# Evolution of the Alfvén Mach number associated with Coronal Mass Ejection Shock

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Astronomy & Astrophysics

Trinity College Dublin
The University of Dublin

Ciara A. Maguire [1,2], Eoin P. Carley [1,2], Joseph McCauley [1], Peter T. Gallagher [2,1]
1. Trinity College Dublin, Ireland. 2. Dublin Institute for Advanced Studies, Ireland.

The Sun regularly produces large-scale eruptive events such as coronal mass ejections (CMEs) that can drive shock waves through the solar corona. Such shocks can result in electron acceleration and subsequent radio emission in the form of a type II radio burst. Here, we study the evolution of CME-driven shock properties by comparing three commonly used methods of calculating the Alfvén Mach number ($M_A$), namely: shock geometry, a comparison of CME speed to a model of the coronal Alfvén speed, and the type II band-splitting method. We applied the three methods to the 2017 September 2 event, focusing on the shock wave observed in extreme ultraviolet (EUV) by the Solar Ultraviolet Imager (SUVI), in white-light by the Large Angle and Spectrometric Coronagraph (LASCO) and the type II radio burst observed by the Irish Low Frequency Array (I-LOFAR). We show that the three different methods of estimating shock $M_A$ yield consistent results and provide a means of relating shock property evolution to the type II emission duration. We find that the type II radio emission came from the nose of the CME when the shock $M_A$ became supercritical and the emission cessation was due to the change in shock-to-magnetic field geometry (**Maguire et al., A&A, 2019).**

## 1. Flare, Coronal Mass Ejection, Radio Burst

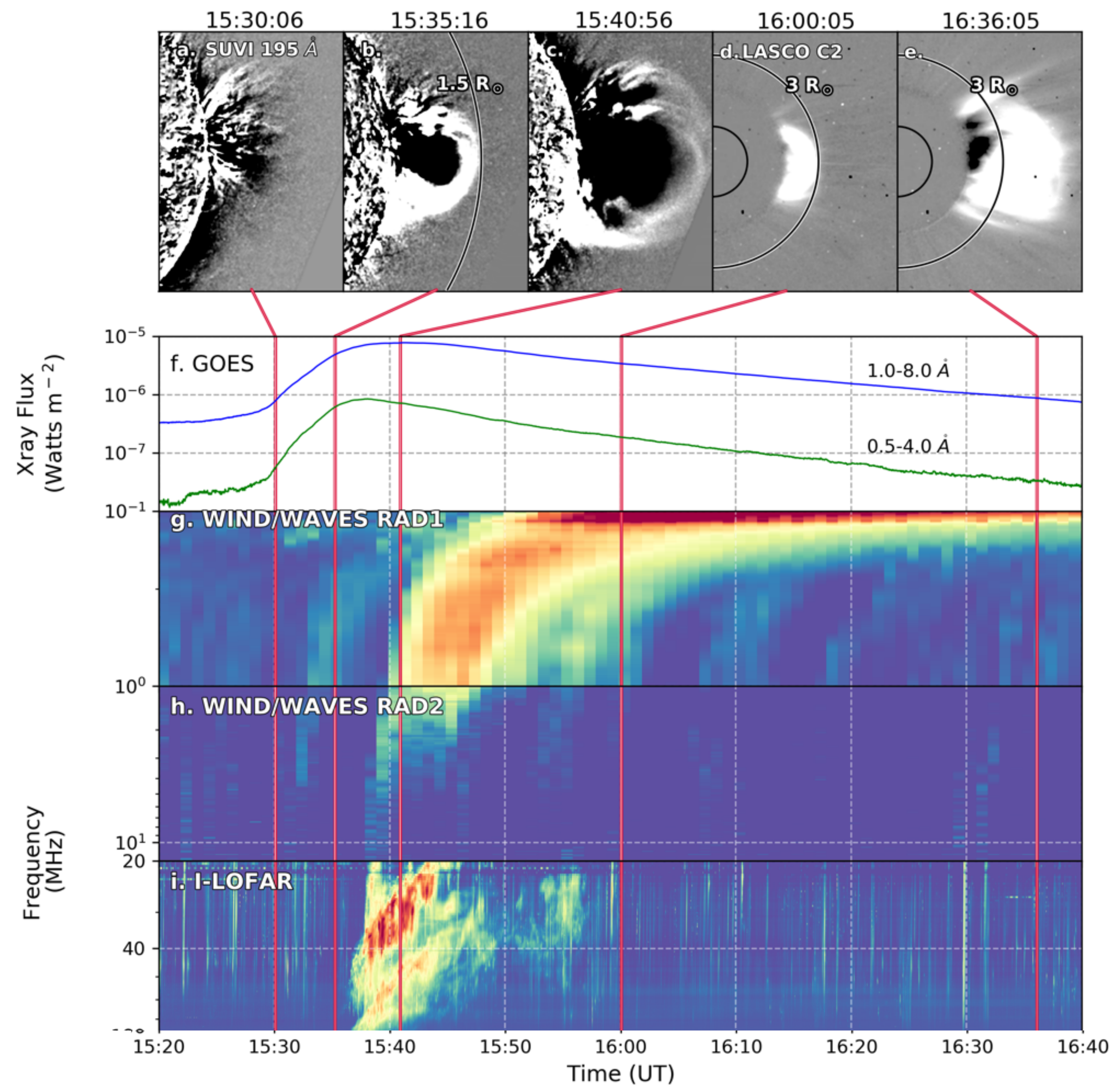


**Figure 1.** Solar flare, CME & associated radio emission observed on Sep 2, 2017 .
**a-c.** SUVI 195 Å images of the C class flare.
**d-e.** LASCO images showing expansion of CME.
**f.** GOES X ray flux.
**g.** WIND/WAVES RAD 1 dynamic spectrum.
**h.** WIND/WAVES RAD 2 dynamic spectrum.
**i.** I-LOFAR dynamic spectrum showing type II radio burst.

## 2. Estimating Alfvén Mach Number

Investigated three different methods to derive the shock Alfvén Mach number from SUVI, LASCO, and I-LOFAR observations.

**Method 1** Standoff Distance $$M_A = \sqrt{1 + \left[1.24\delta - \frac{(\gamma-1)}{(\gamma+1)}\right]^{-1}}$$

**Method 2** CME speed / Alfvén speed $$M_A = v_{CME}/v_A$$

**Method 3** Band-Splitting $$M_A = \sqrt{X(X+5)/2(4-X)}$$

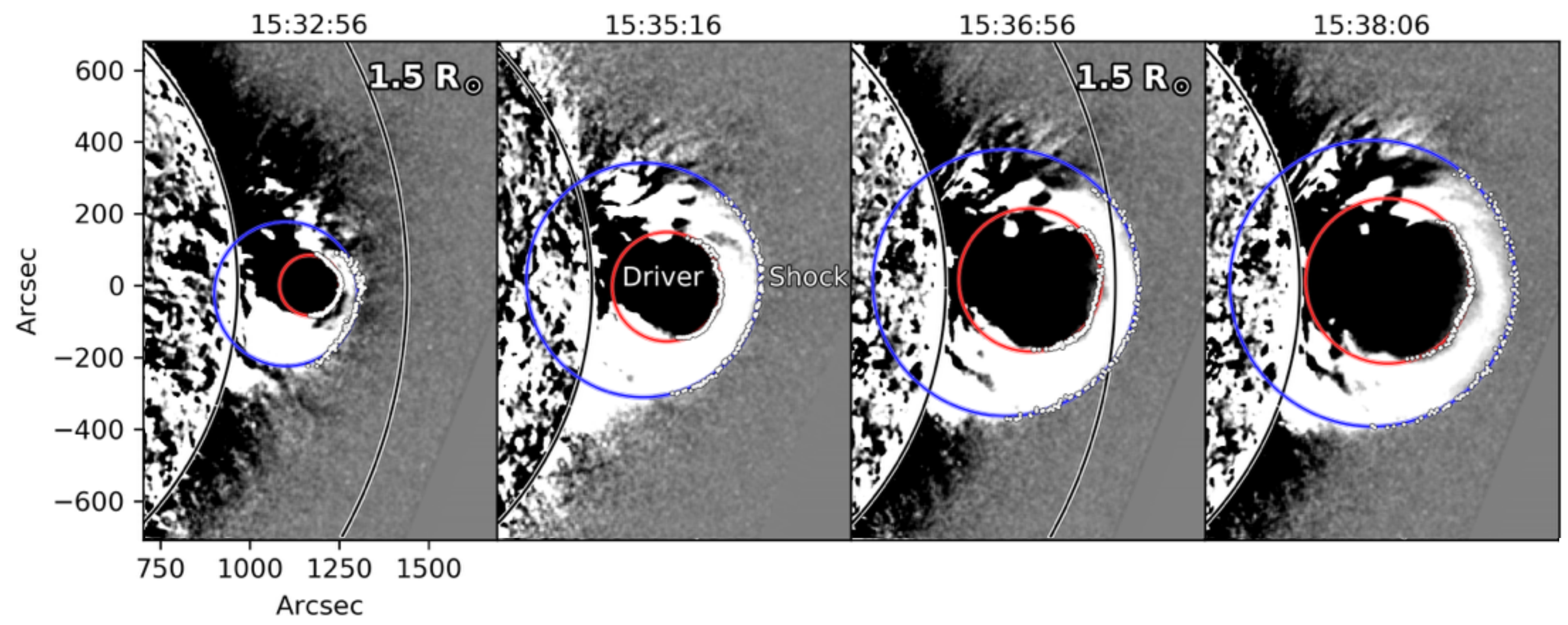


**Figure 2.** Standoff distance method applied to SUVI images.

## 3. CME Shock Properties Comparison

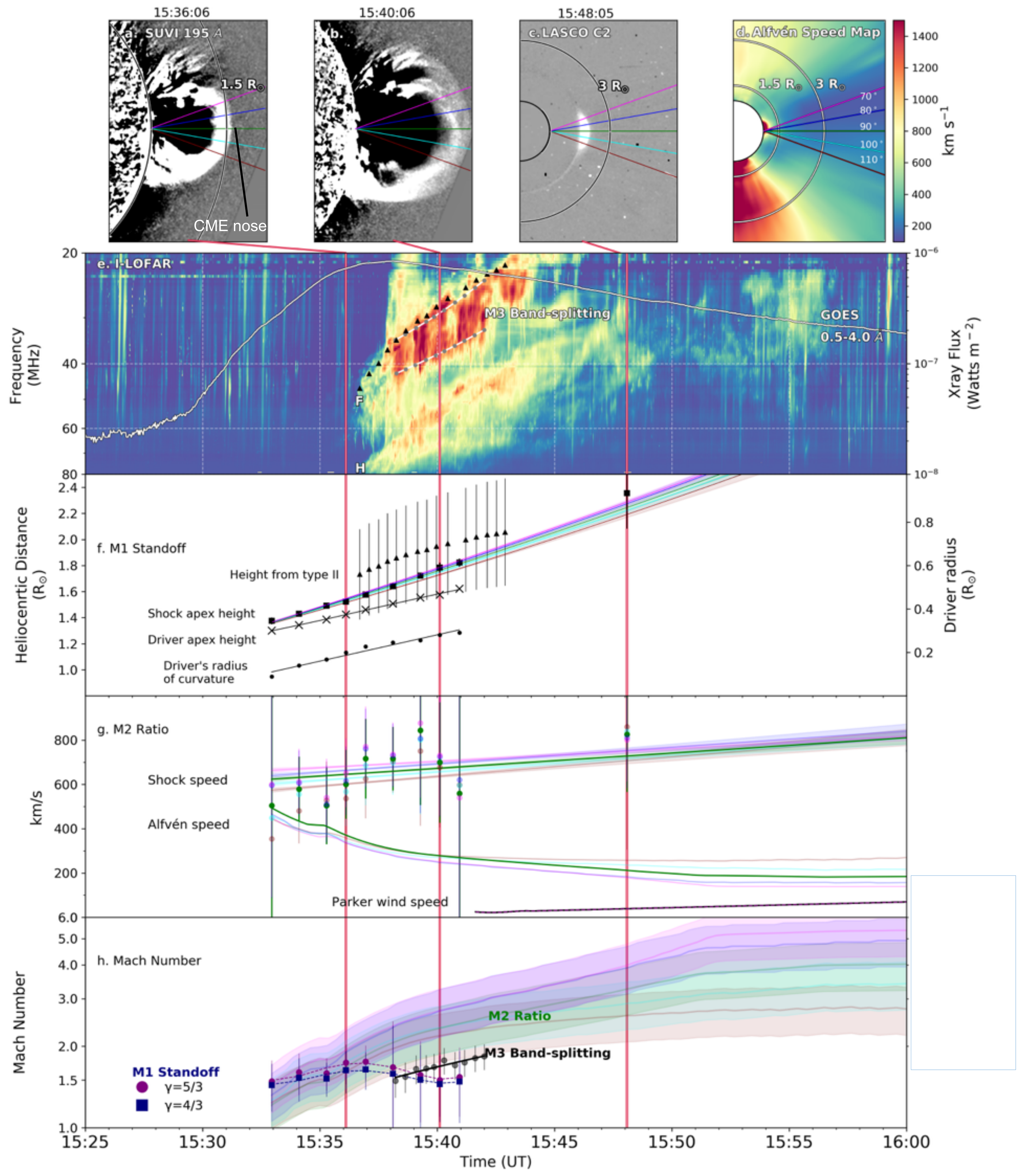


**Figure 3.** CME shock properties derived from SUVI, LASCO and I-LOFAR.

- Location of radio burst source was found to be on CME nose.
- Three methods to derive Alfvén Mach Number were found to be consistent.

## 4. Why did the Type II Start & Stop?

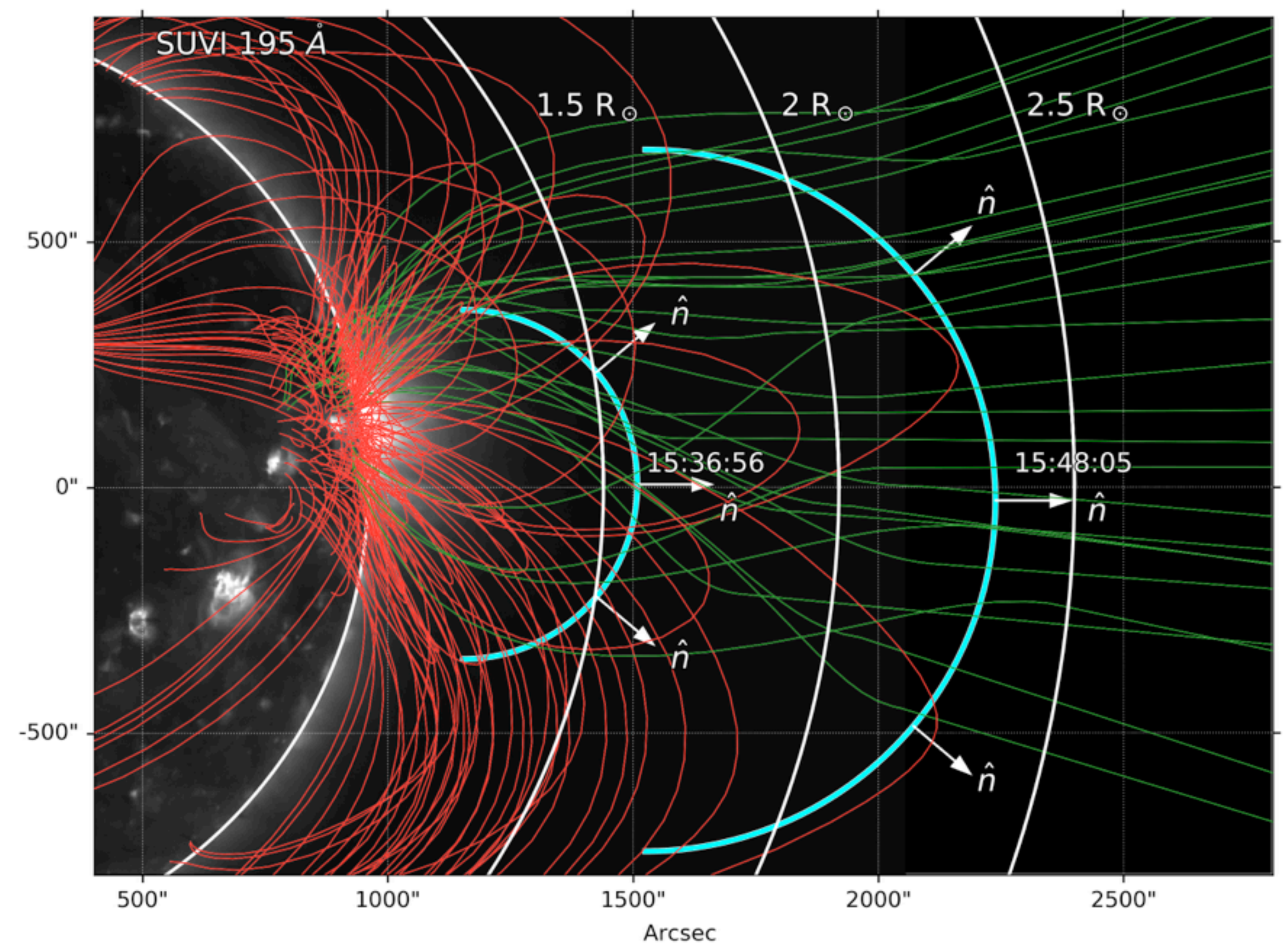


**Figure 4.** Magnetic field extrapolation on 2 September 2017

- Open (green) and closed (red) magnetic field lines and the location of CME nose when type II began and ceased (cyan arcs).
- Type II emission began when the shock became super-critical in a region where the shock-to-magnetic field geometry was quasi-perpendicular.
- The type II ceased when the shock became quasi-parallel.

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http://dias.ie/ciaramaguire
ciara.maguire@dias.ie
@ciara_a_maguire