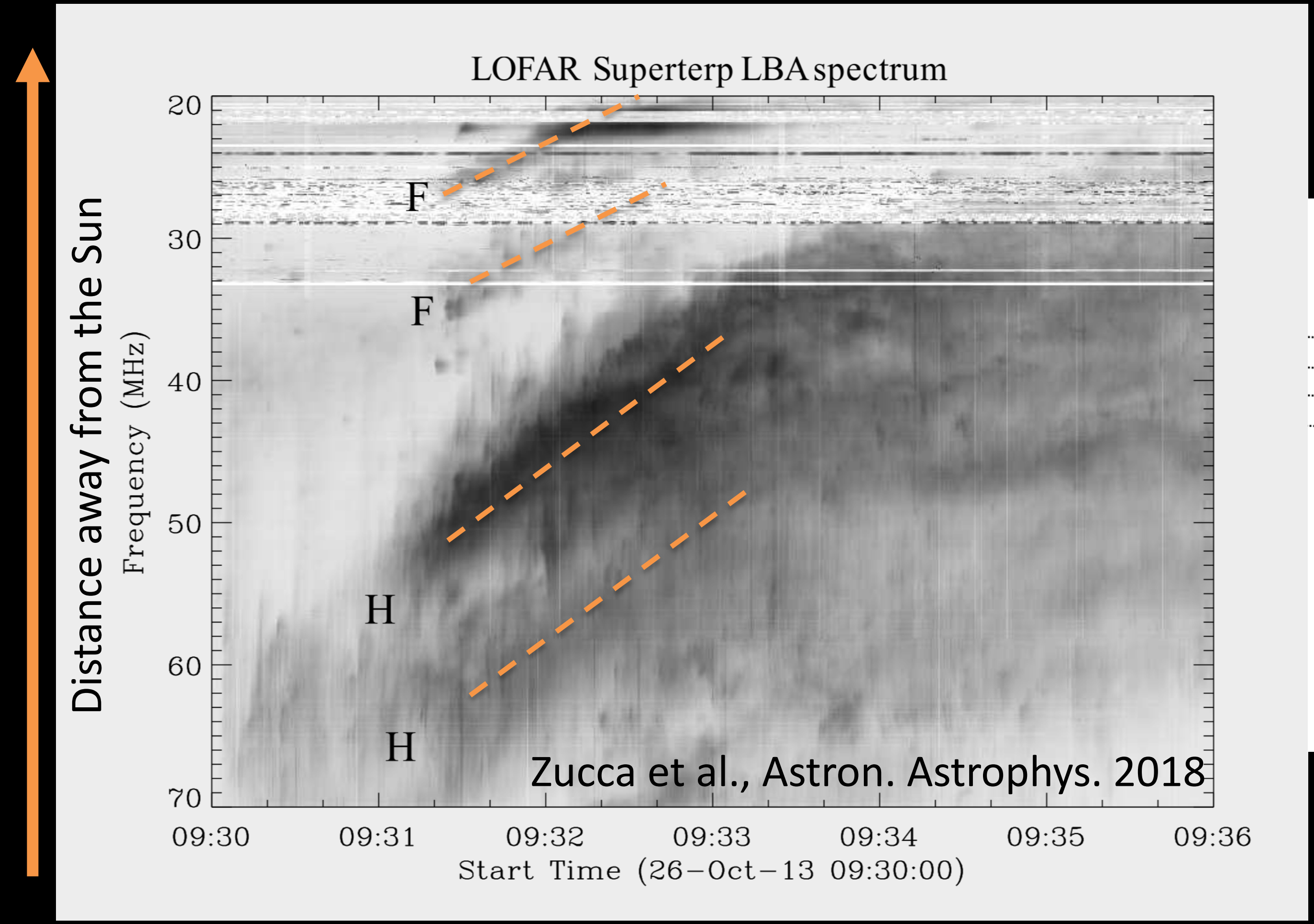




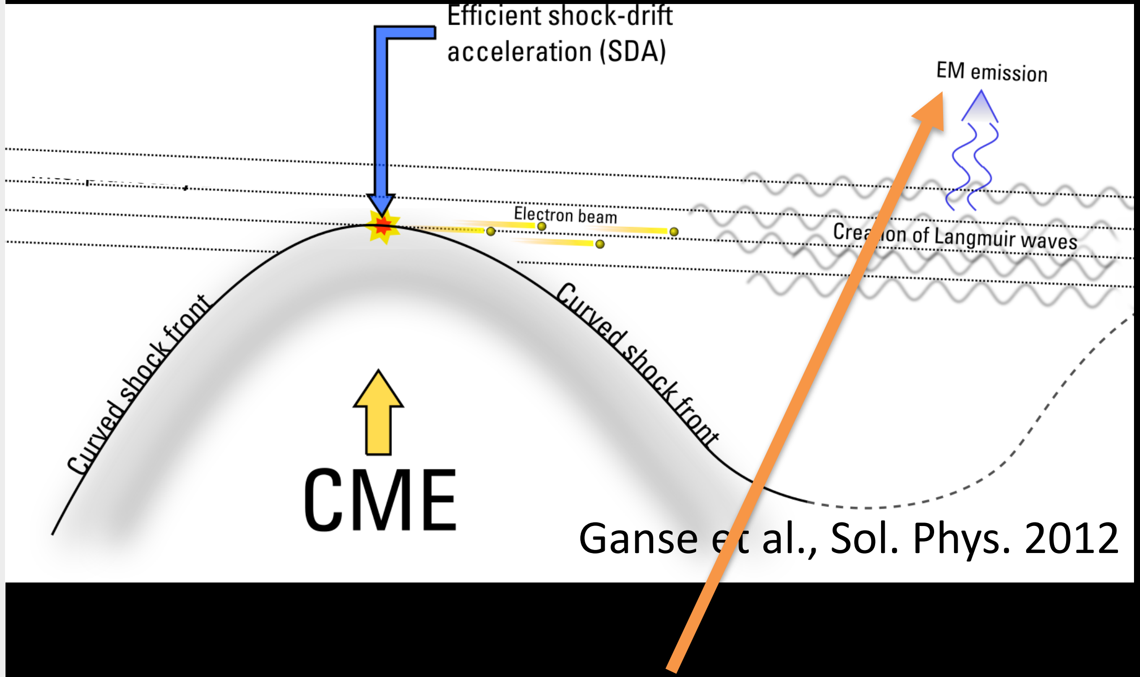


LBAs from the LOFAR core and I-LOFAR station (Ireland) observed the Sun on 10 September 2017

What did we expect to see with LOFAR? – Type II radio bursts

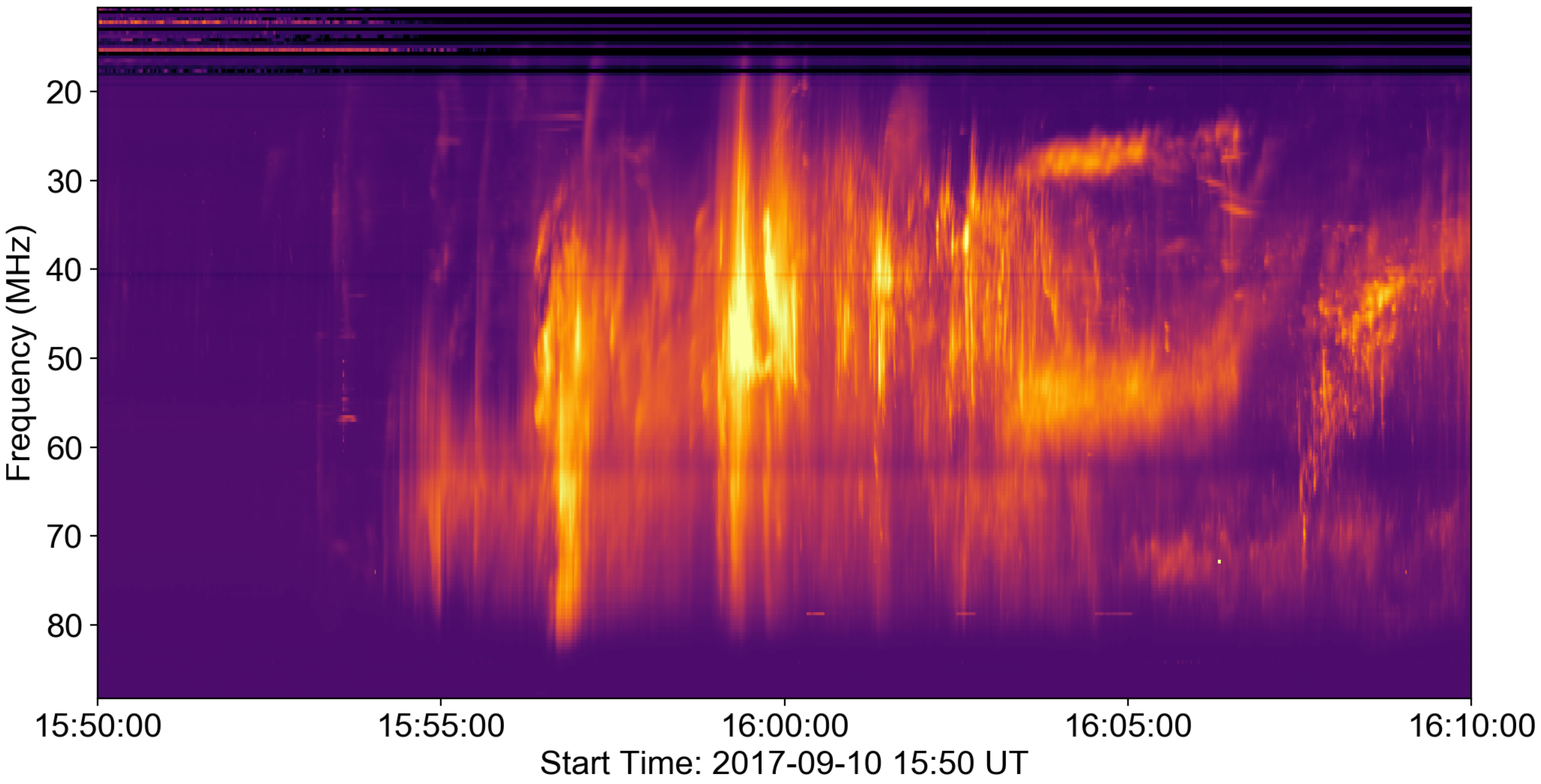


How do shocks accelerate electrons in the corona?

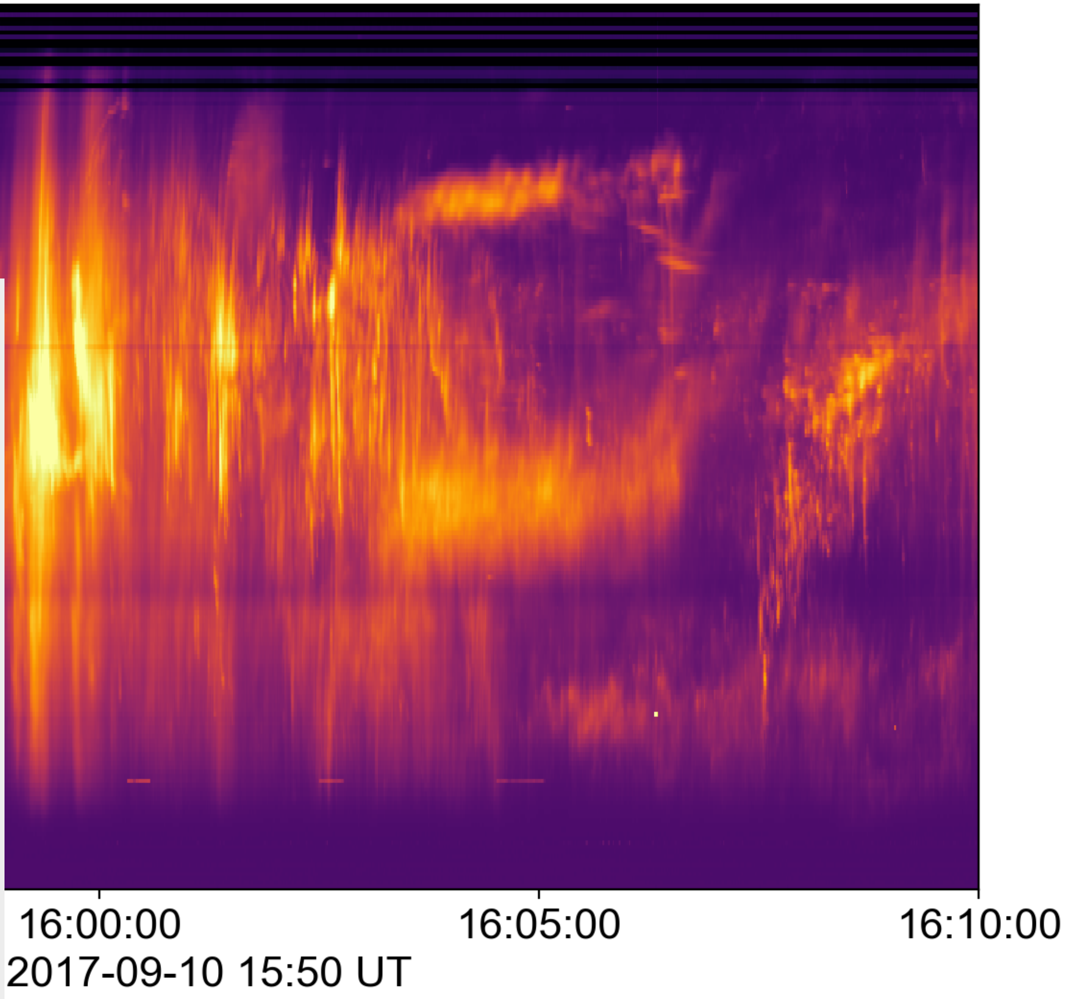


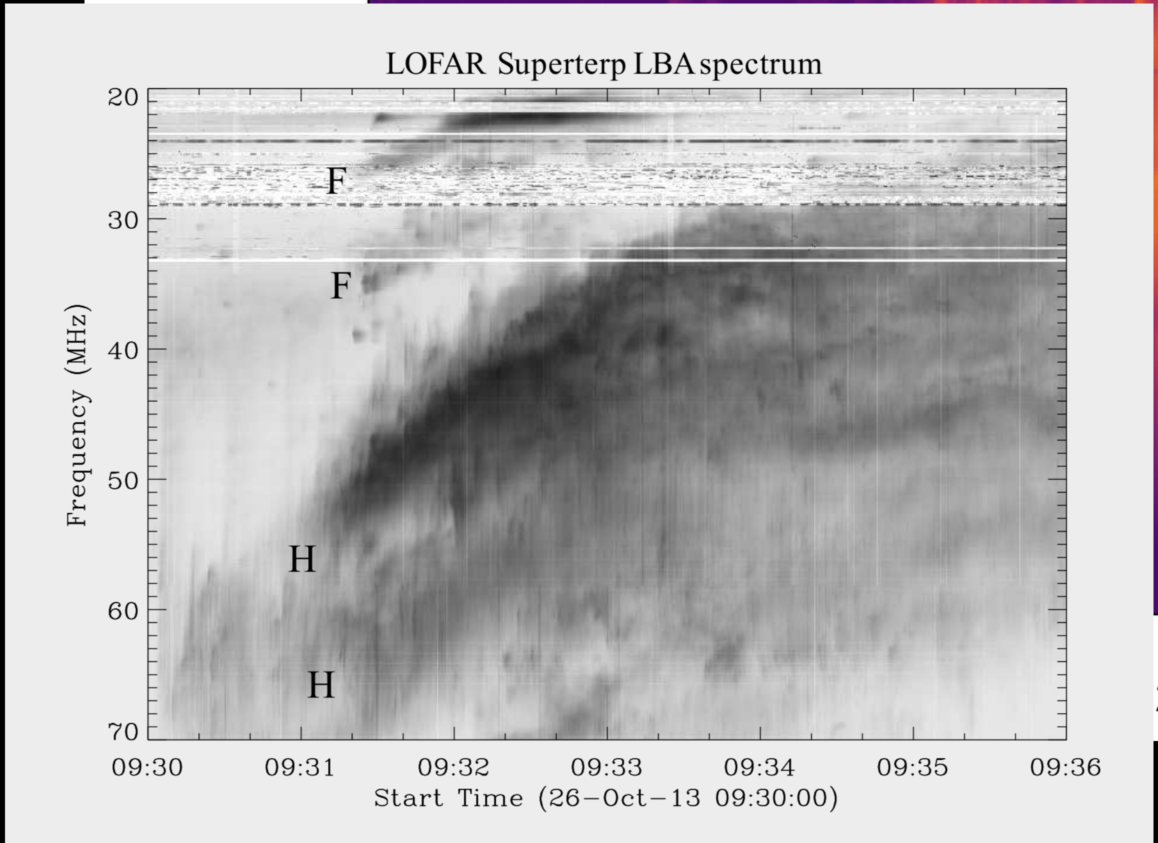
$$f = nf_p = 9000\sqrt{n_e}\ \text{(Hz)}$$

What we actually saw with LOFAR:

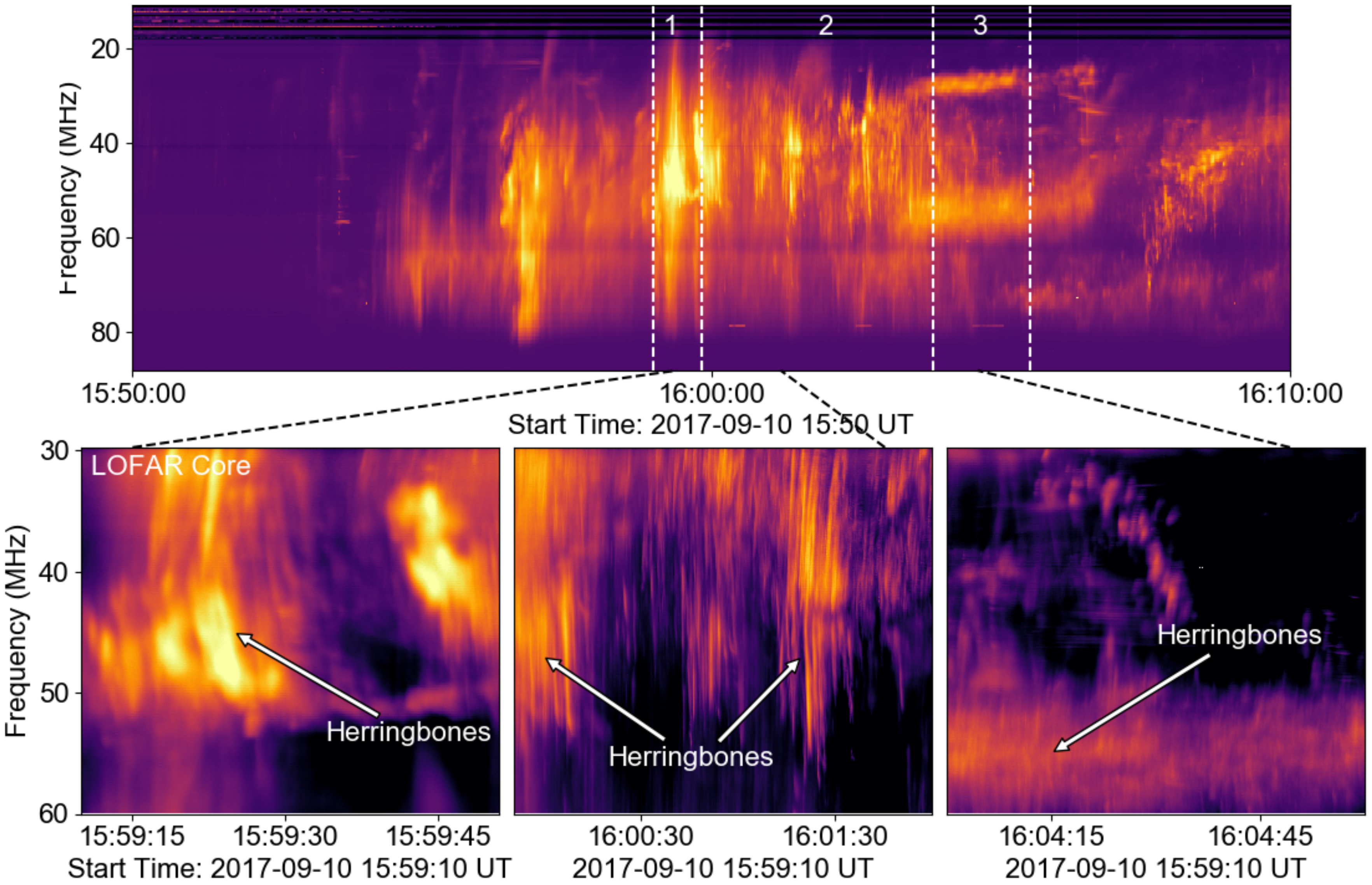


I-LOFAR Observations of the Event

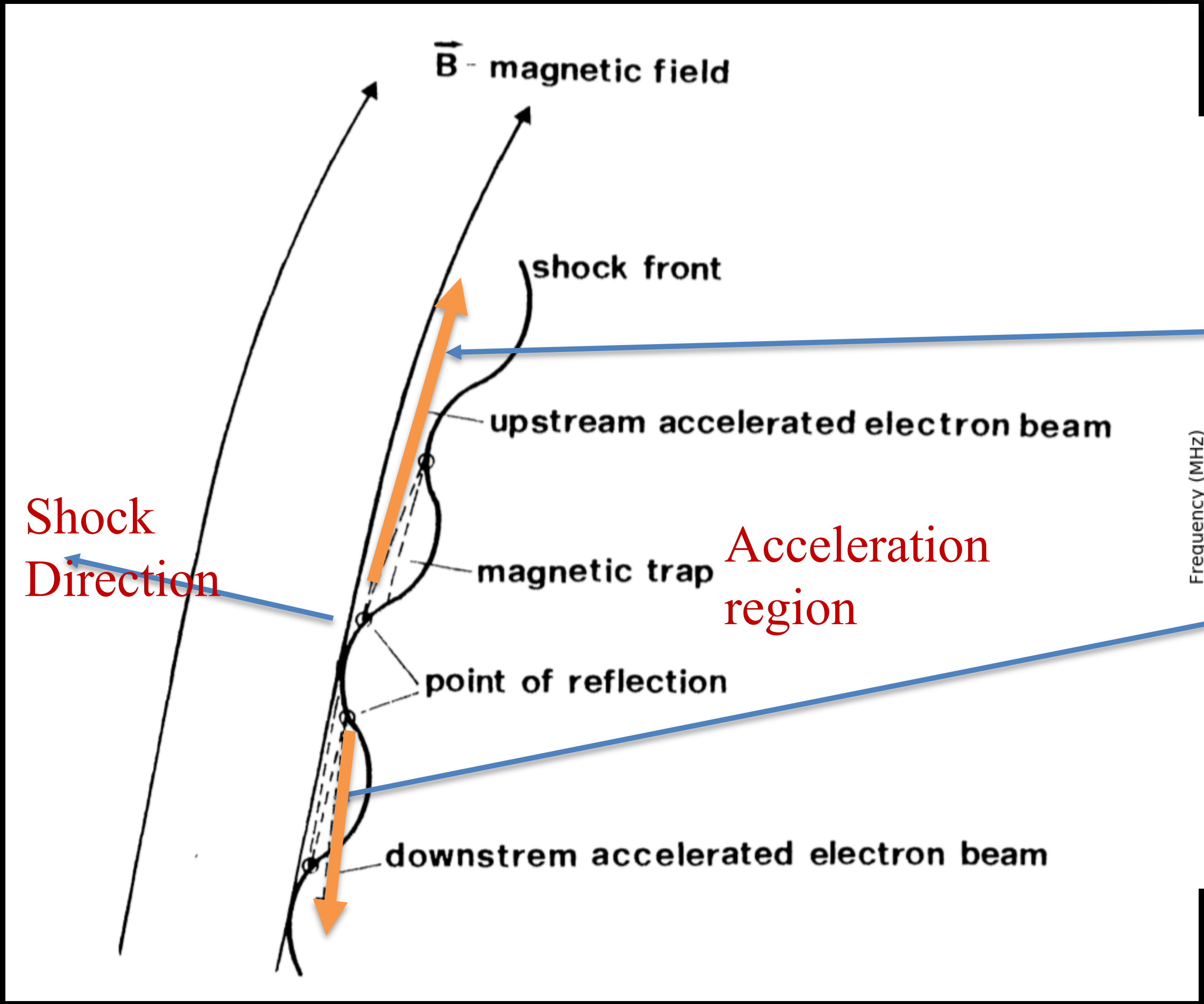


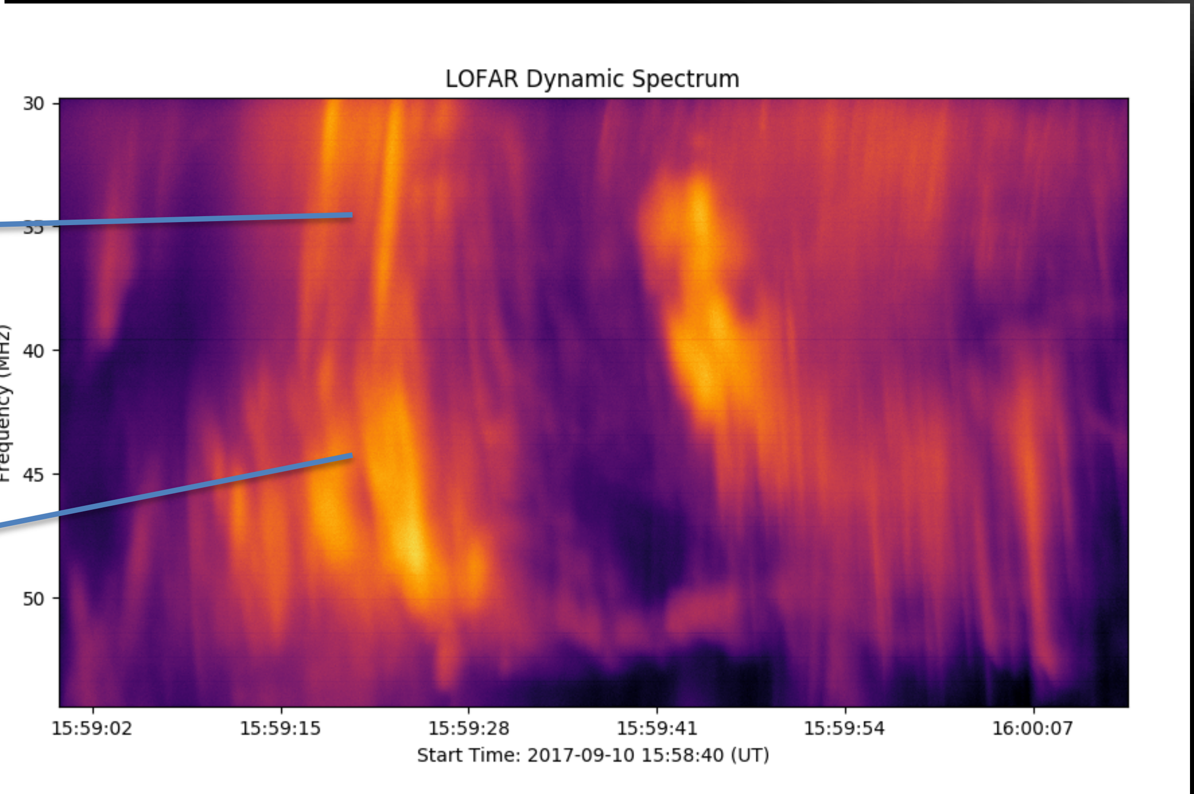


LOFAR Core and I-LOFAR Observations of the Event



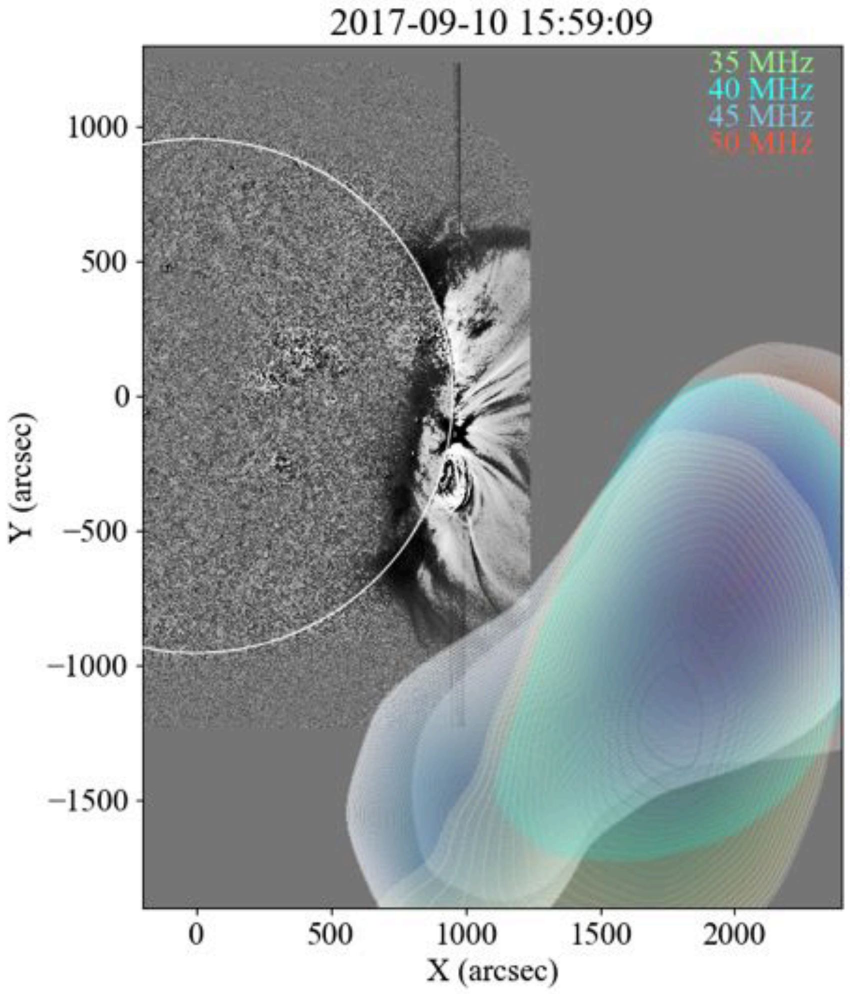
Theoretical Model of Herringbones

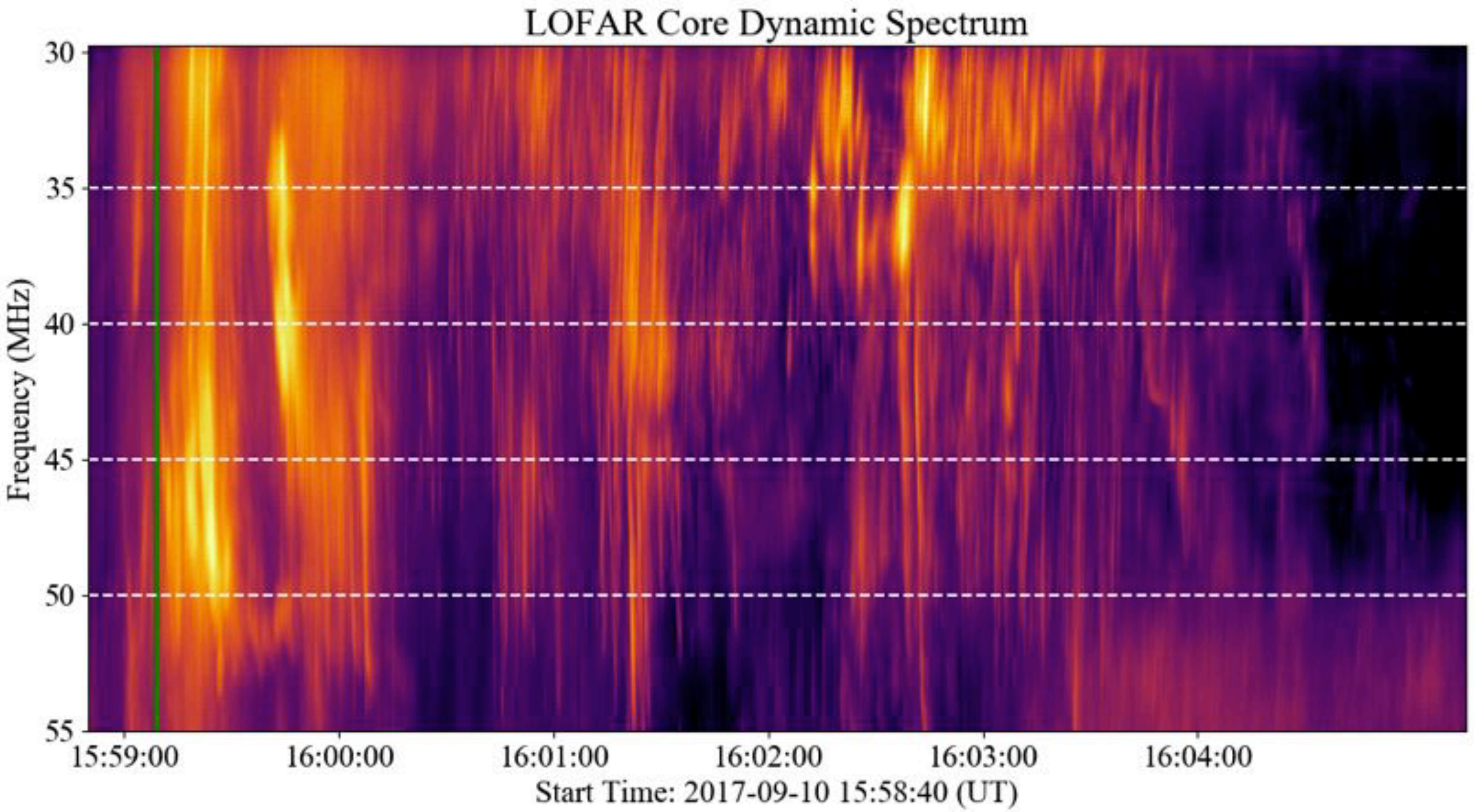




Herringbones Model – Zlobec et al., 1993

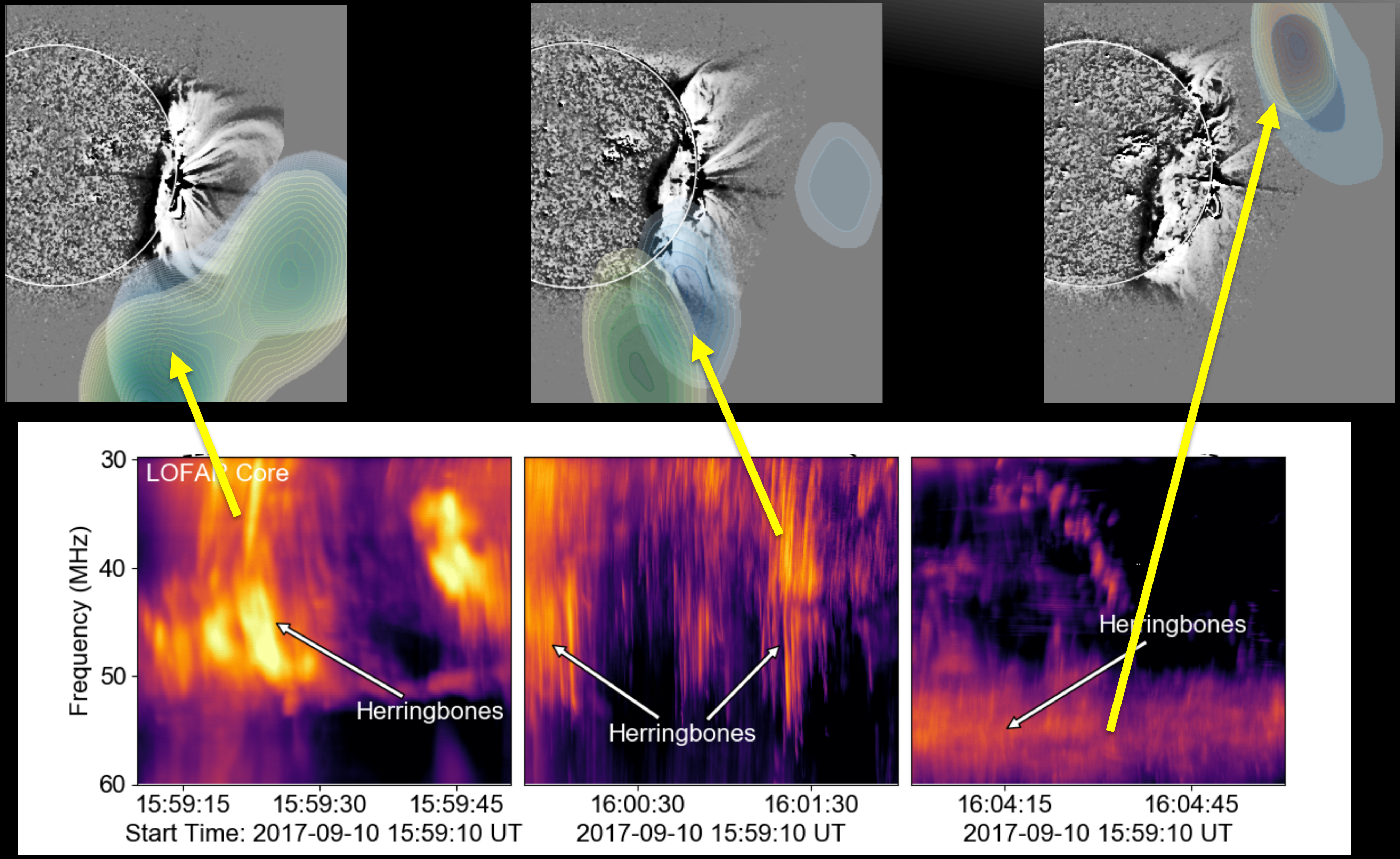
LOFAR Tied-array Imaging of Herringbones



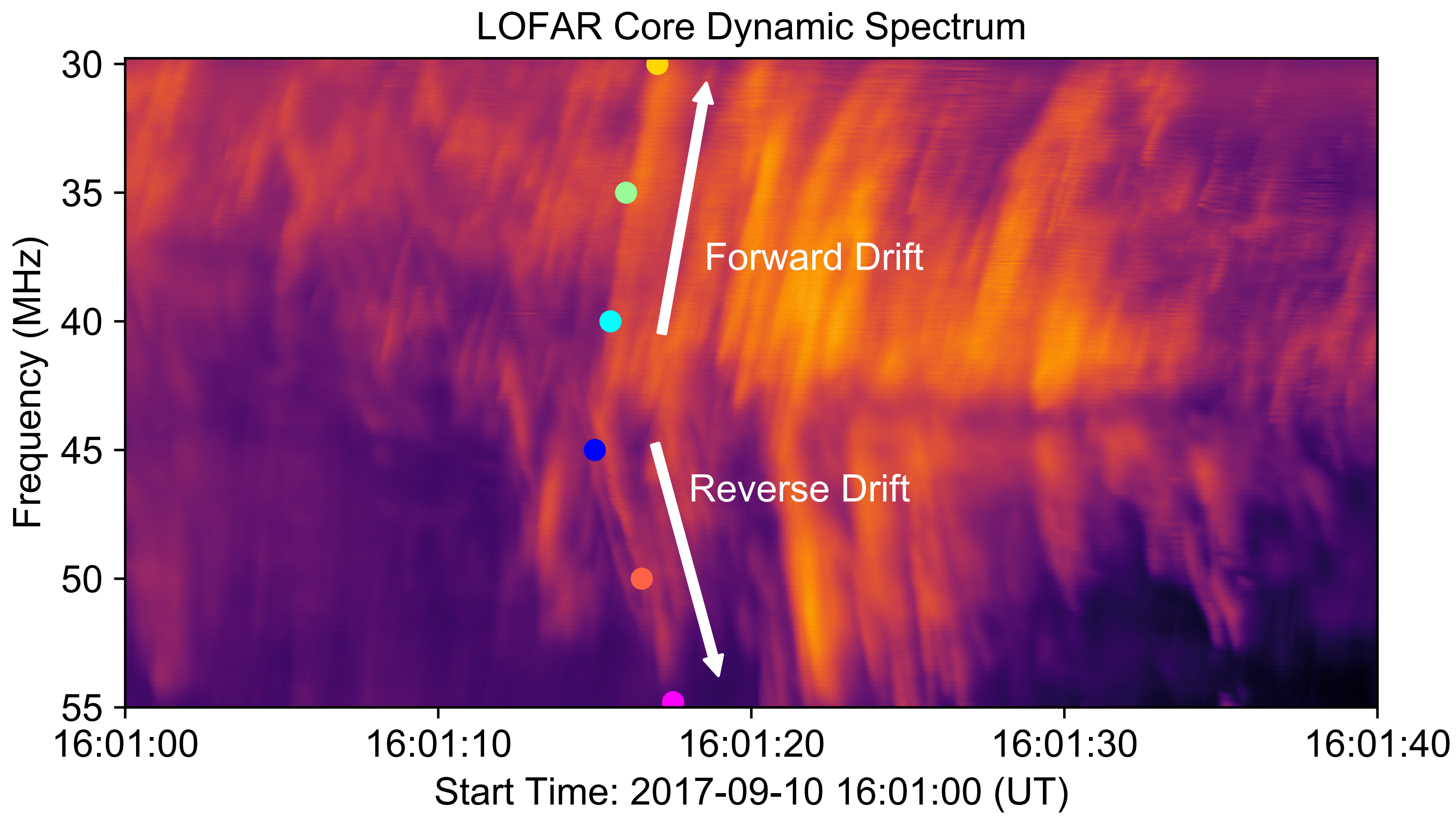


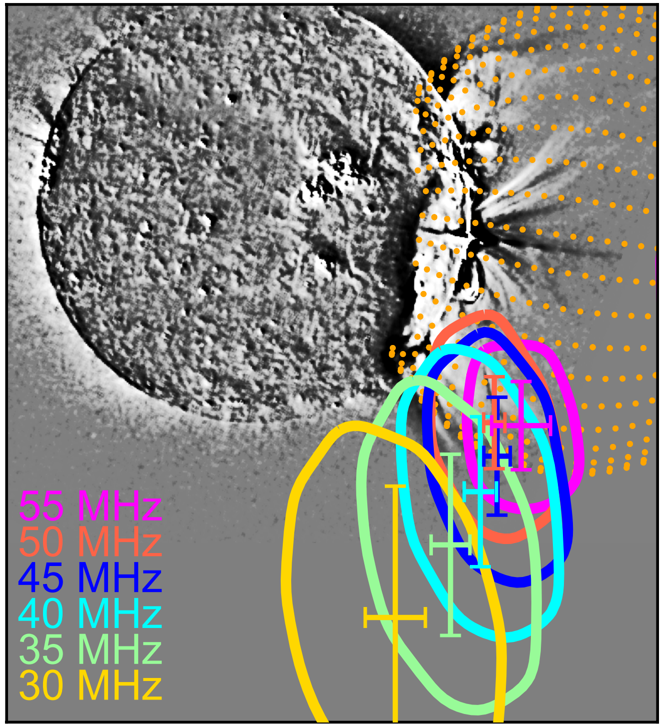
Morosan et al., Nat. Astron. 2019

Three separate region where particles are accelerated:

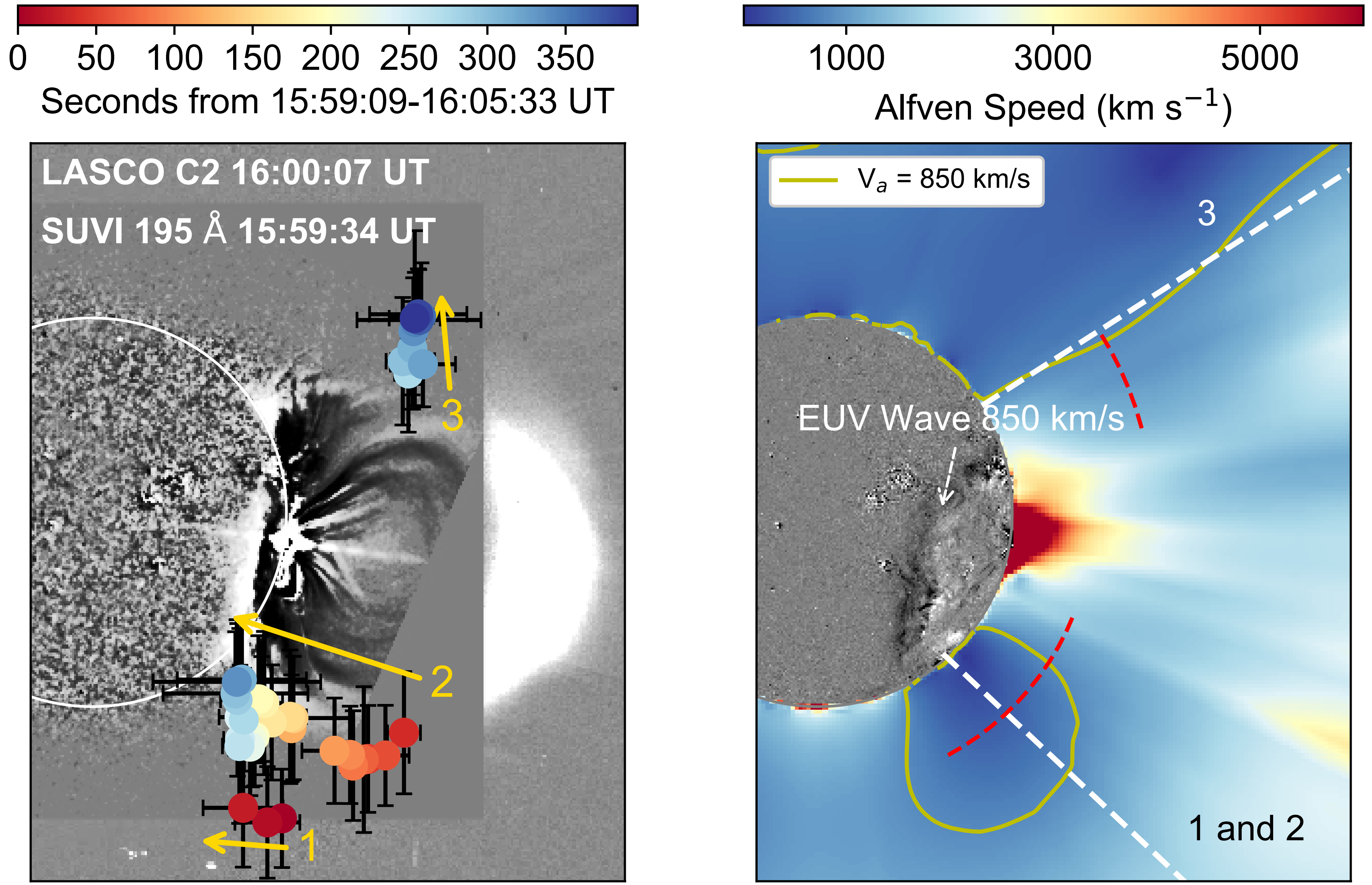


Finding the location of an individual herringbone

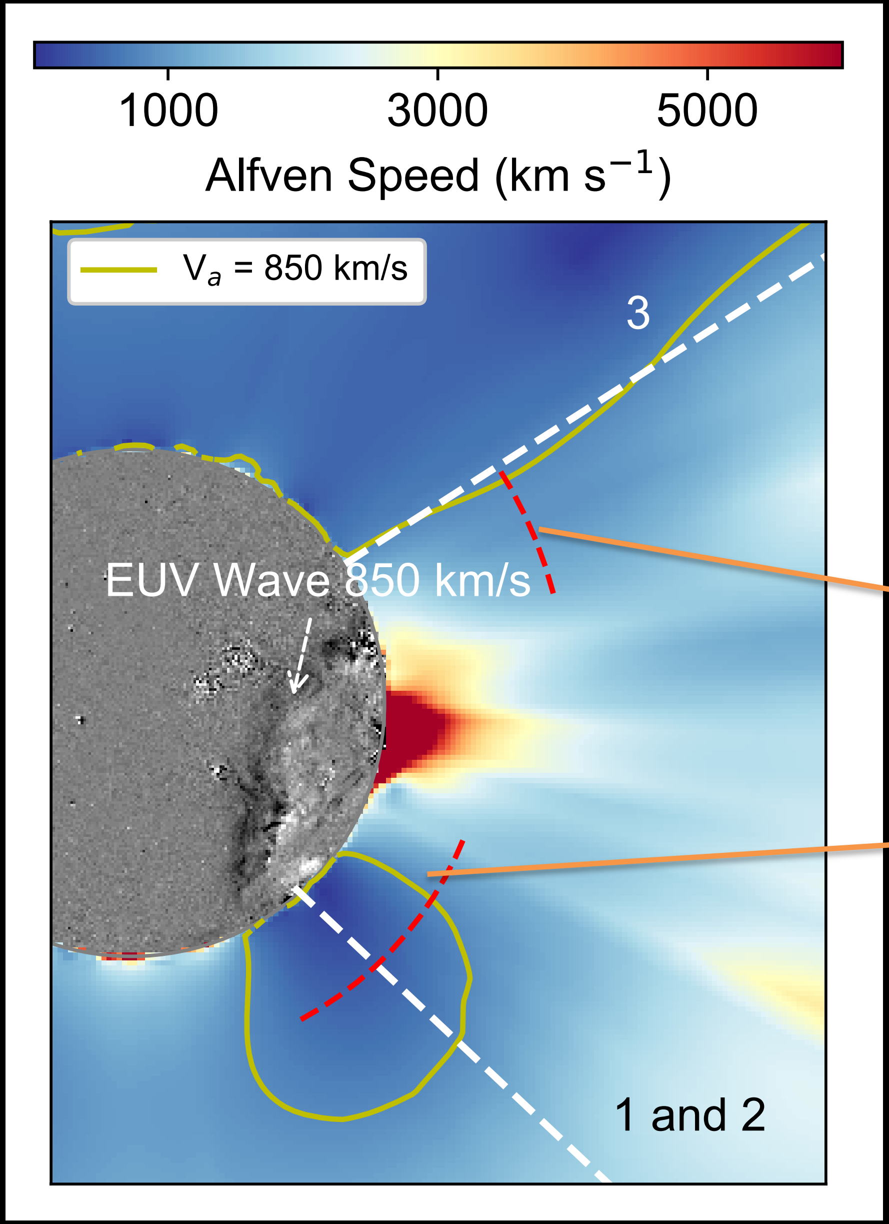




Is there a shock at the CME flank in the pane-of-sky?

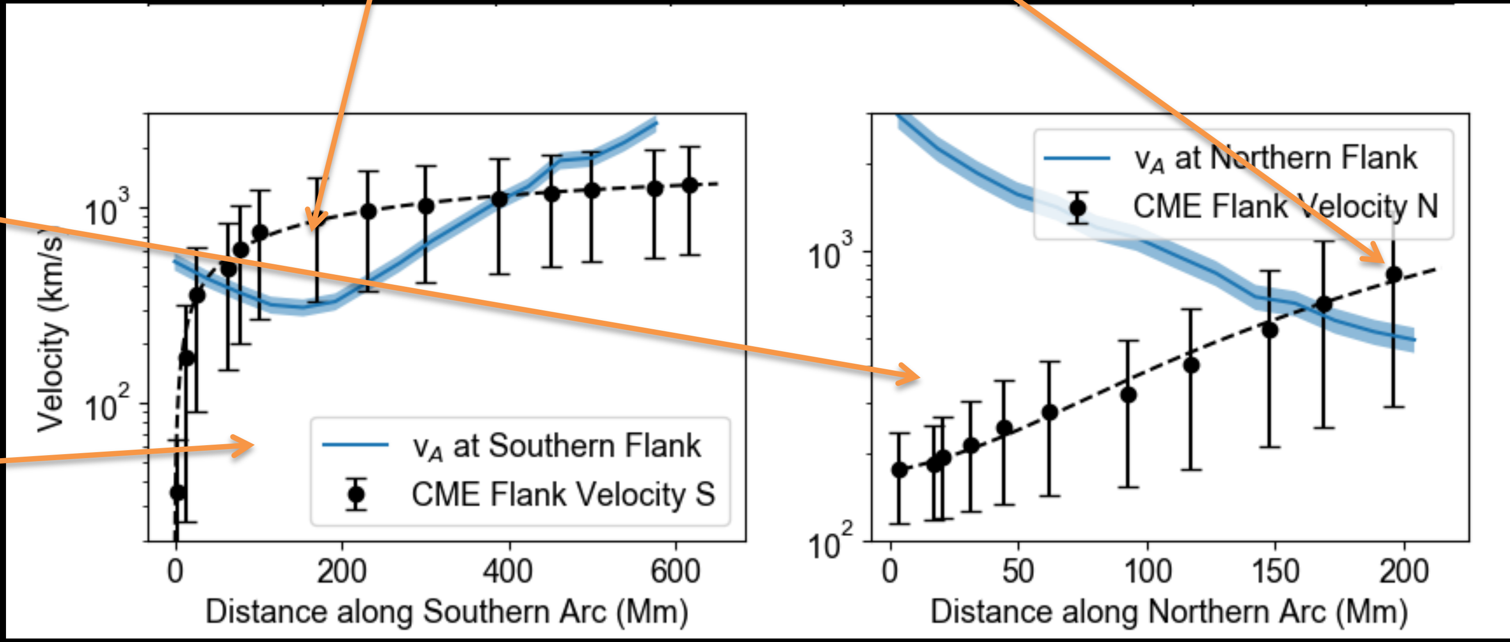


Plane-of-sky Shock Locations



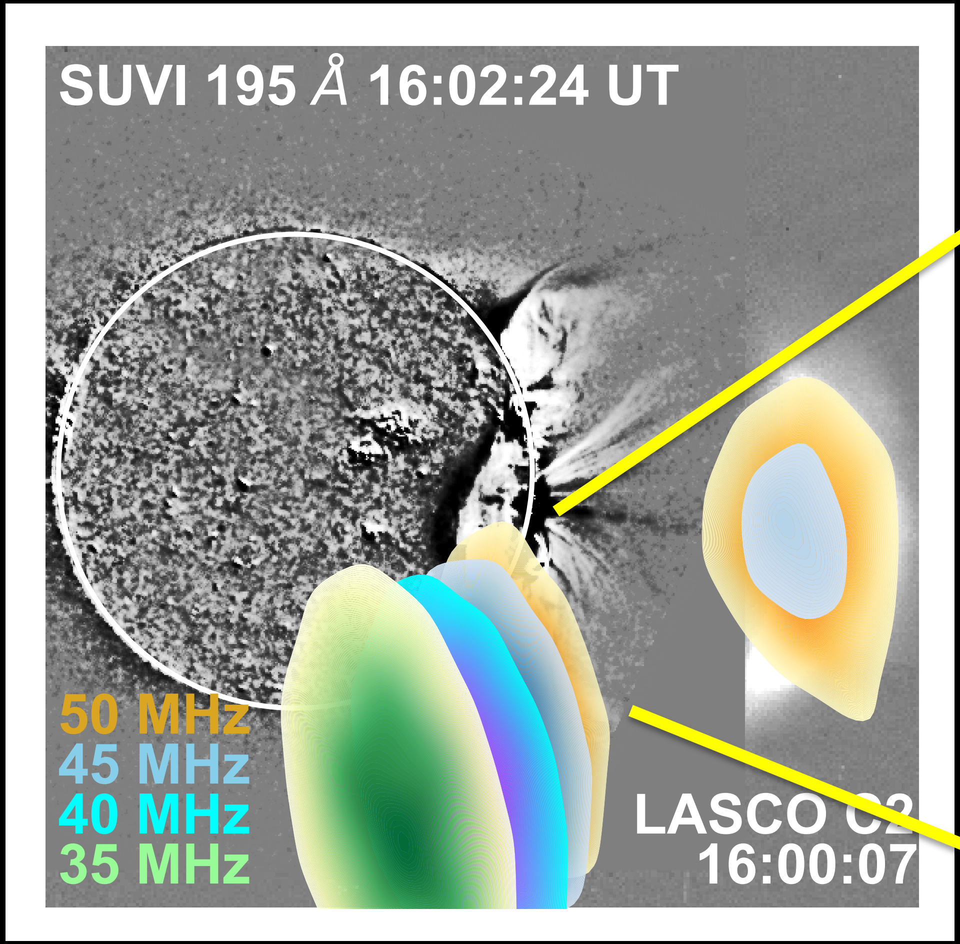
Shock - Mach 3

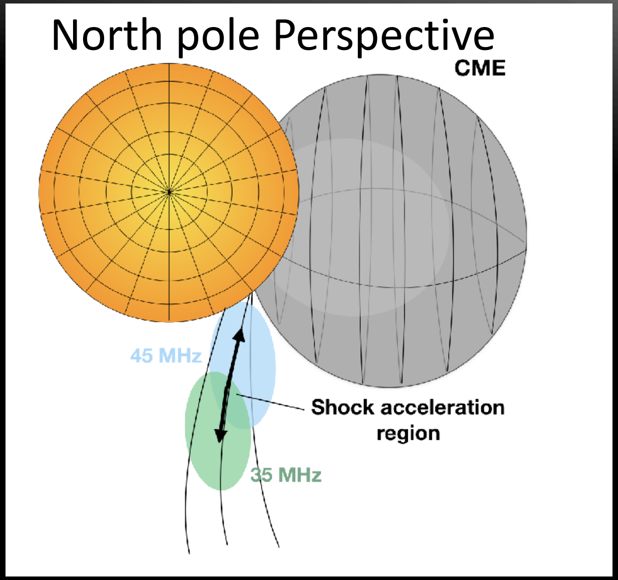
Shock - Mach 1.7

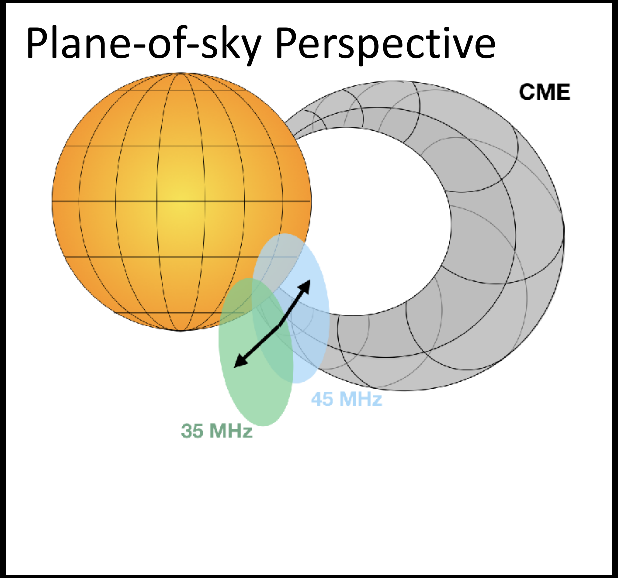


Morosan et al., in review

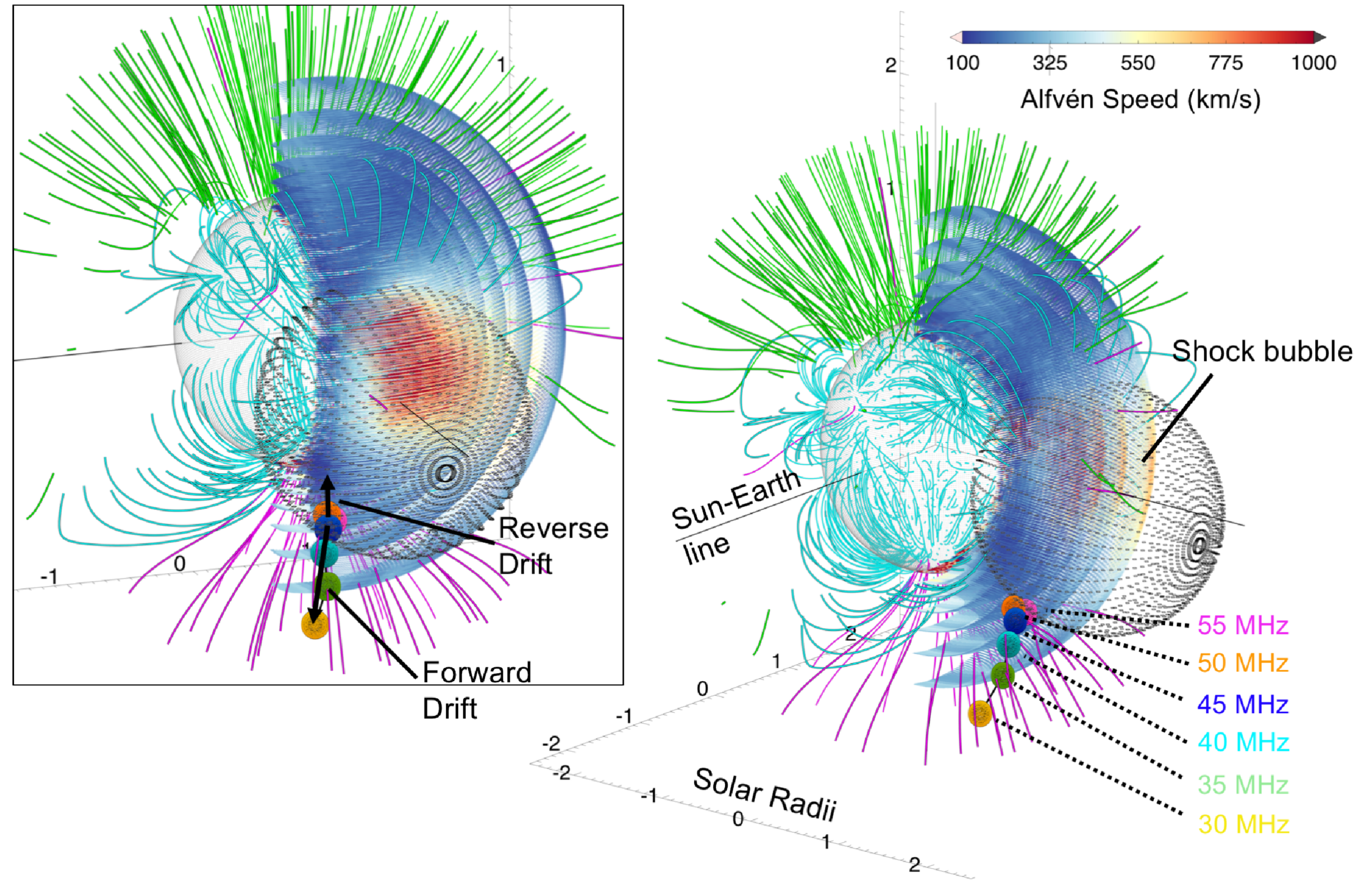
Plane-of-sky to 3D Herringbone Locations



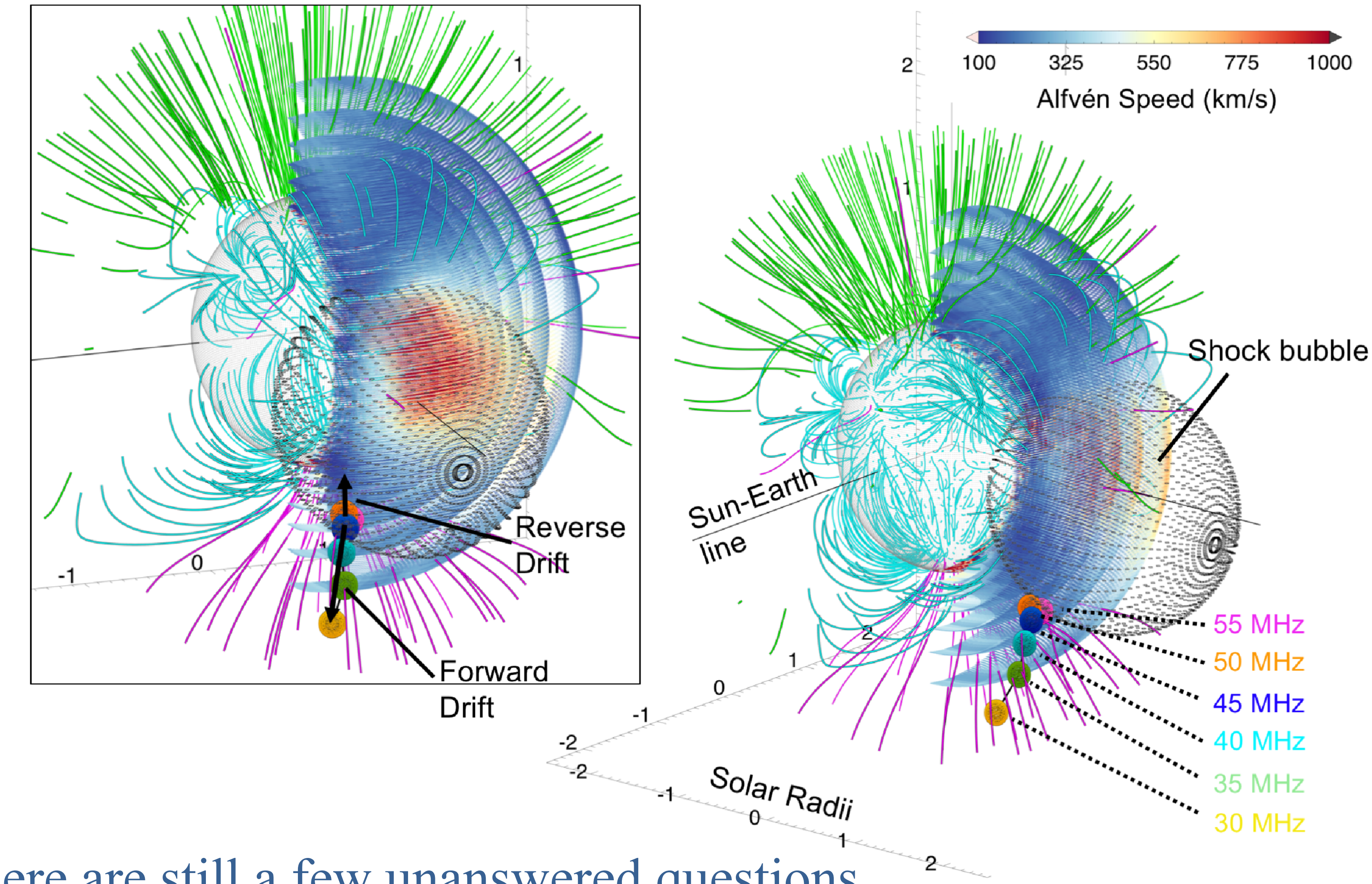




Reconstruction of 3D Herringbone and Shock Locations

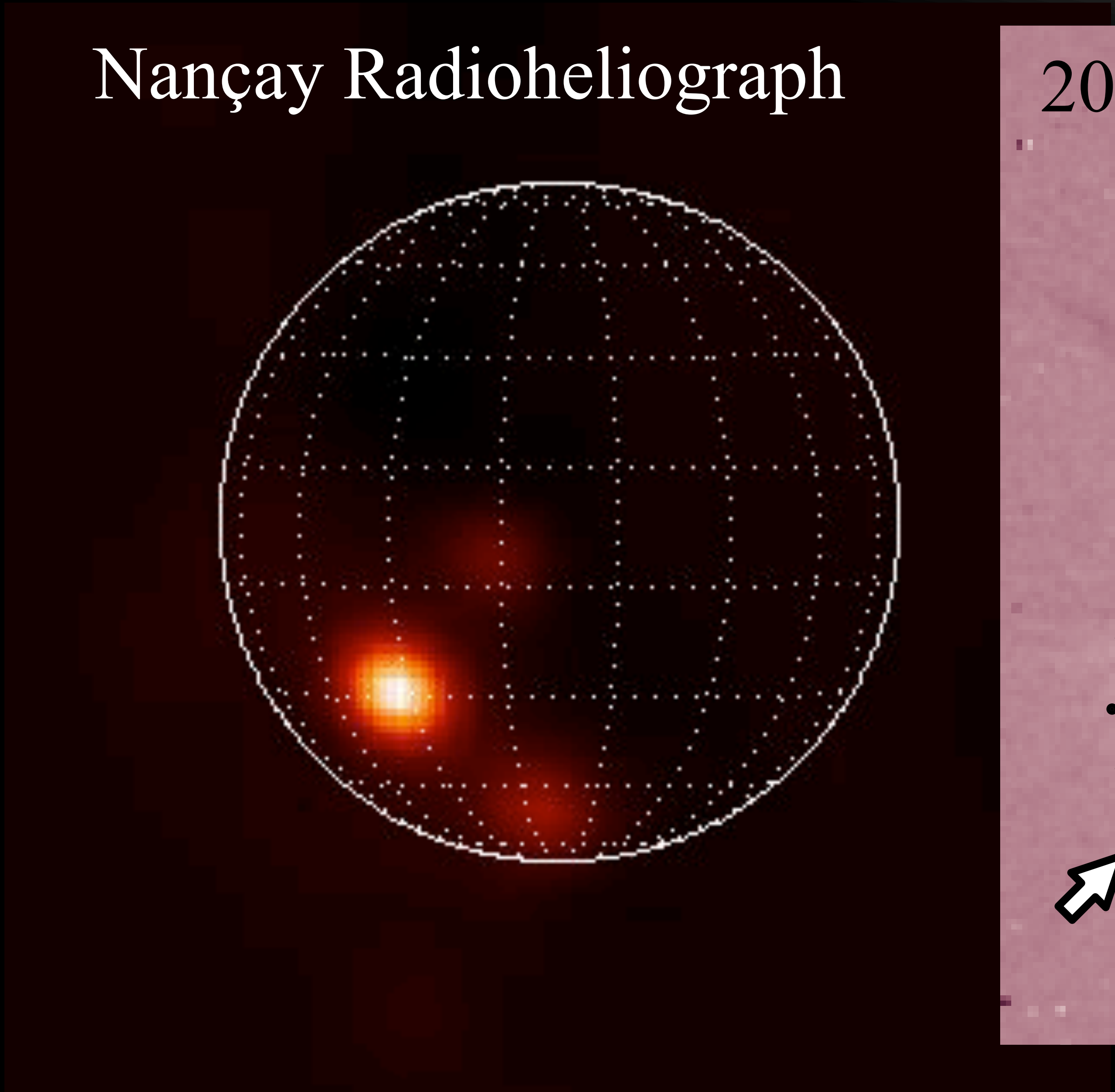


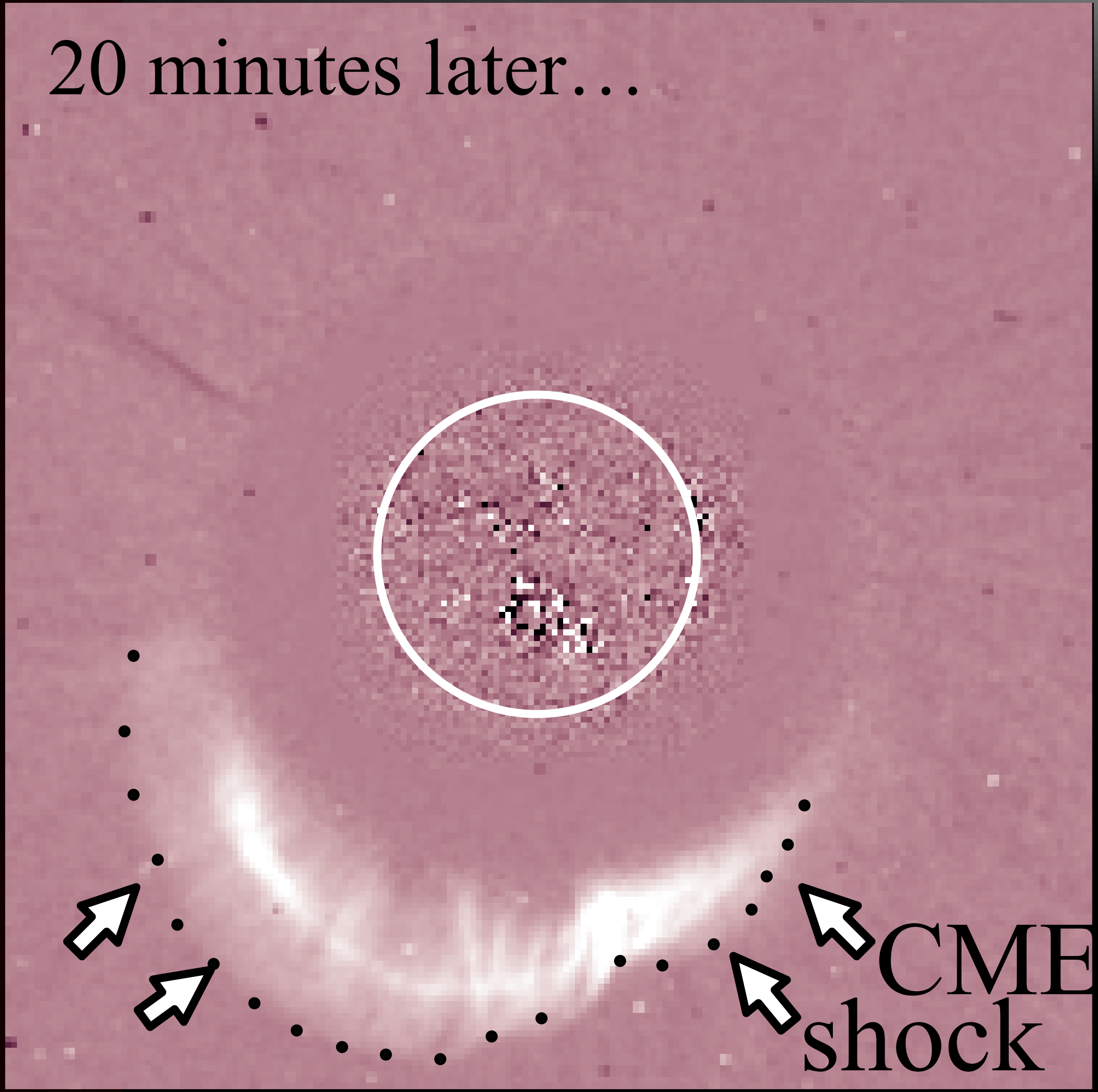
Reconstruction of 3D Herringbone and Shock Locations



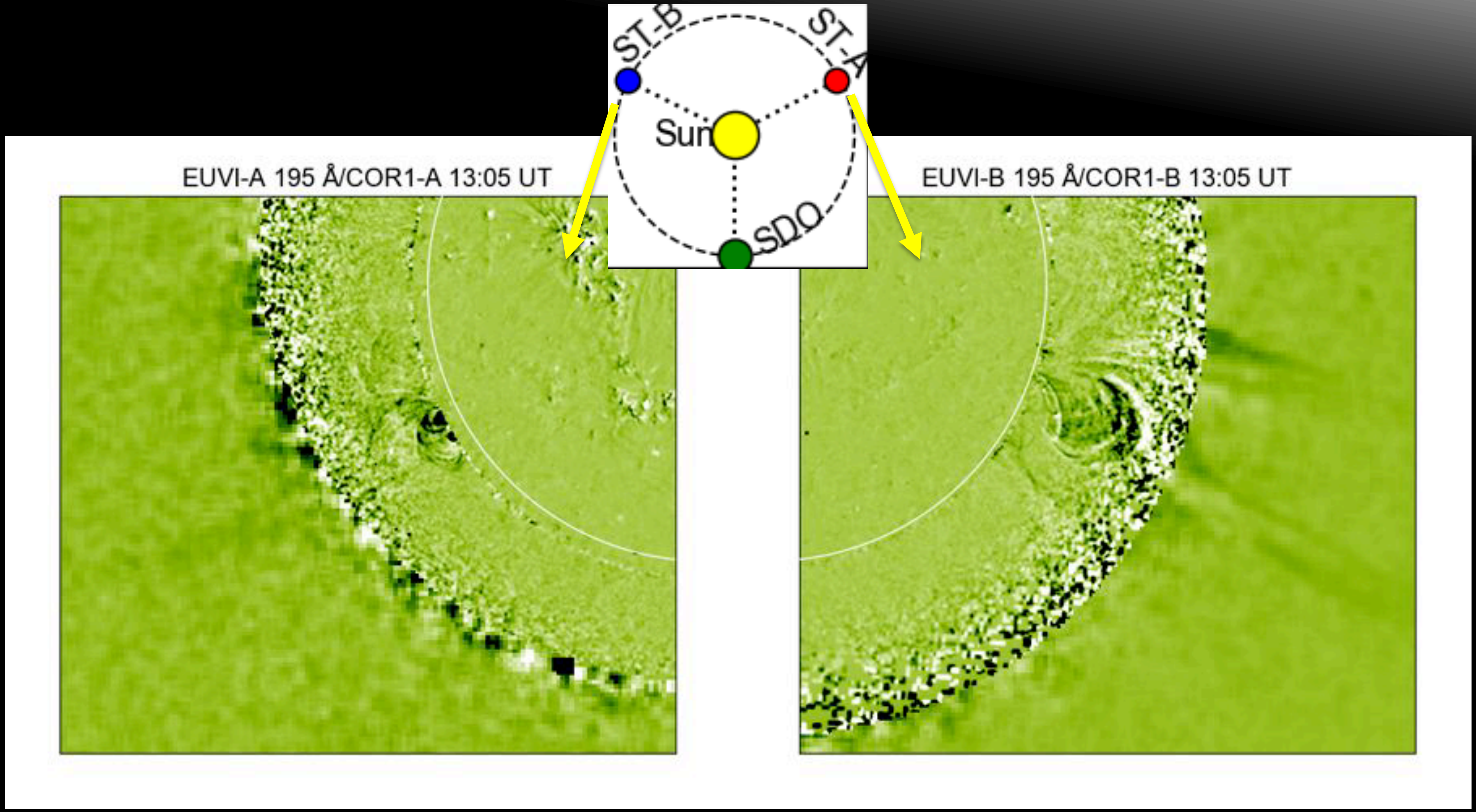
But there are still a few unanswered questions…

More Shock Accelerated Electrons

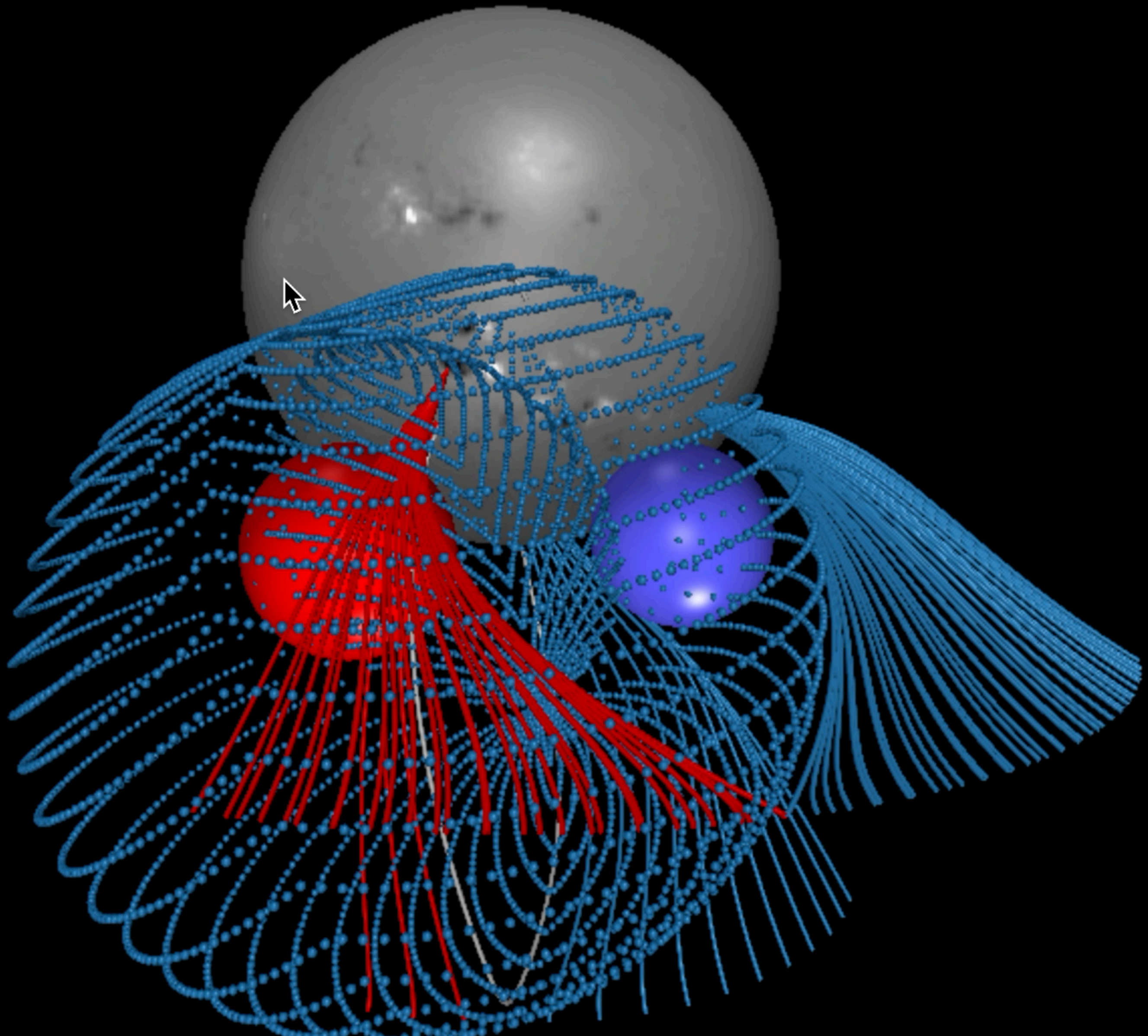




More Shock Accelerated Electrons



More Shock Accelerated Electrons



LOFAR Breakthroughs and Future Work

- LOFAR made it possible to track an individual electron beam and to find evidence for electrons accelerated at multiple locations on the expanding CME flank.

- But, there are still many unanswered questions and more ToO LOFAR observations of CMEs can help:
  - why are electrons accelerated only at specific locations since CME shocks are large scale structures?
  - can we get any information on shock morphology in the corona from high resolution interferometric observations?