University of Exeter

Tracking a Near-Ecliptic Merged Interaction Region

Longitudinally Spaced Observations of a Magnetic-Cloud like Structure Embedded in a Co-rotating Interaction Region

Claire Foullon

Megan L. Maunder, University of Exeter

Robert Forsyth, Imperial College London

David Barnes, and Jackie A. Davies, STFC RAL Space

Introduction

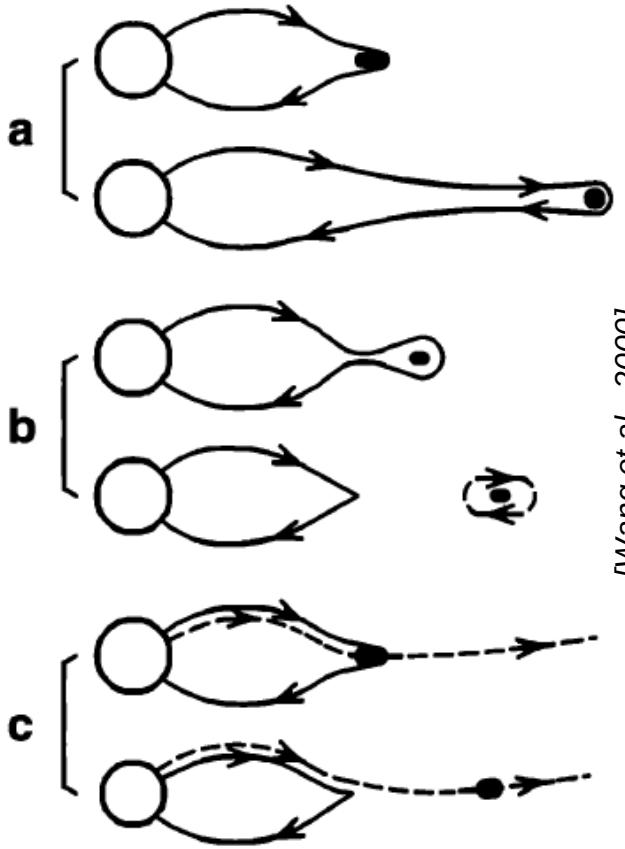
Slow solar wind (at least in part): transient events from **magnetic reconnection** generated **either at the cusps** of streamers **or between the coronal hole boundaries and the cusps of streamers**.

Formation of Plasmoids – Three possible mechanisms

a) **Outward pressure of the trapped material, stretching the loop to infinity.**

b) **X-type neutral point pinching off detached plasmoid** → *in 3D: cross-section of flux rope with both ends still attached to the Sun.*

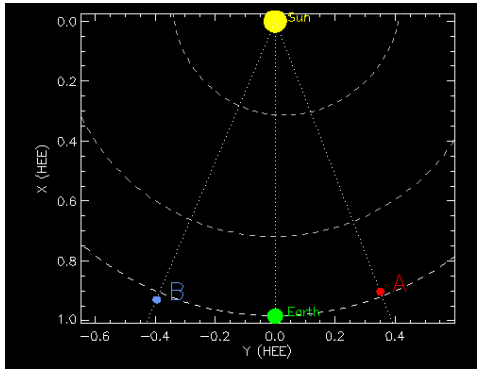
c) **Interchange reconnection.**



[Wang et al., 2000]

Introduction

- **A multi-spacecraft study of the HCS with STEREO, where we looked at the slow solar wind around the HCS as a boundary layer** (Foullon, Lavraud, Luhman et al. 2011)

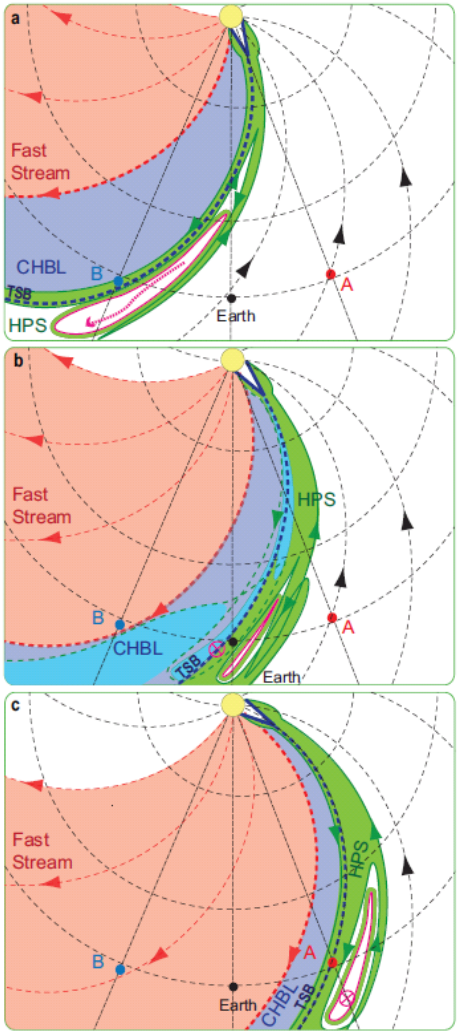


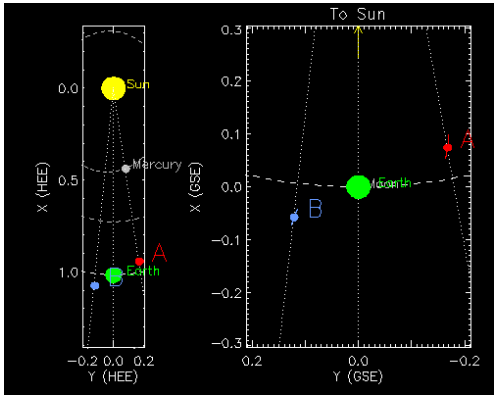
2008 event, evolution observed from East to West:

Differential rotation-driven evolution → asymmetry by interchange

Continuous releases of plasmoids

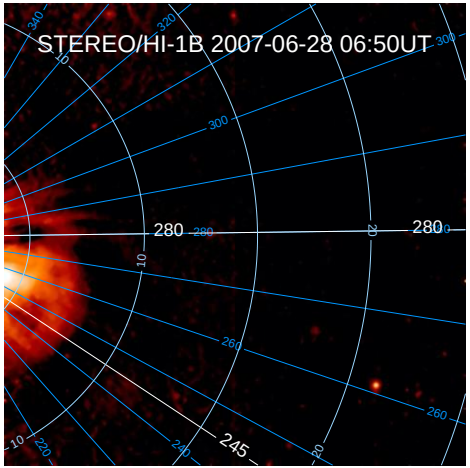
- **Observations show the transient release of density blobs and flux ropes through sequential magnetic reconnection at the tip of the helmet streamer** with STEREO remote sensing (e.g. Sanchez-Diaz et al. 2017a, 2017b) and PSP in-situ (Lavraud et al. 2020).

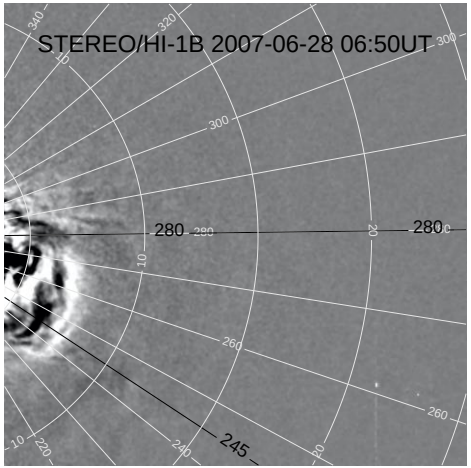




Observations on 3-4 July 2007

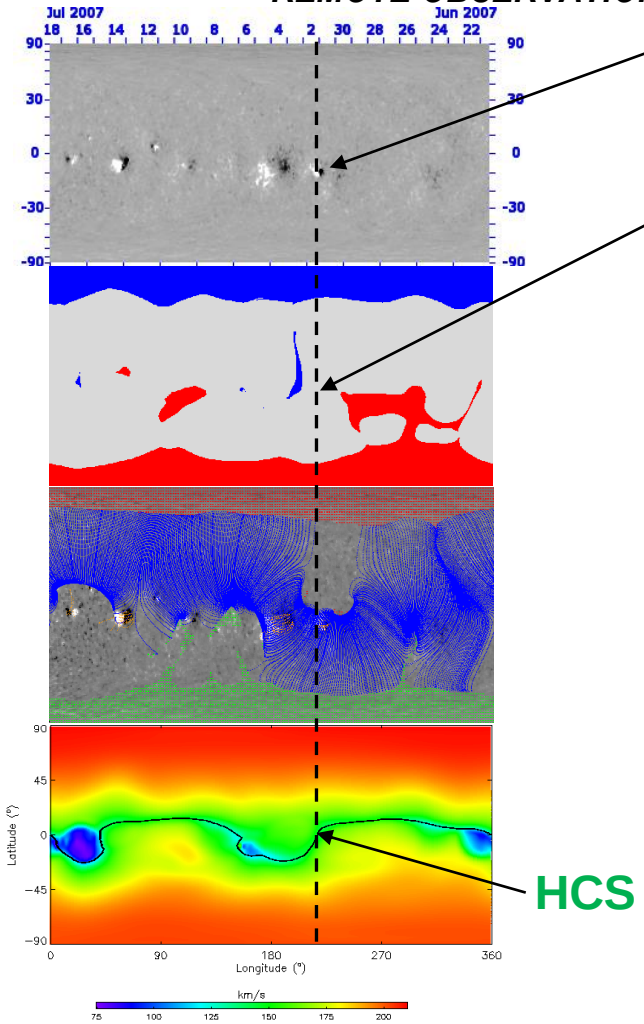
- Near-ecliptic in-situ observations of the **Heliospheric Current Sheet (HCS)**, **Corotating/Stream Interaction Region (CIR/SIR)** **and a High Speed Stream (HSS).**
- Travelling the distance of 1 AU with the HSS speed of about 600 km/s indicates that the relevant coronal hole plasma parcel for the in-situ observations will be seen 2.9 days earlier on **1st of July 2007 at the Sun.**





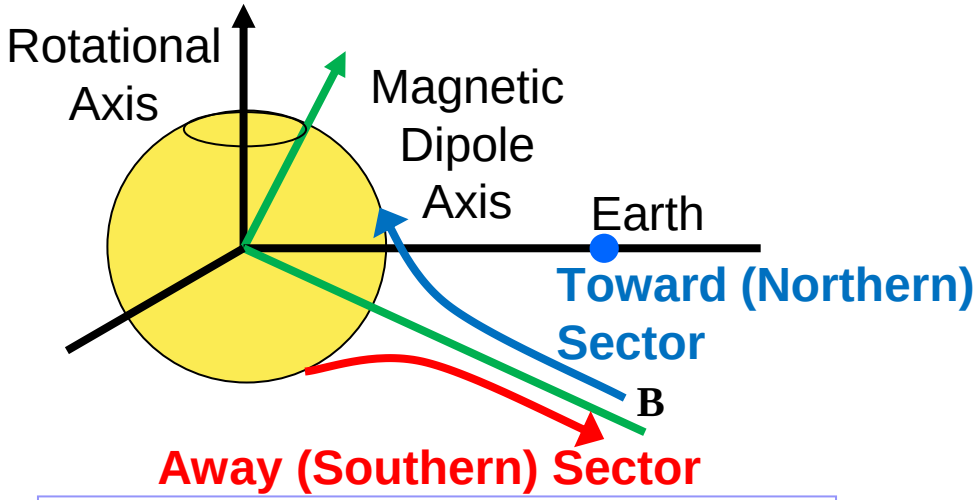
- Note the contemporaneous (I)CME event in **Maunder, Foullon et al. (2022)** analysed using remote-sensing from STEREO and in-situ *Ulysses* showing its in-situ counterpart outside the ecliptic plane.

REMOTE OBSERVATIONS



HCS

- AR centred on the disk, located across the field inversion neutral line, thus at the base of the helmet streamer belt.
- Coronal holes with **inward** and **outward** IMF polarity.



In this period near solar minimum, the **toward sector** (sunward IMF) is connected to the northern solar magnetic hemisphere, and the **away sector** (anti-sunward IMF) to the southern hemisphere.

IN-SITU OBSERVATIONS

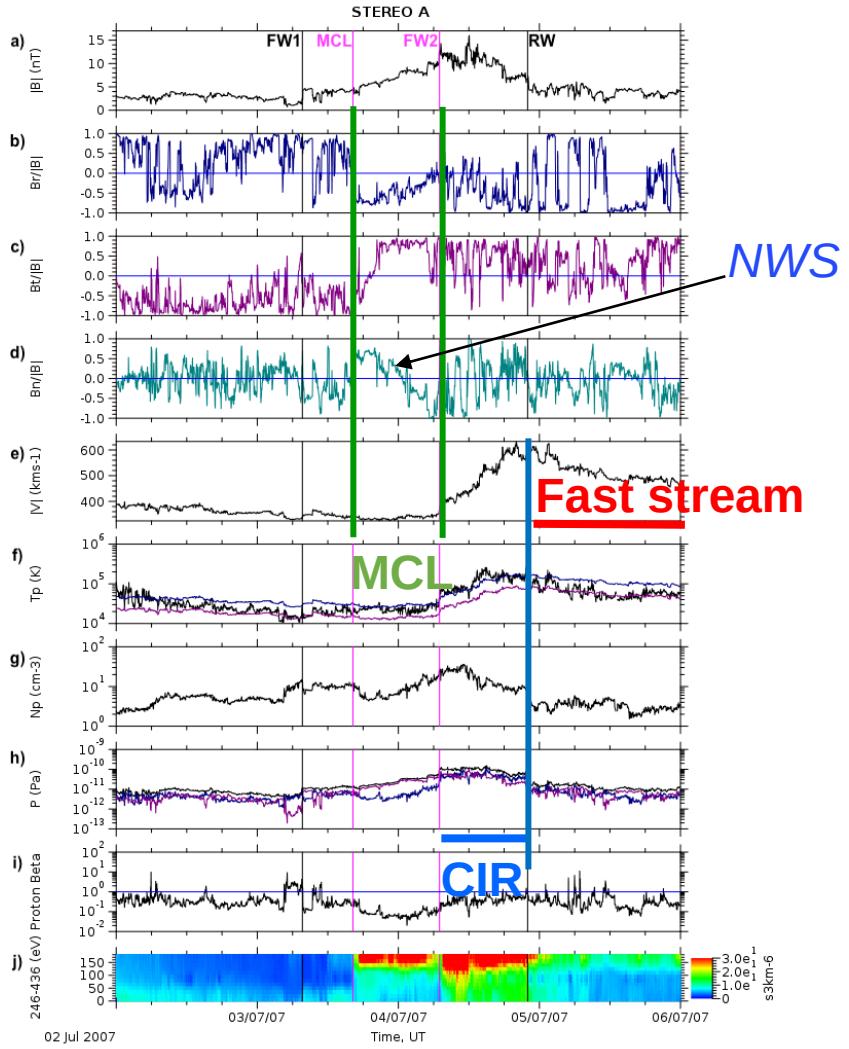
Magnetic Clouds (MCs): enhanced magnetic field and smooth, large-scale rotation of the magnetic field vectors.

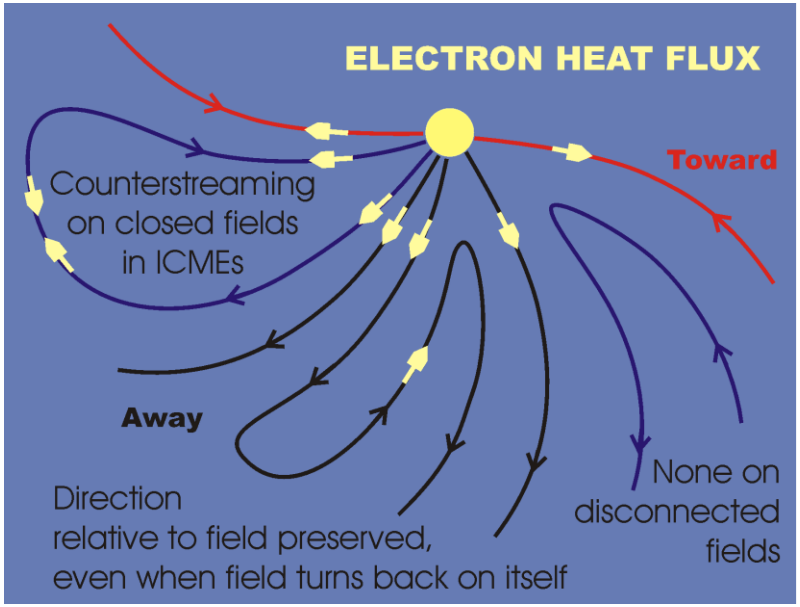
Magnetic Cloud Like-structures (MCLs): same as MCs, except that a traditional flux-rope model cannot be fitted.

Corotating Interaction Regions (CIRs): regions where the ambient plasma is compressed as a result of fast wind emerging behind slow wind from adjacent longitudinal sources.

Merged Interaction Regions (MIRs): complex structures arising from flux-rope interactions including with a HSS, SIR, or HCS.

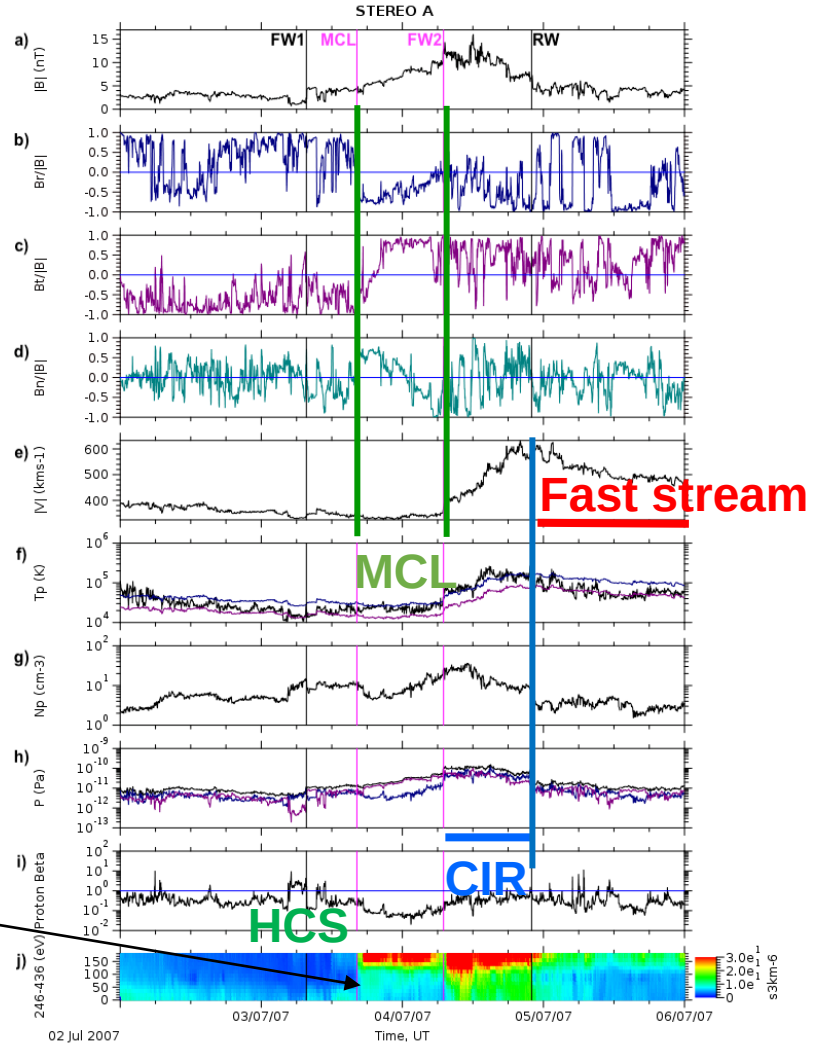
Presence of a CIR and its combination with the MCL observed as a MIR.



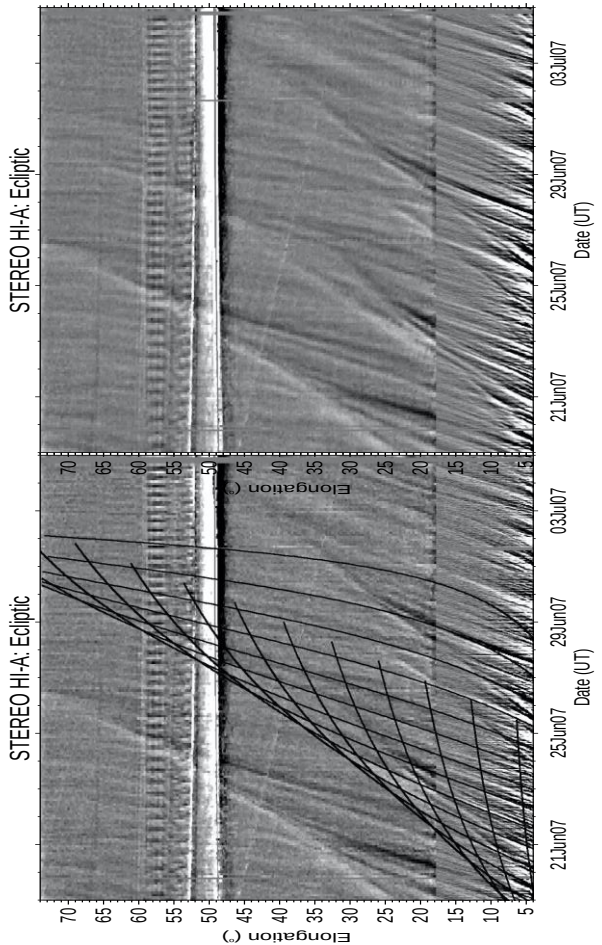


To correctly identify the HCS crossing(s), we use suprathermal electrons as sensors of magnetic topology.

The magnetic field is anti-sunward before and sunward during and after the MCL and CIR, which is consistent with the crossing of the HCS near the start of the MCL.



REMOTE OBSERVATIONS

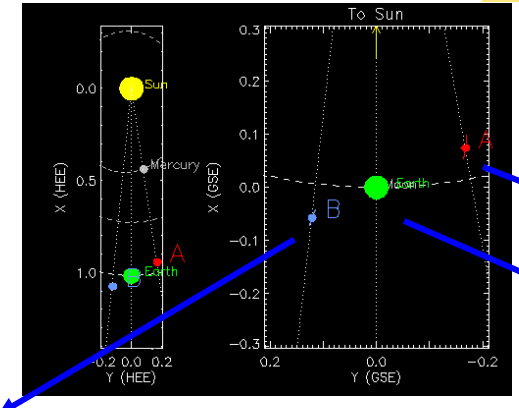


- Time–elongation maps, or J-maps, from STEREO/SECCHI-HI-A → nest of converging tracks :: a pattern of CIR-entrained blobs.
- Set of blobs all travelling with the same speed of 302 ± 21 km s^{-1}.
- The CIR is predicted to arrive at ST-B at 15:15 UT on 3 July and at ST-A at 03:13 UT on 4 July 2007.
- Similar to the observed earlier arrival time for STEREO-B and separation of ~12 hours.

Arrival times of the entrained MCL consistent with an ICME in a CIR.

MULTI-SPACECRAFT STUDY

Differences in MIR observed at different longitudes.

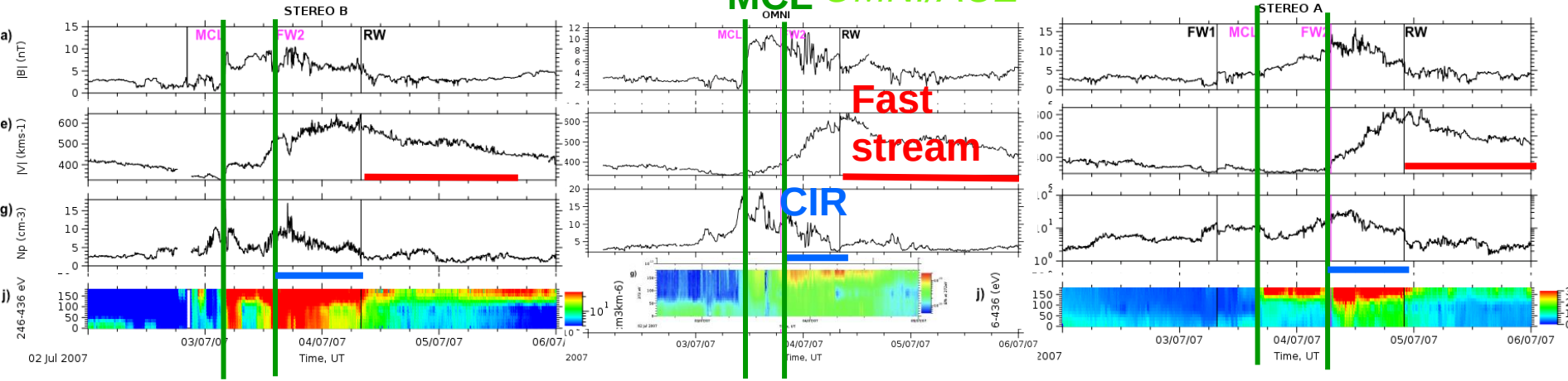


- differences in MCL size and (negative) expansion velocities
- formation of sheath
- presence of forward and reverse waves
- small-scale structuring

ST-B

MCL *OMNI/ACE*

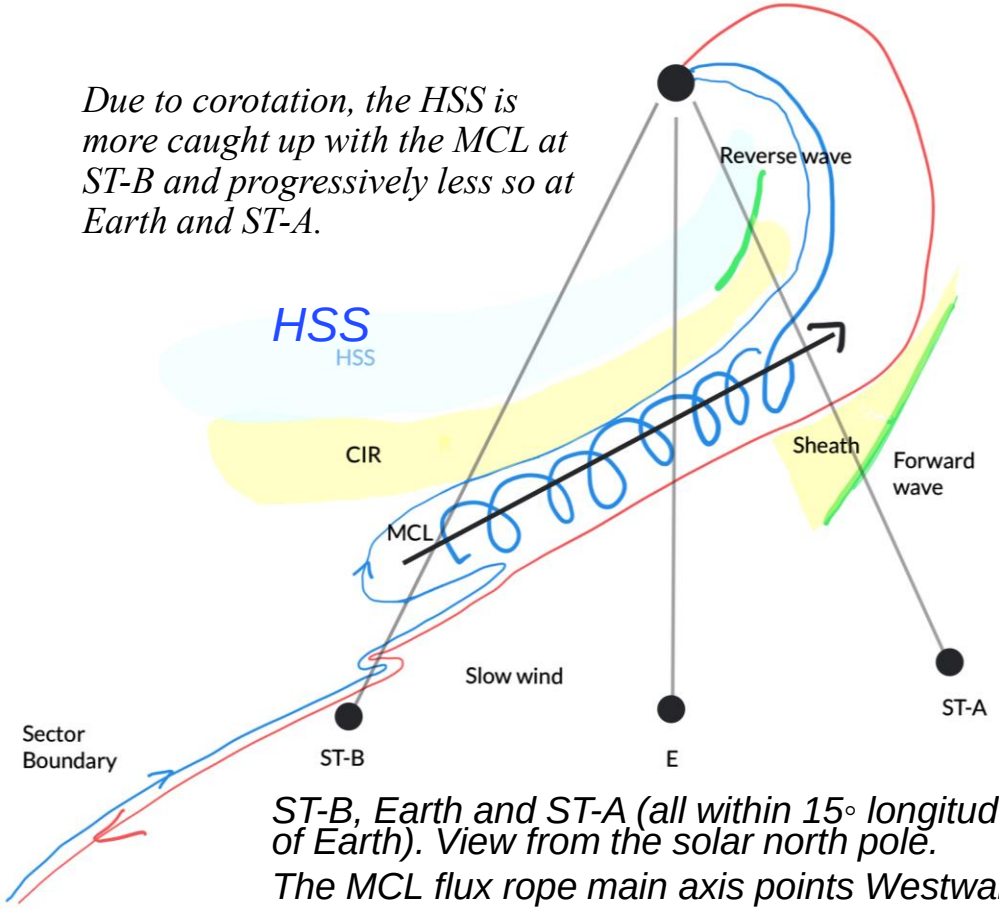
ST-A



The MIR variations across longitudes demonstrates the radial evolution of the MIR.

- **Earlier stage at ST-A:** a forward wave and front sheath are produced ahead of the MCL and a reverse wave is found at the back of the CIR as a result of the interaction with the HSS.
- **Next stages at Earth and ST-B:** the MCLs are smaller and more turbulent and the main sector boundary crossing appears to coincide with the start of the MCL (no sheath).
- **Later stage at ST-B:** MCL fully entrained in the CIR (higher speed); ahead of the MCL, small-scale structures in the field and electron data indicative of multiple magnetic folds, that may result from greater interactions with the HCS (e.g. produced by interchange reconnection with the HCS).

Due to corotation, the HSS is more caught up with the MCL at ST-B and progressively less so at Earth and ST-A.

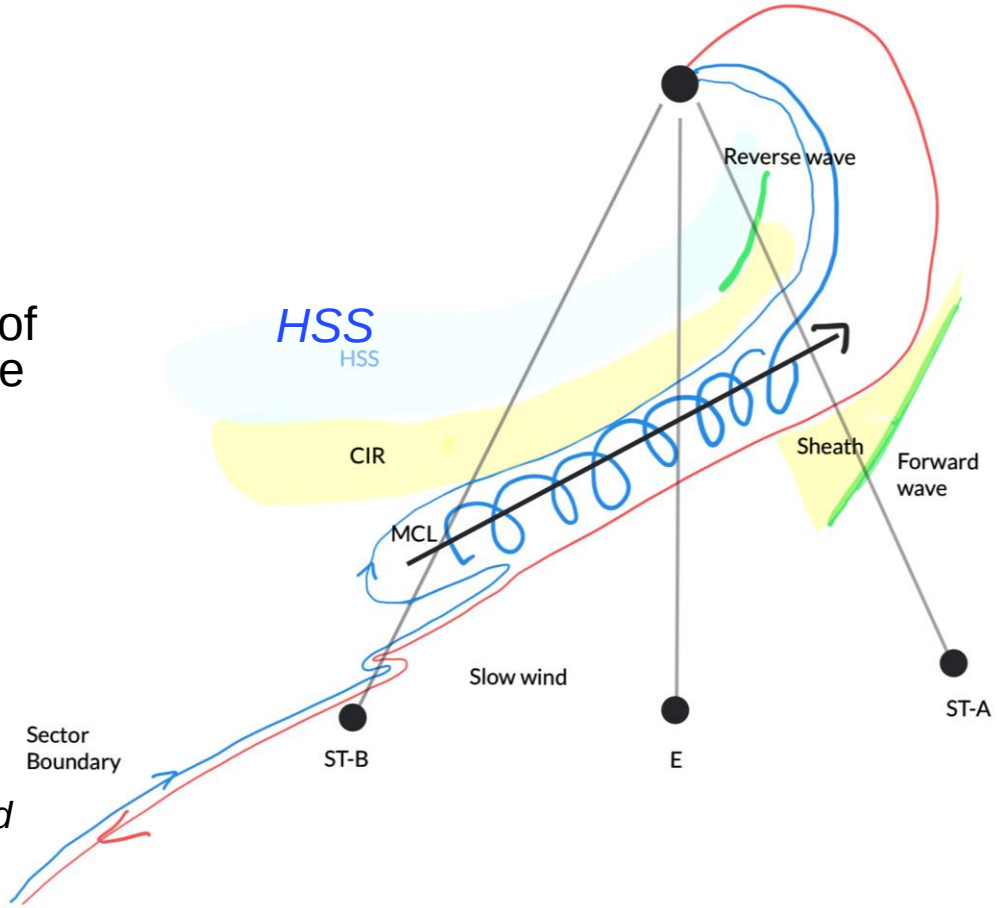


ST-B, Earth and ST-A (all within 15◦ longitude of Earth). View from the solar north pole.

The MCL flux rope main axis points Westward.

Key Findings

- Presence of a CIR and its combination with the MCL observed as a MIR.
- The MIR is shown as the result of the MCL interacting with both the CIR and the HCS.
- The MIR variations across the spacecraft demonstrate the progression of the interaction between the CIR and MCL from West to East.



Maunder, Foullon, Forsyth, Barnes, and Davies, 2024, Annales Geophysicae.