Multiple Regions of Shock Accelerated Particles in the Solar Corona

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The Sun is an active star that can launch large eruptions of magnetised plasma into the heliosphere, called coronal mass ejections. These ejections can drive shocks that accelerate particles to high energies, often resulting in radio emission at low frequencies (<200 MHz). To date, the relationship between the expansion of coronal mass ejections, shocks and particle acceleration is not well understood, partially due to difficulties associated with radio imaging at low frequencies. Here, we report unique radio, whitelight and ultraviolet imaging of the second largest flare in the current solar cycle and associated very fast coronal mass ejection (~3000km/s). For the first time, we identify the location of a multitude of radio shock signatures, called herringbones, and find evidence for shock accelerated electron beams at multiple locations along an expanding coronal mass ejection, supporting theories of non-uniform, rippled shock fronts.

1. Flare, Coronal Mass Ejection, Radio Burst

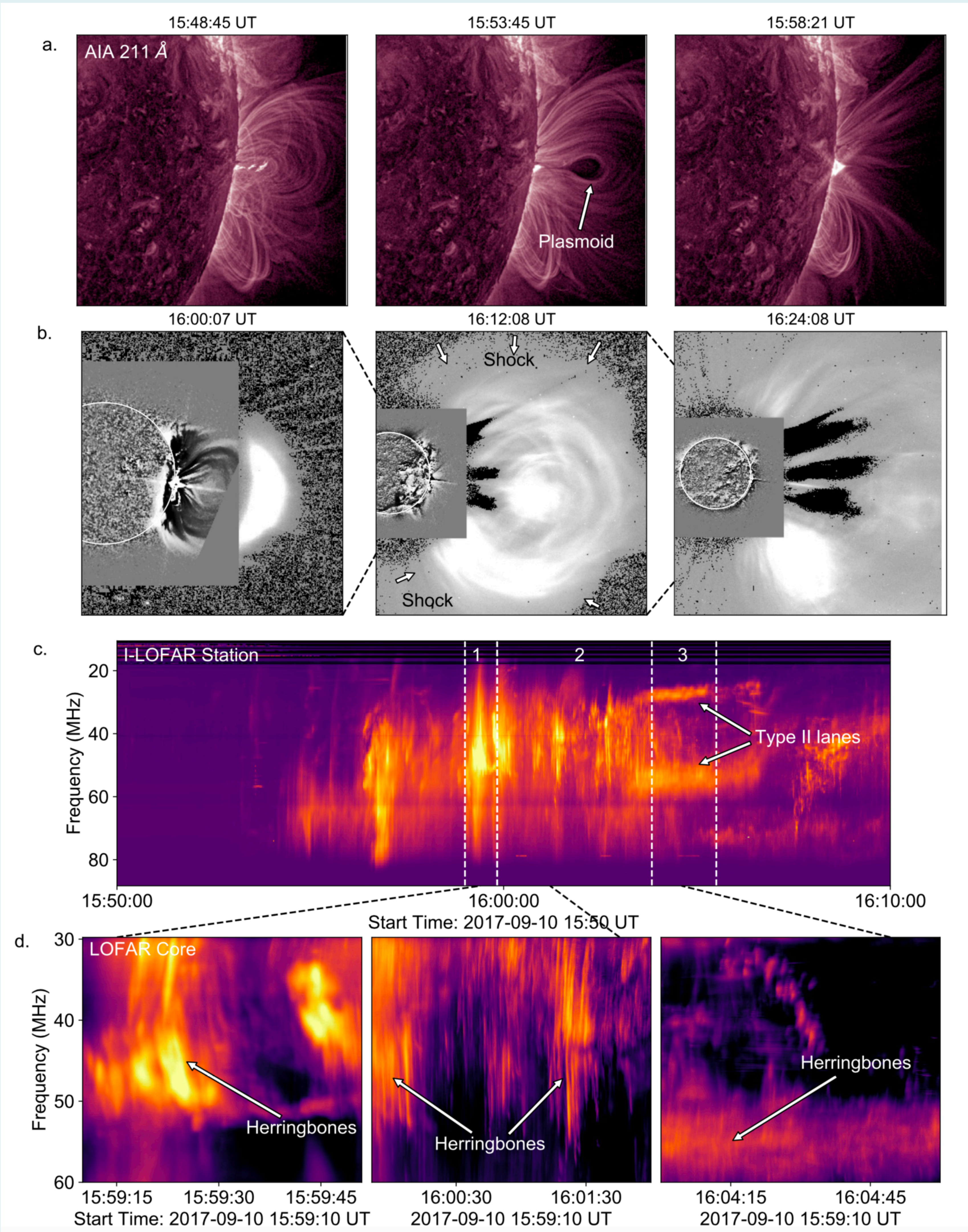

Figure 1. Solar flare, CME and associated radio emission observed on 10 September 2017.

(a) AIA 211 Å of the 10 September 2017 X8.2 flare and plasmoid.
(b) SUVI and LASCO images showing expansion of the CME.
(c) I-LOFAR dynamic spectrum showing complex burst.
(d) LOFAR core dynamic spectra showing "herringbones".

2. Herringbone Spectra and Imaging

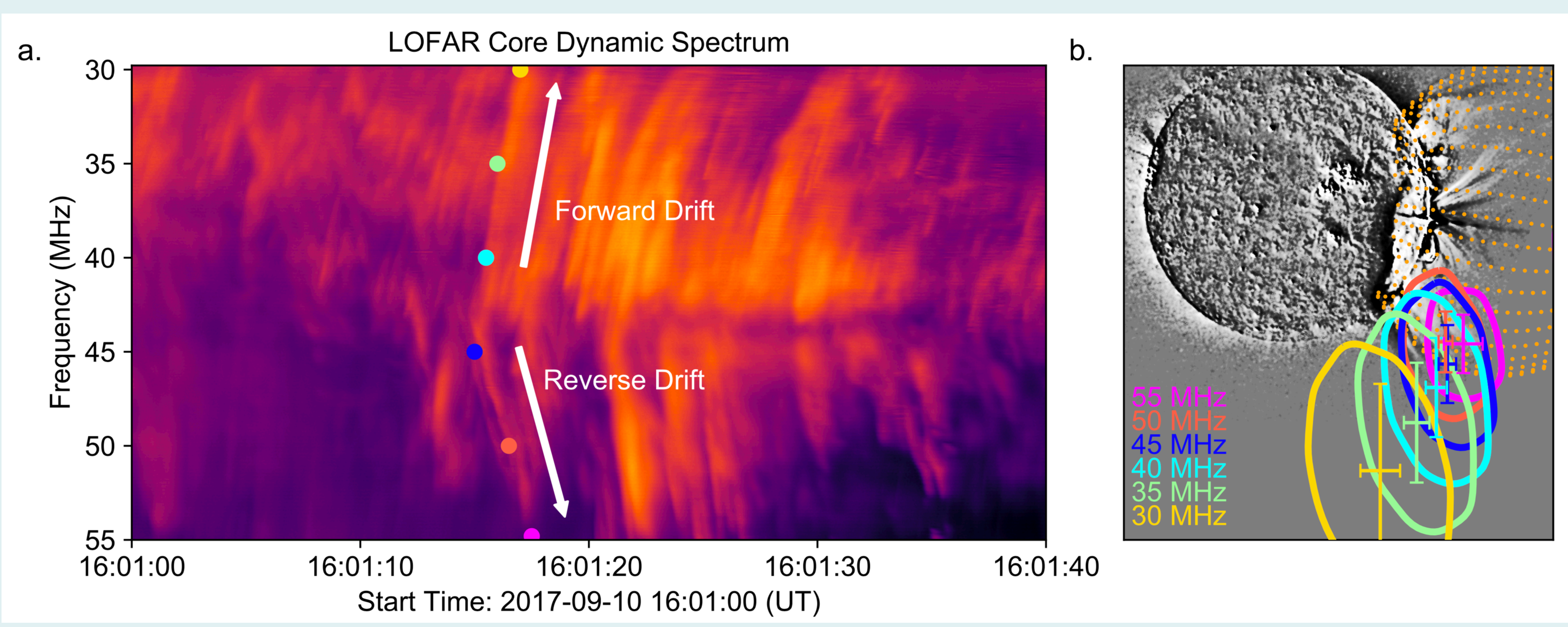

Figure 2. Herringbone forward and reverse drifts and their locations.

(a) LOFAR dynamic spectrum of herringbones.
(b) LOFAR image contours at 6 frequencies overlaid on the SUVI running difference image and estimate of the 3D shock bubble surrounding the CME (orange dots).

3. Model of CME and Shocks

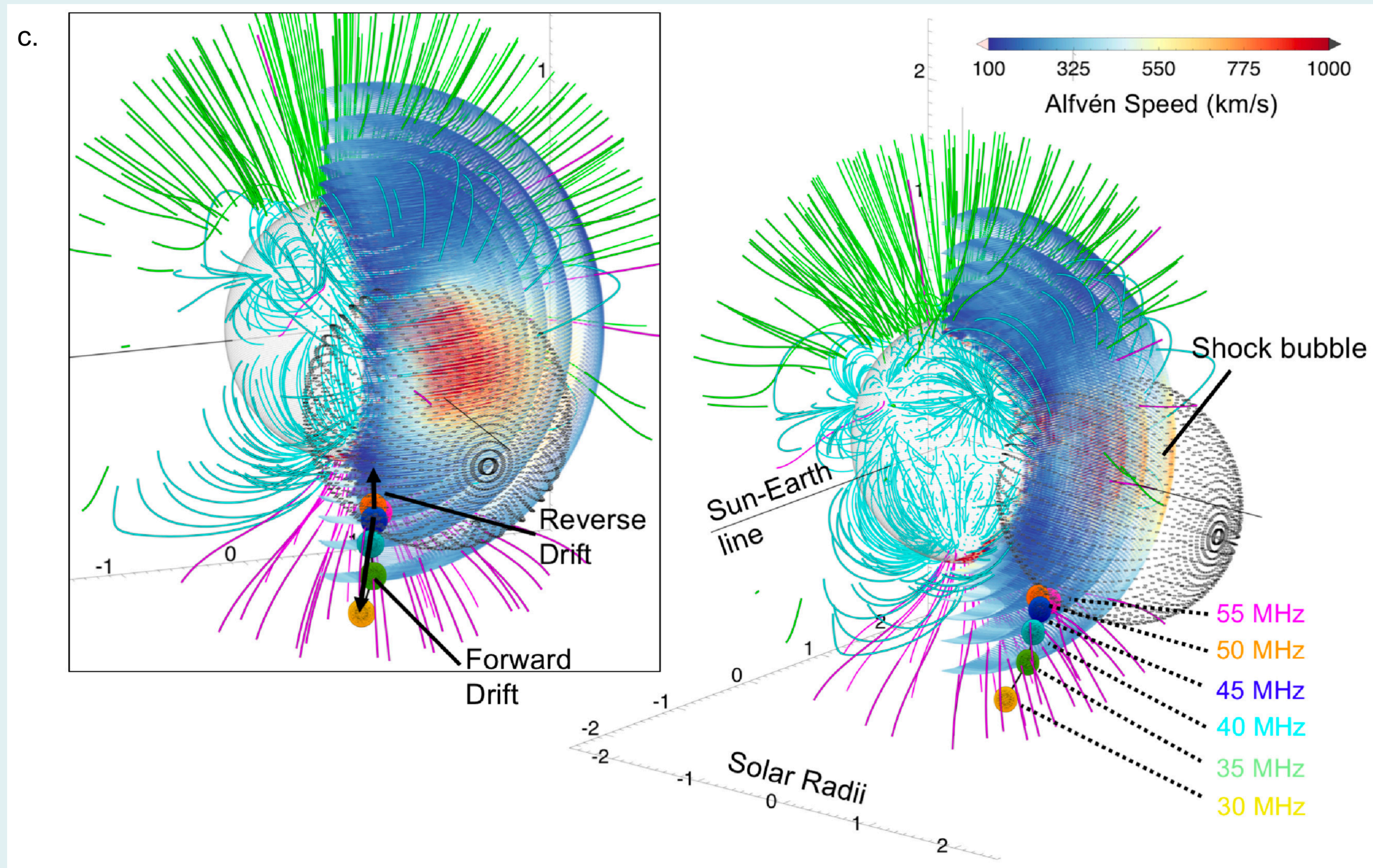

Figure 3. Model of Alfvén speed surfaces in 3D relative to the CME shock bubble.

- CME shock bubble (black dots), open magnetic field lines (purple and green lines) and the location of the de-projected radio source centroids in Figure 2(b) at six frequencies.
- The herringbone sources are located on top of the shock bubble in areas of low Alfvén speed and open field lines.

4. Source Motion and Shock Locations

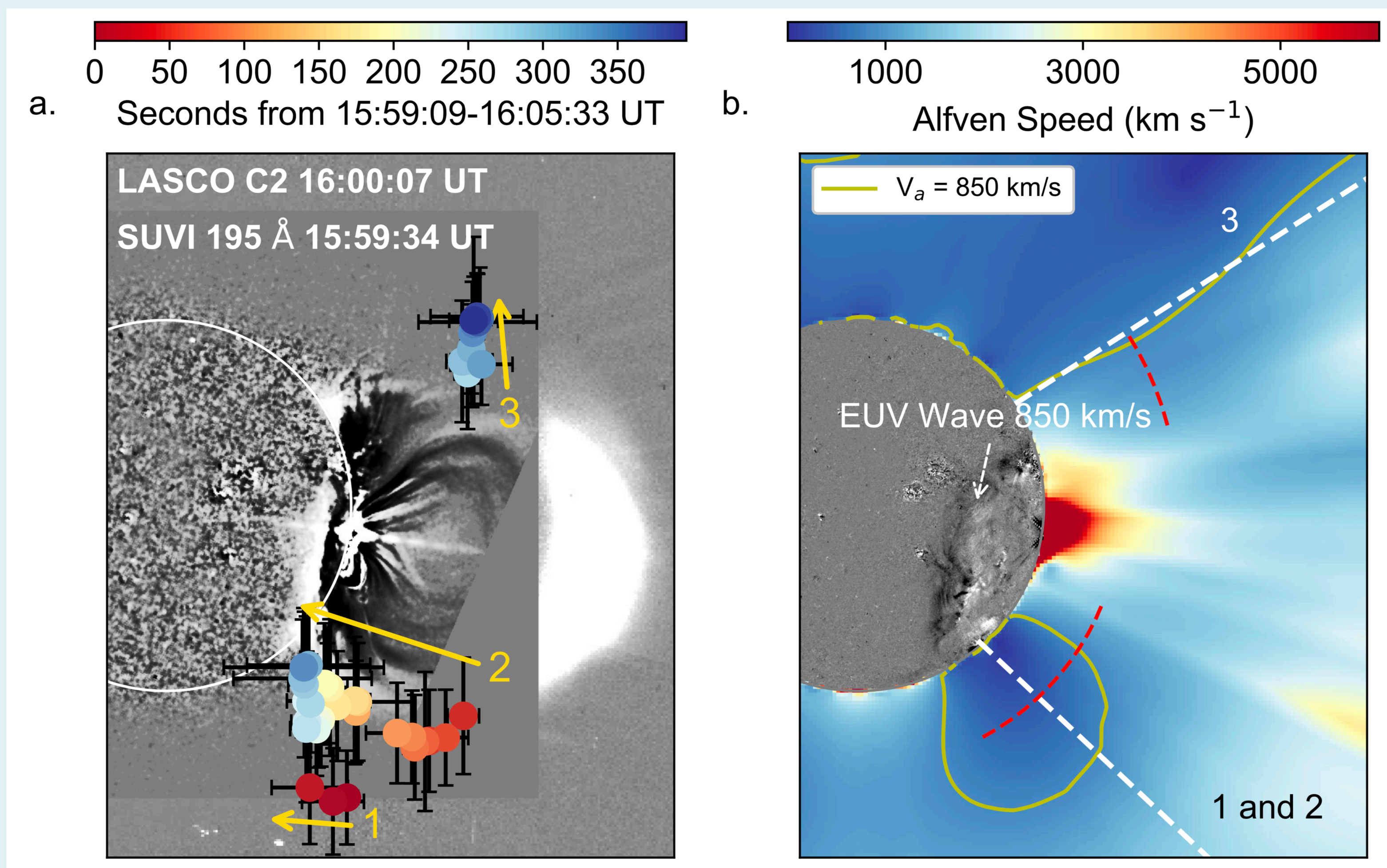

Figure 4. The movement of radio sources and the Alfvén speed environment.

(a) SUVI wave and CME overlaid are the centroids of shock signatures showing the direction of the 3 groups of herringbone sources.
(b) AIA wave at 16:05 UT and plane-of-sky Alfvén speed map. Herringbone sources occur in regions of low Alfvén speed.

5. References/Acknowledgments

[1] Morosan et al., in review.
[2] This work is supported by Science Foundation Ireland and the Irish Research Council.