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solar orbiter

MAG: Measuring the heliospheric magnetic field

Tim Horbury, Imperial College London

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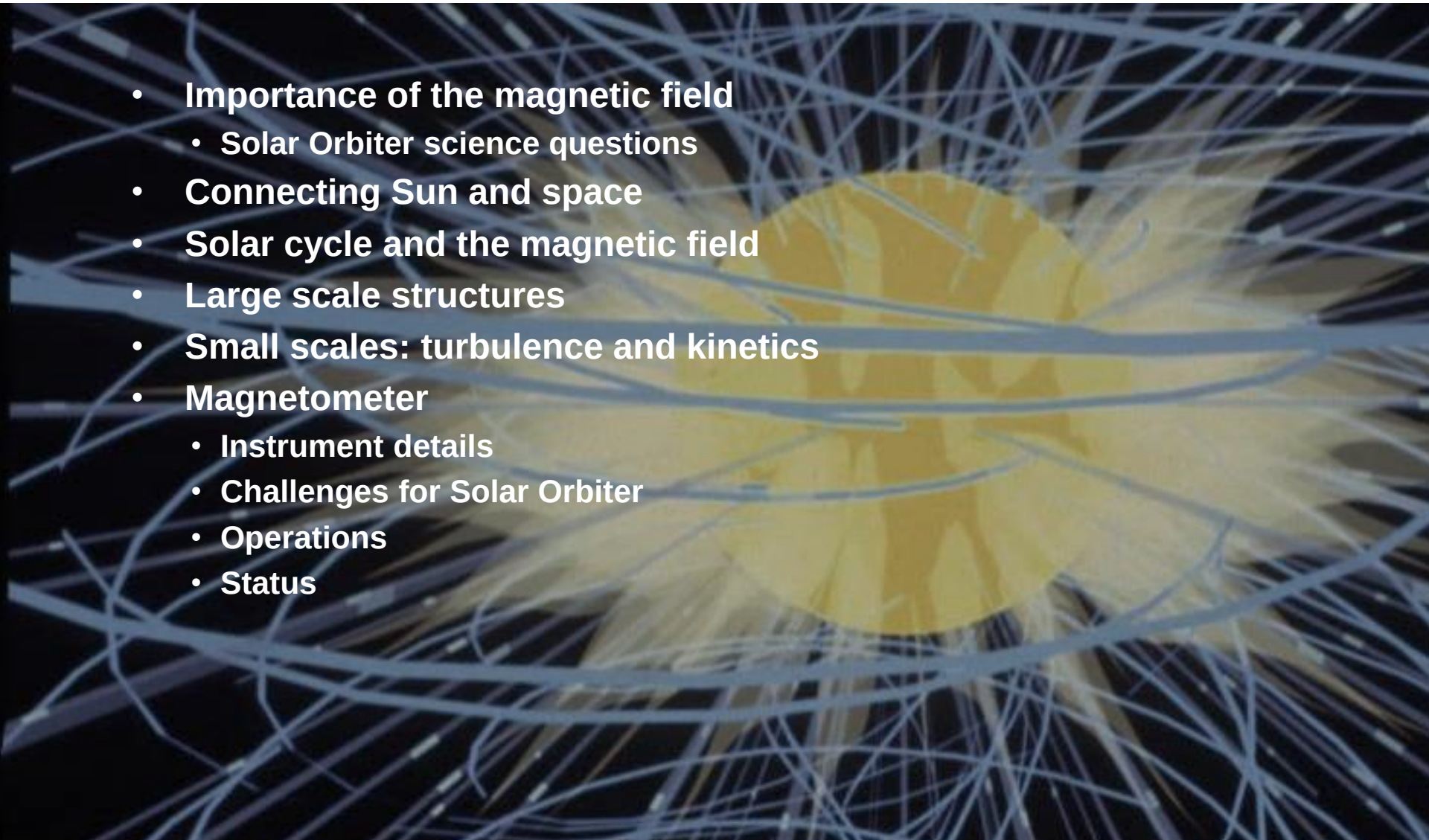
Overview



- Importance of the magnetic field
  - Solar Orbiter science questions
- Connecting Sun and space
- Solar cycle and the magnetic field
- Large scale structures
- Small scales: turbulence and kinetics
- Magnetometer
  - Instrument details
  - Challenges for Solar Orbiter
  - Operations
  - Status

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Why measure the heliospheric magnetic field?

Magnetic field is key to plasma dynamics

- Orders all particle motion
- Field-particle interactions heat the plasma

Magnetic connectivity

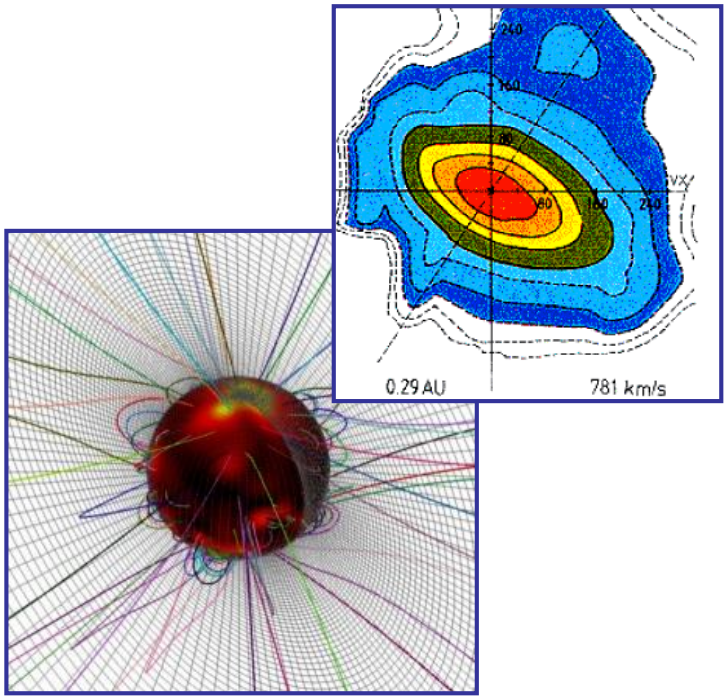
- Connecting remote and local observations

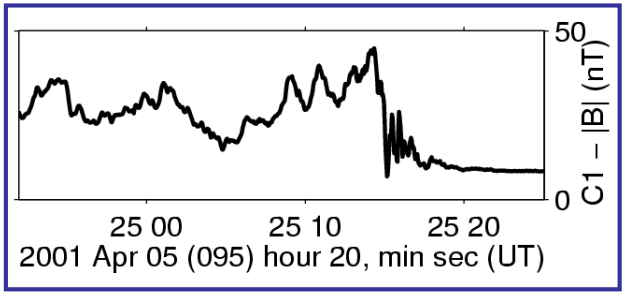
High-precision measurement

- Study waves, turbulence, shocks, ...

Local field direction to particle instruments

- Calculate reduced products, e.g. moments





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Solar Orbiter science questions

- How and where do the solar wind plasma and magnetic field originate in the corona?
- How do solar transients drive heliospheric variability?
- How do solar eruptions produce energetic particle radiation that fills the heliosphere?
- How does the solar dynamo work and drive connections between the Sun and the heliosphere?

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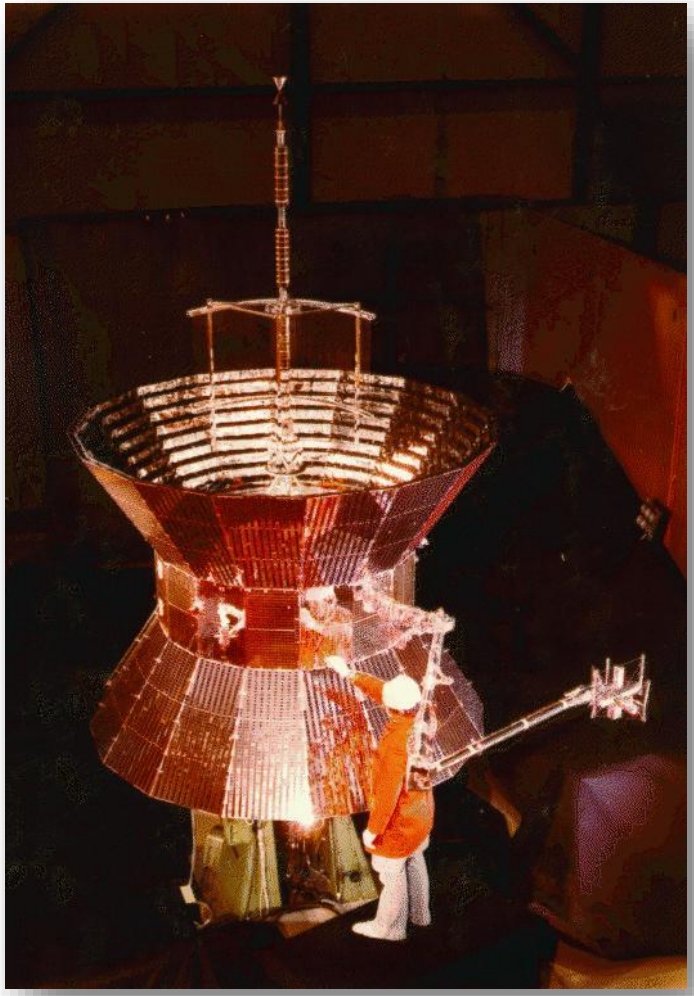
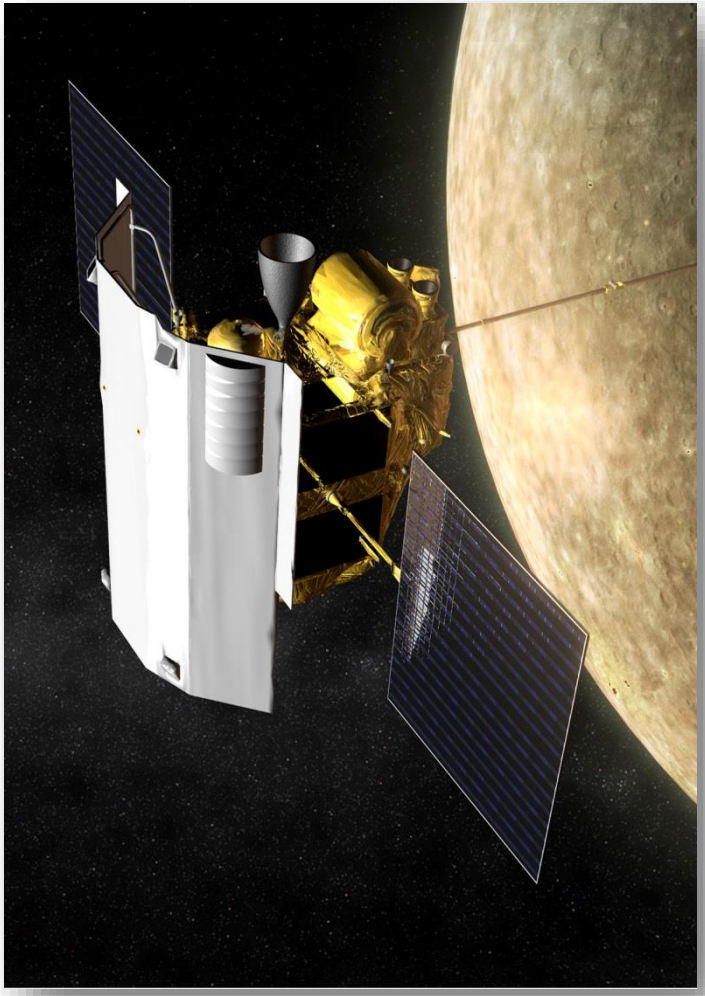
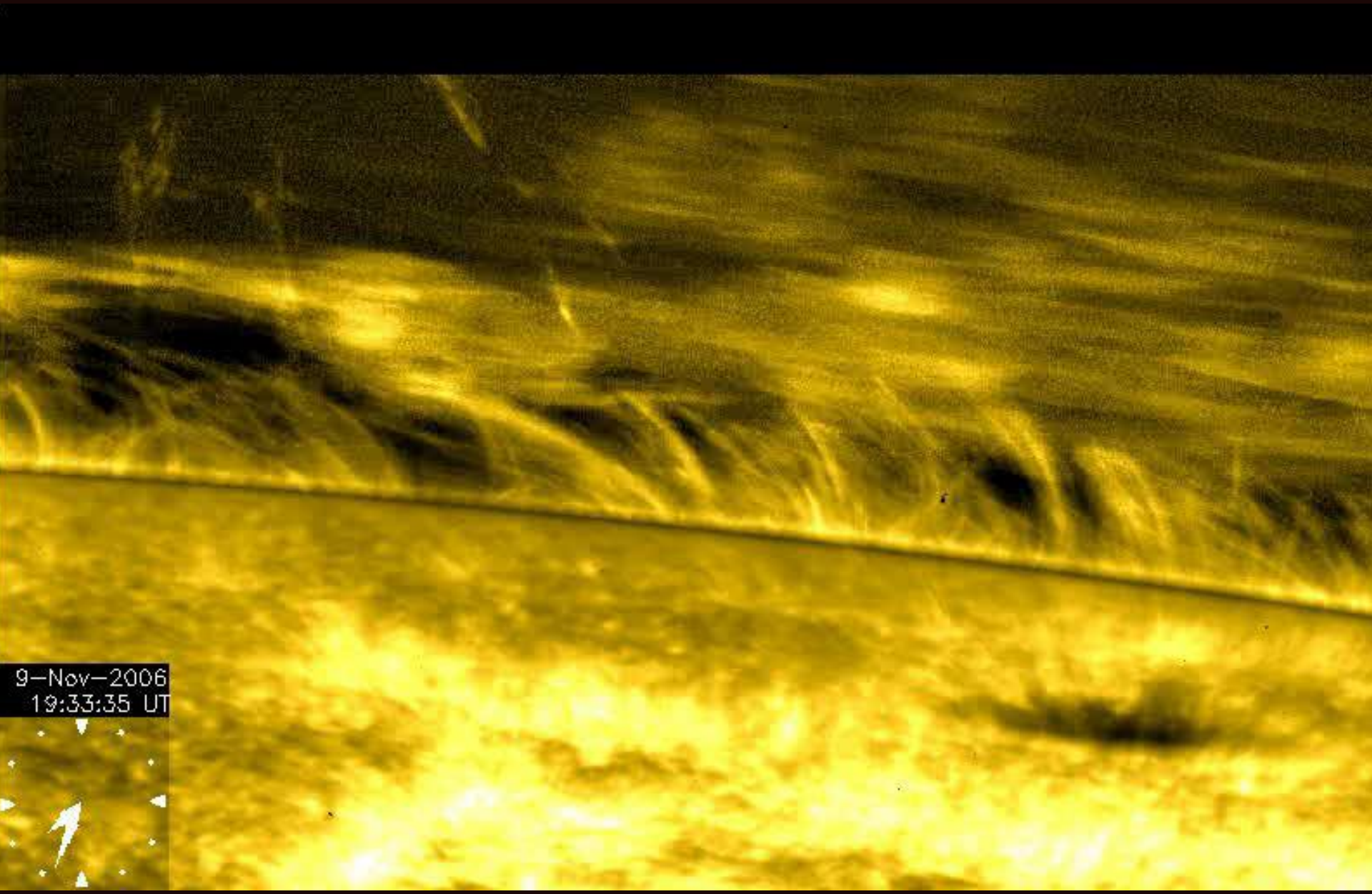
The elephants in the room



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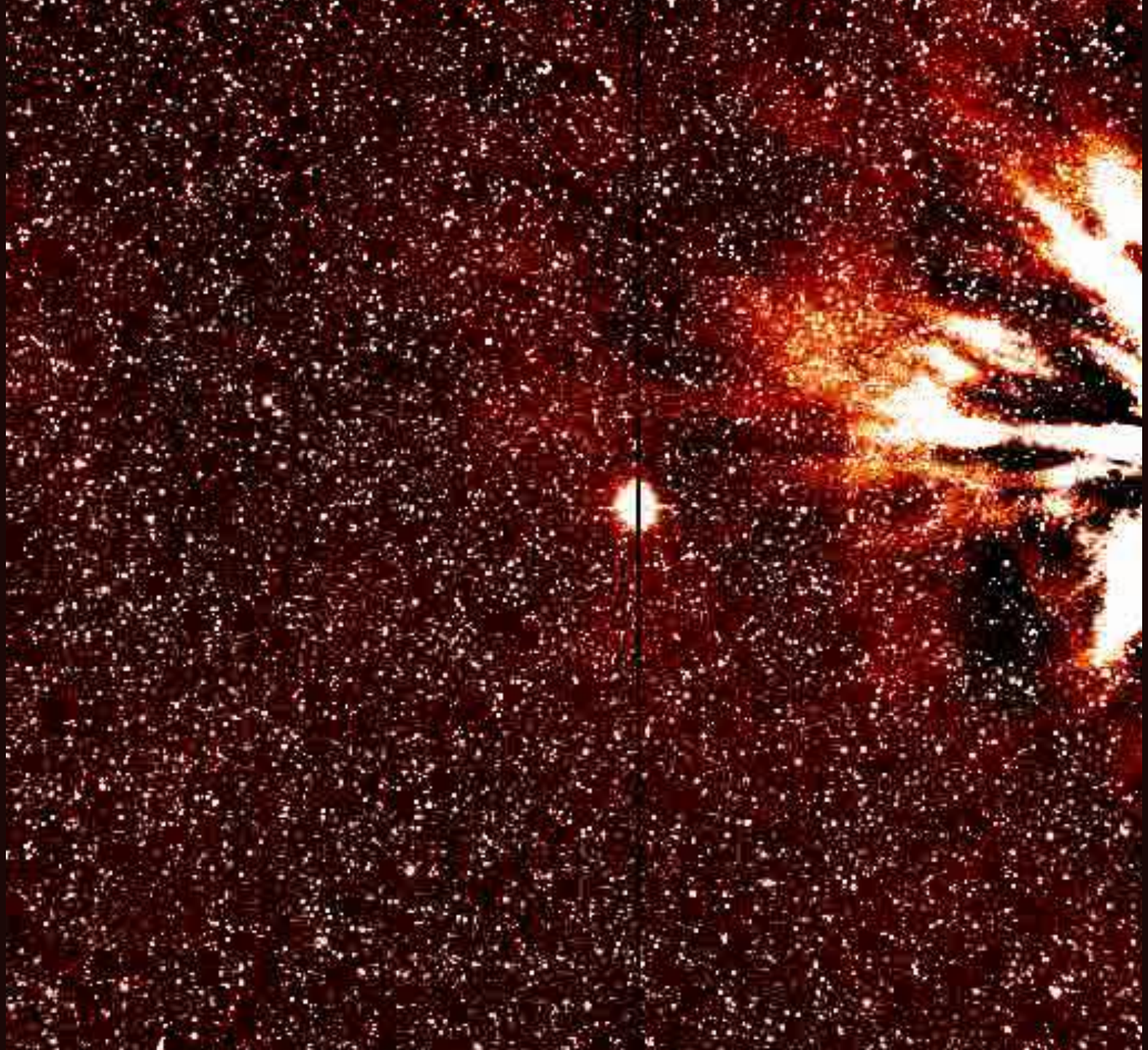

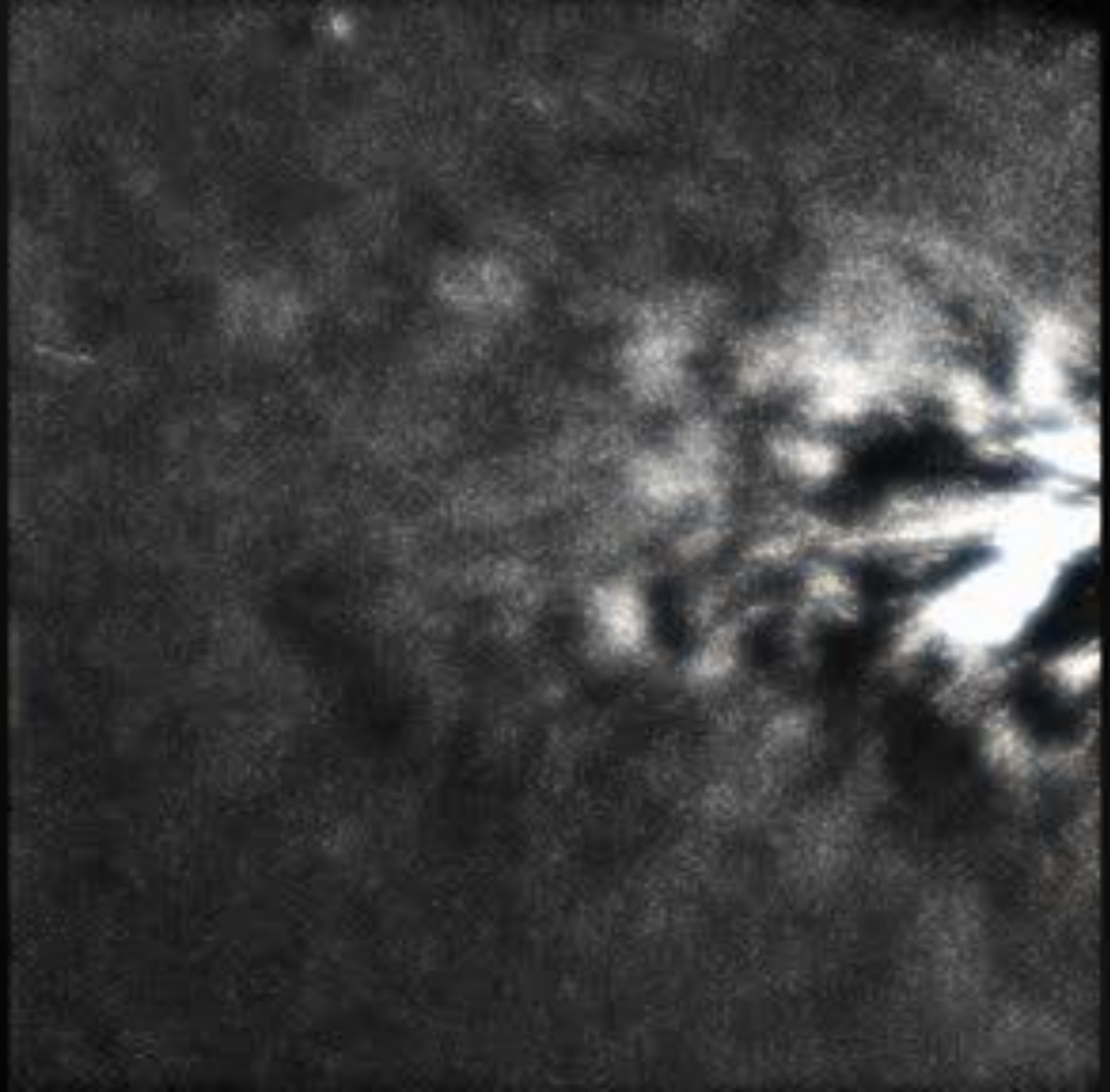

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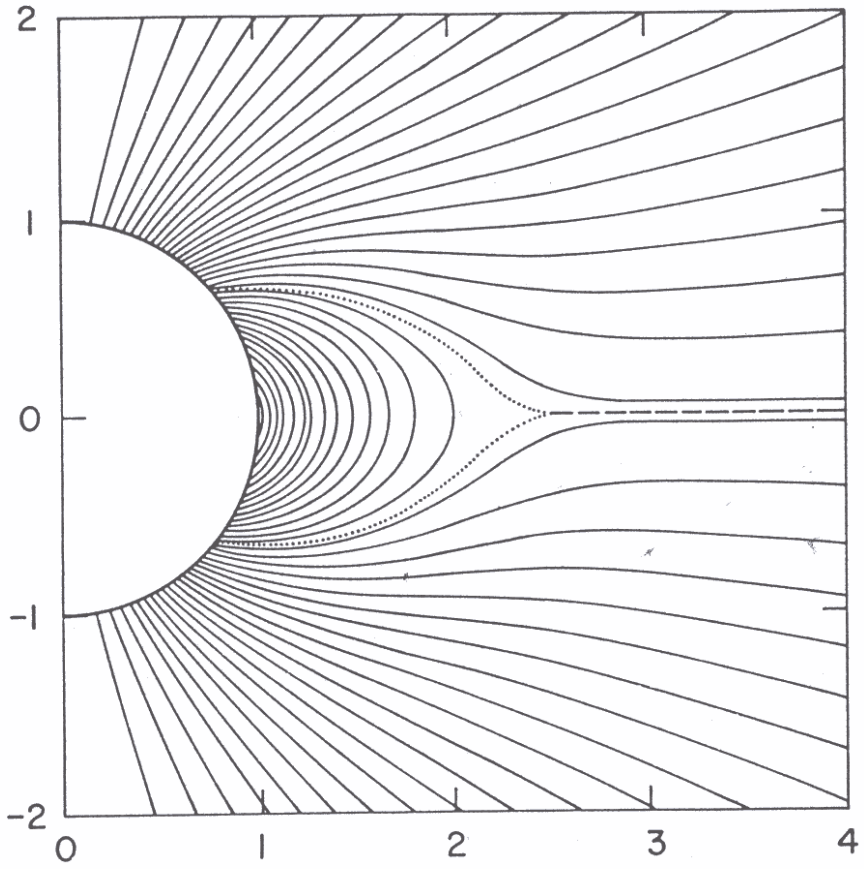
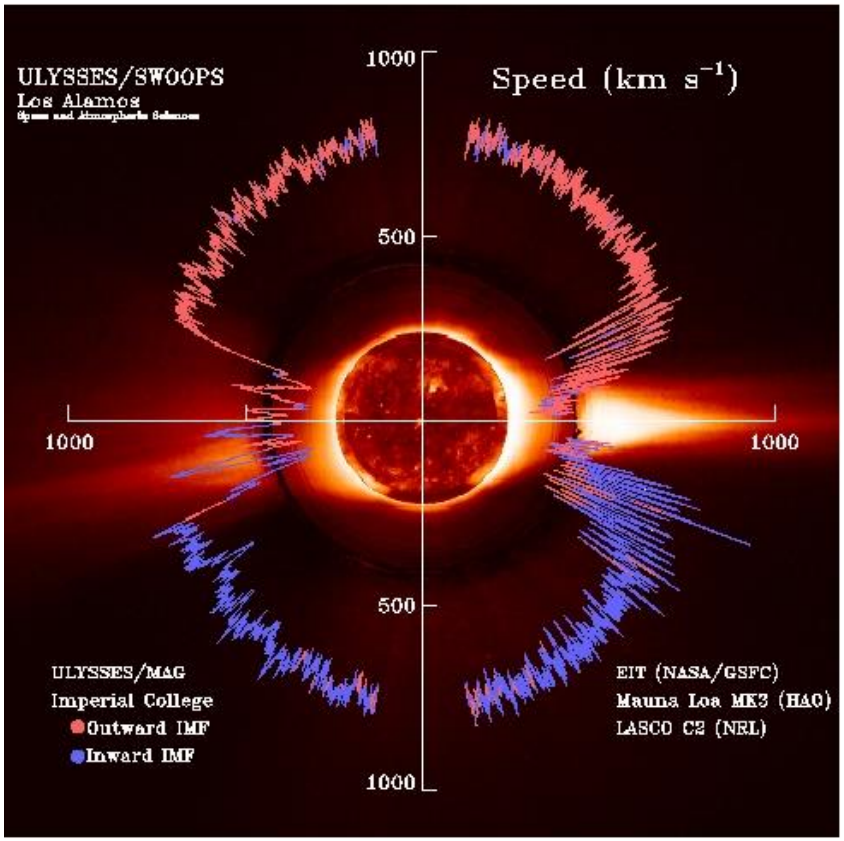
Link between solar and heliospheric magnetic fields





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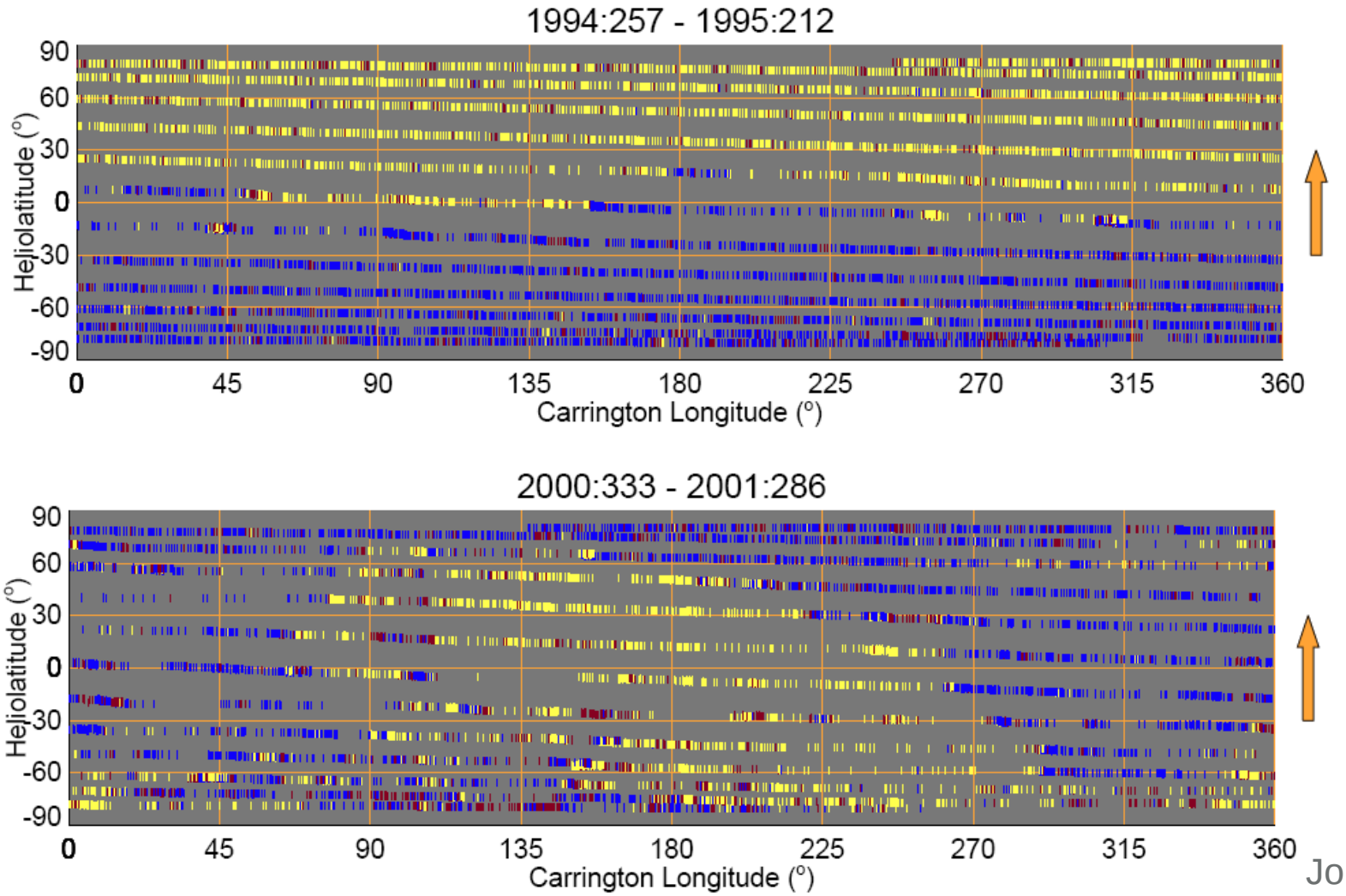
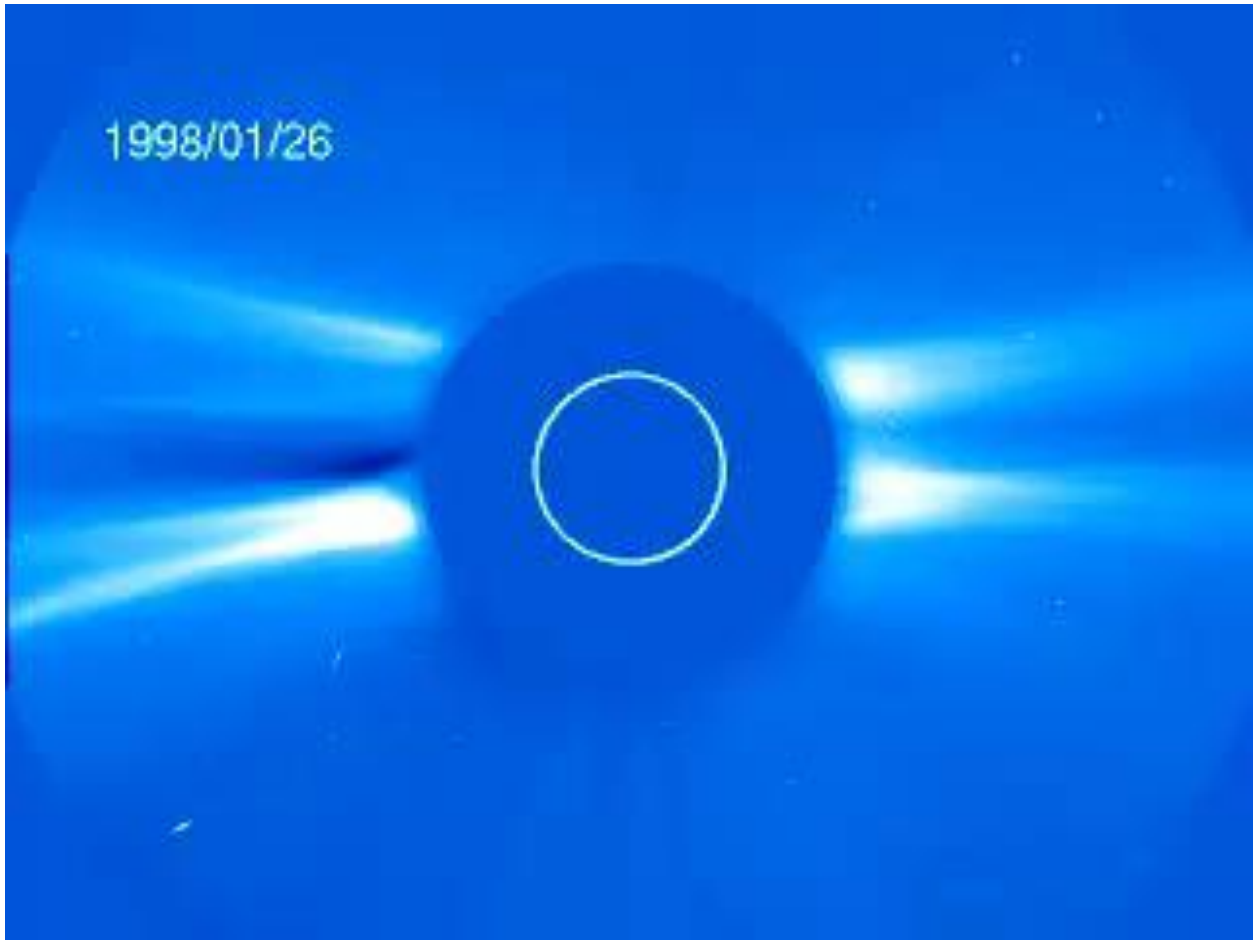
The global heliospheric magnetic field



Jones et al.

Heliospheric current sheet



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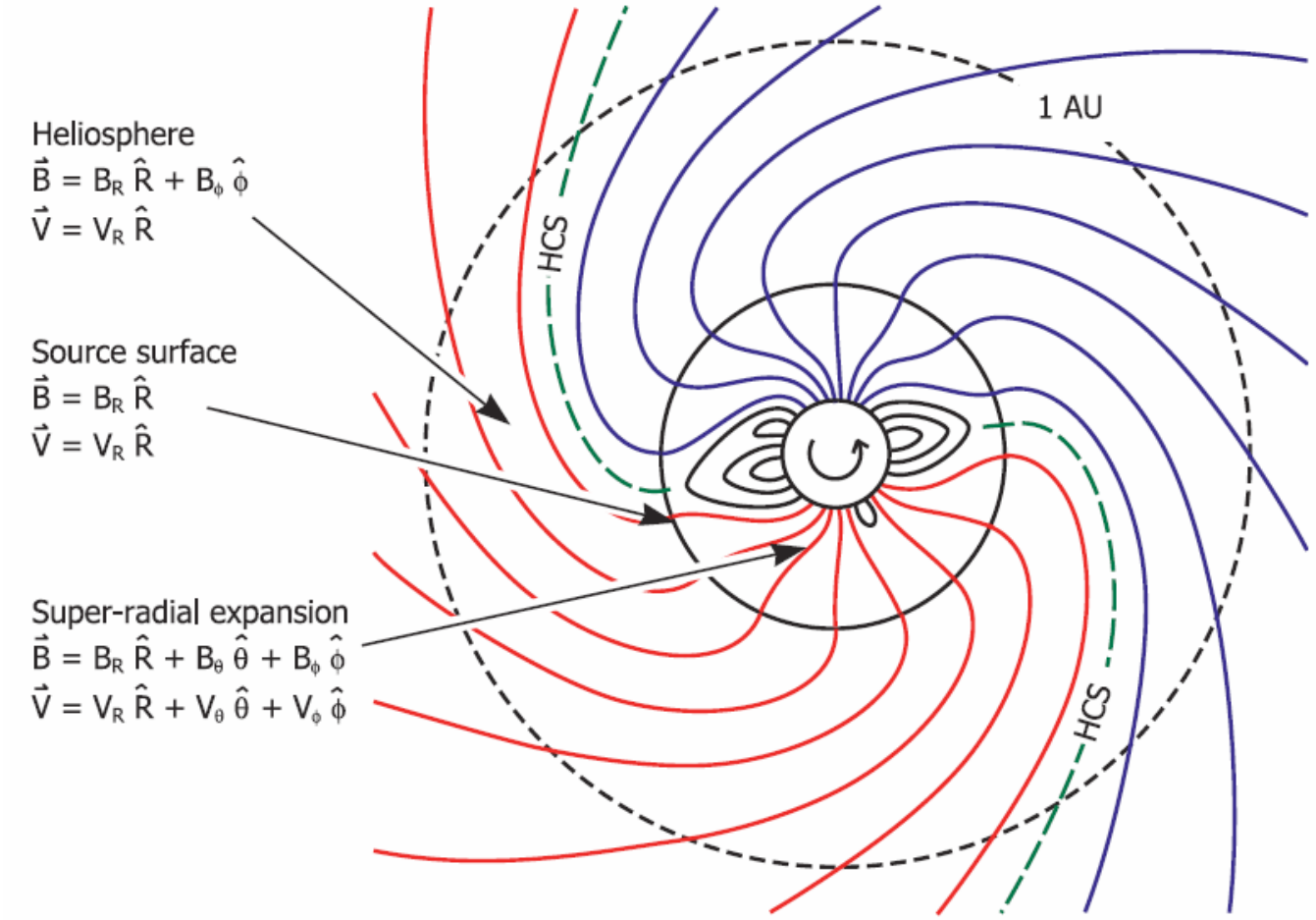
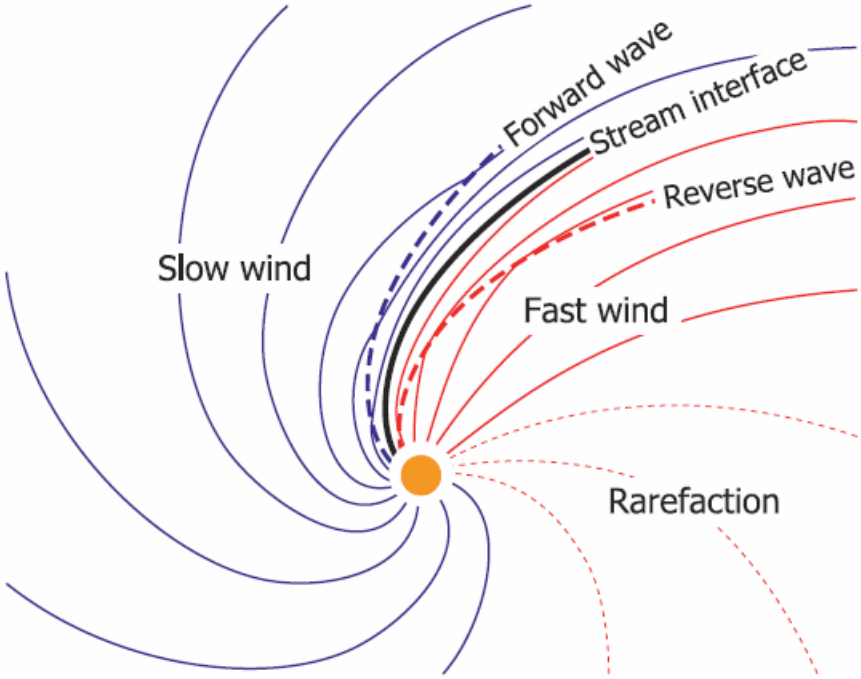
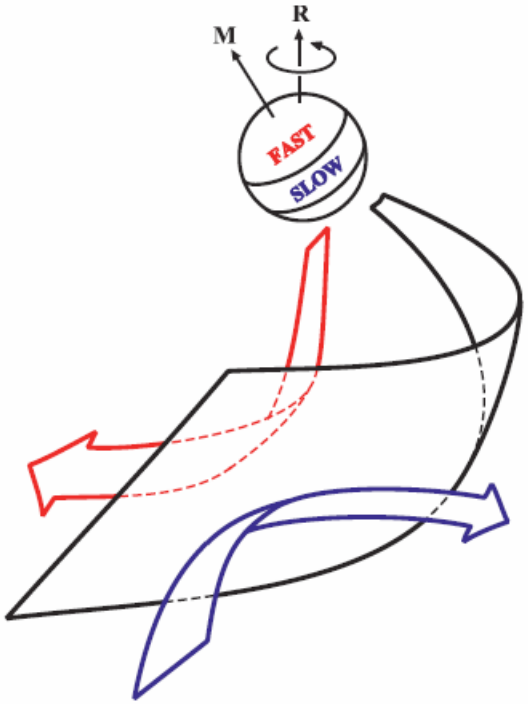
Global morphology of the interplanetary magnetic field



Owens and Forsyth, 2014

Corotating interaction regions and the IMF





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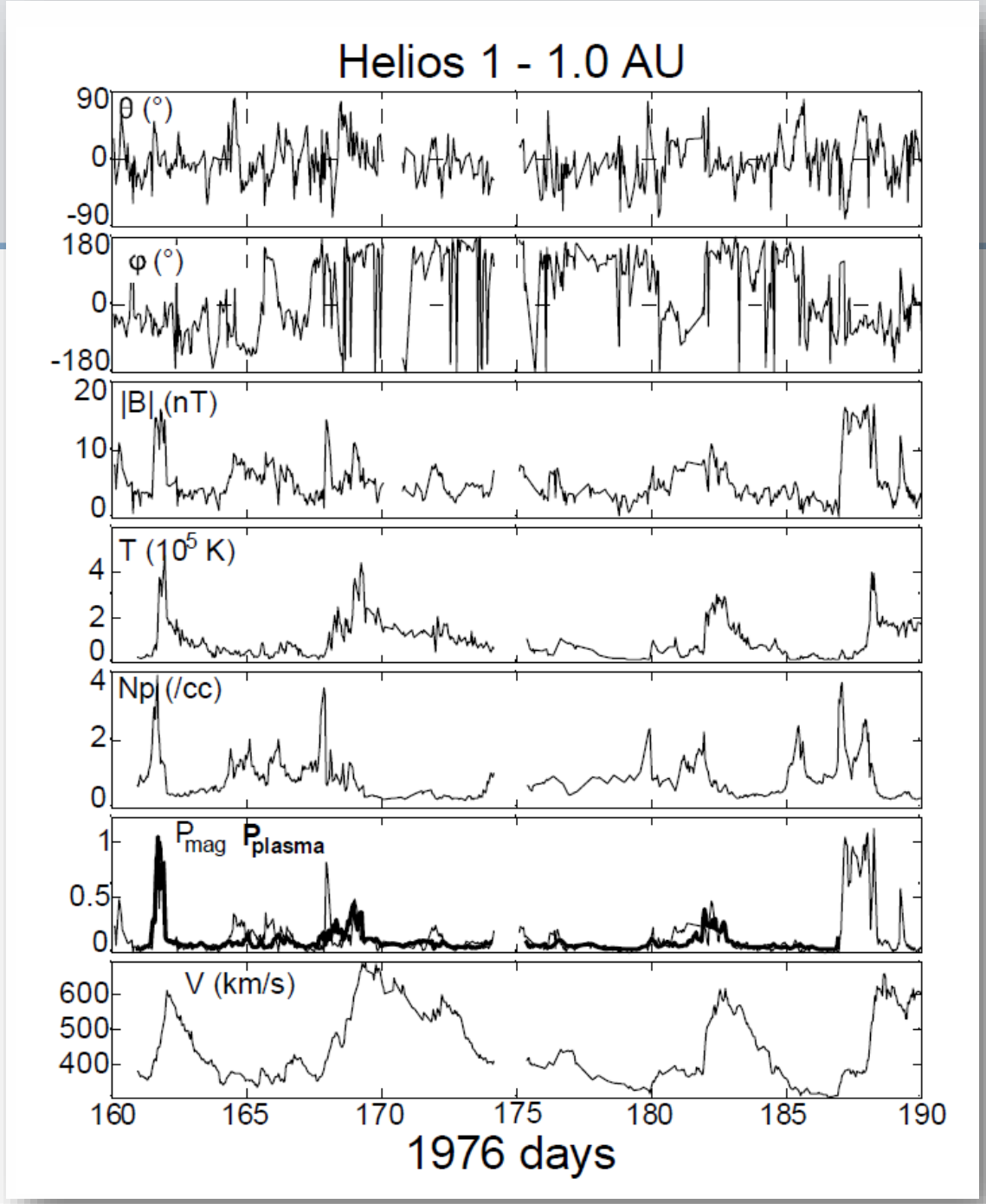
Solar wind at 1 AU



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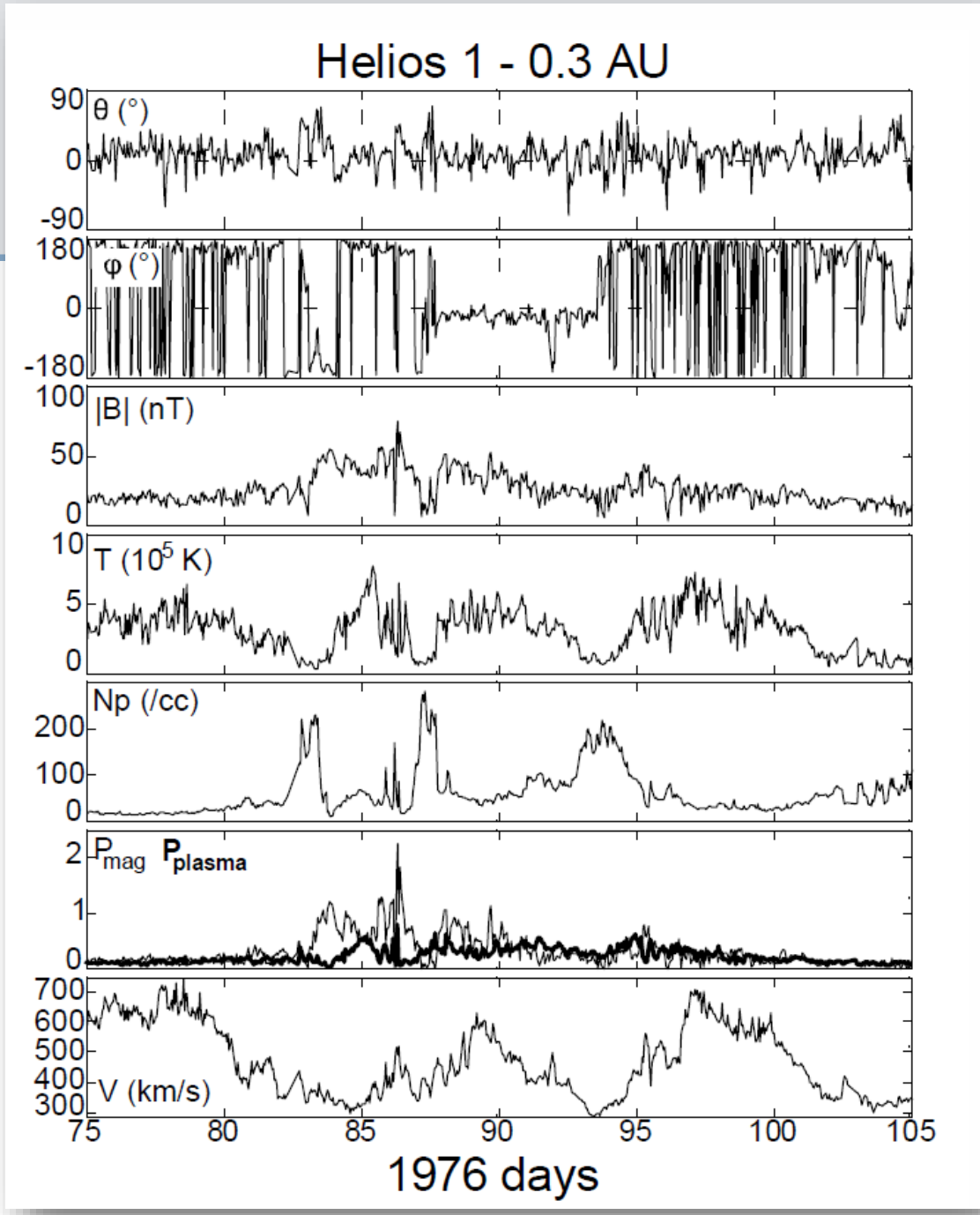
Solar wind at 0.3 AU



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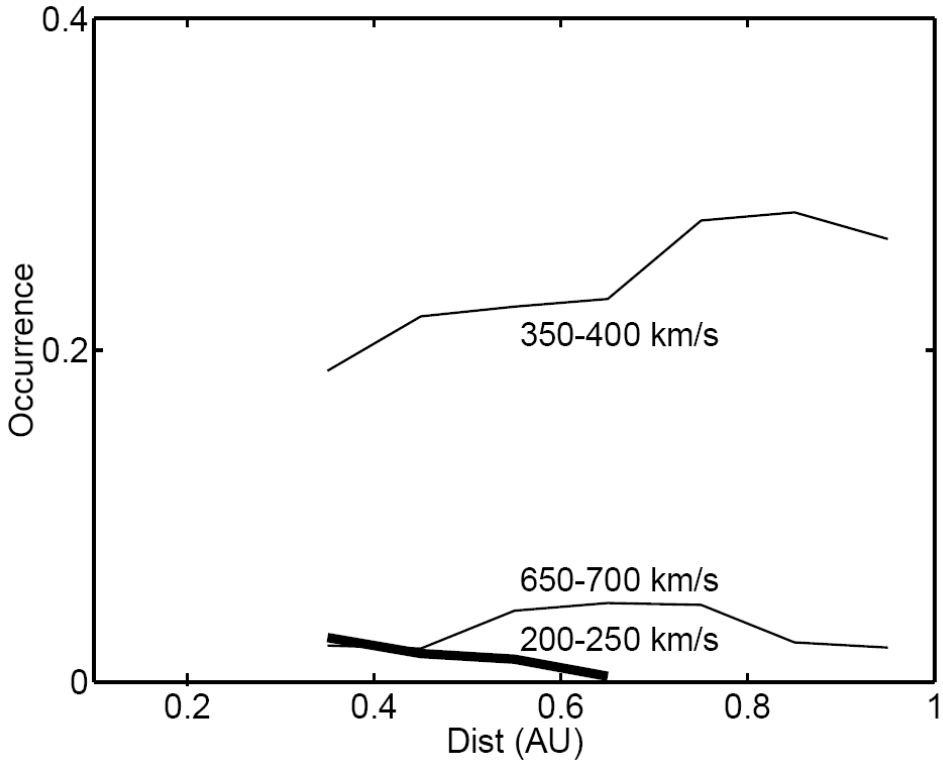
Disappearance of the slowest wind

- Very slow (V<250km/s) wind is swept up very quickly by faster flows
- Indistinguishable by 0.6 AU – can't study at 1 AU
- Could also be evidence of remnant acceleration
- Note: fastest wind is not significantly removed
- **How is very slow wind merged into the bulk wind?**



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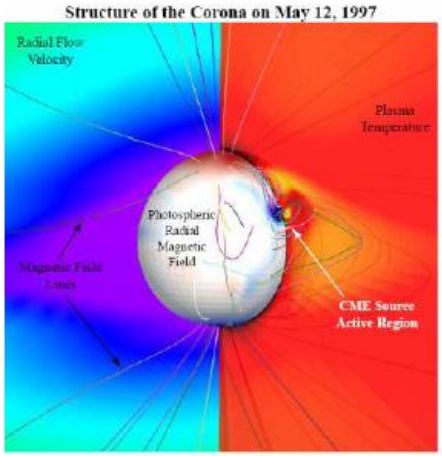
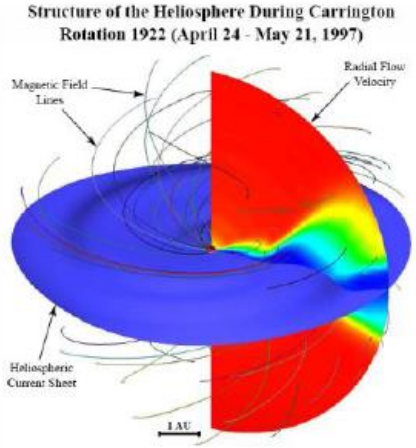
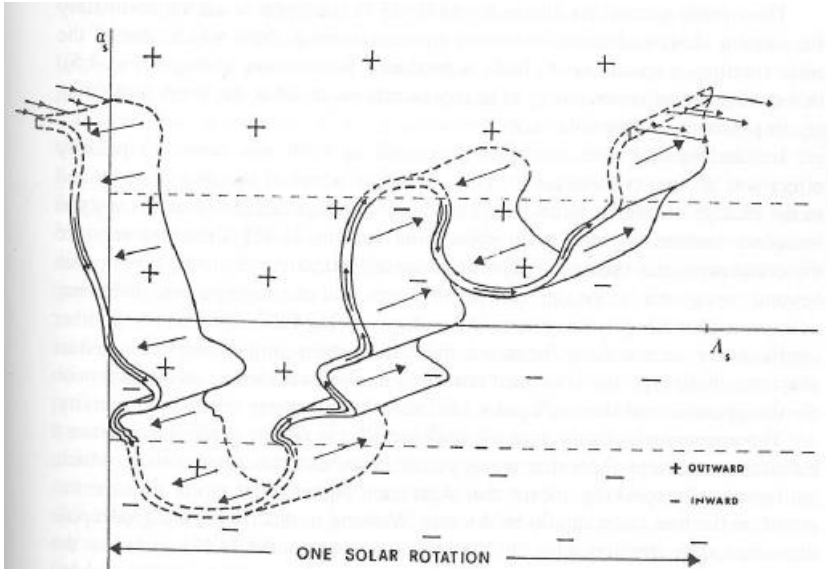
Heliospheric current sheet and slow solar wind

- How is the slow solar wind related to the heliospheric current sheet?
- What is the magnetic topology of slow wind?
- How do ripples in the HCS form and evolve?

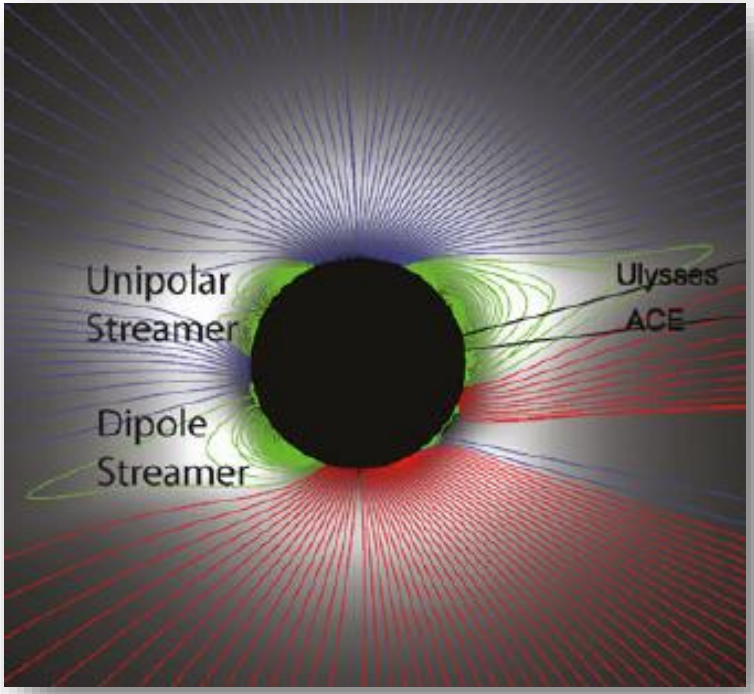


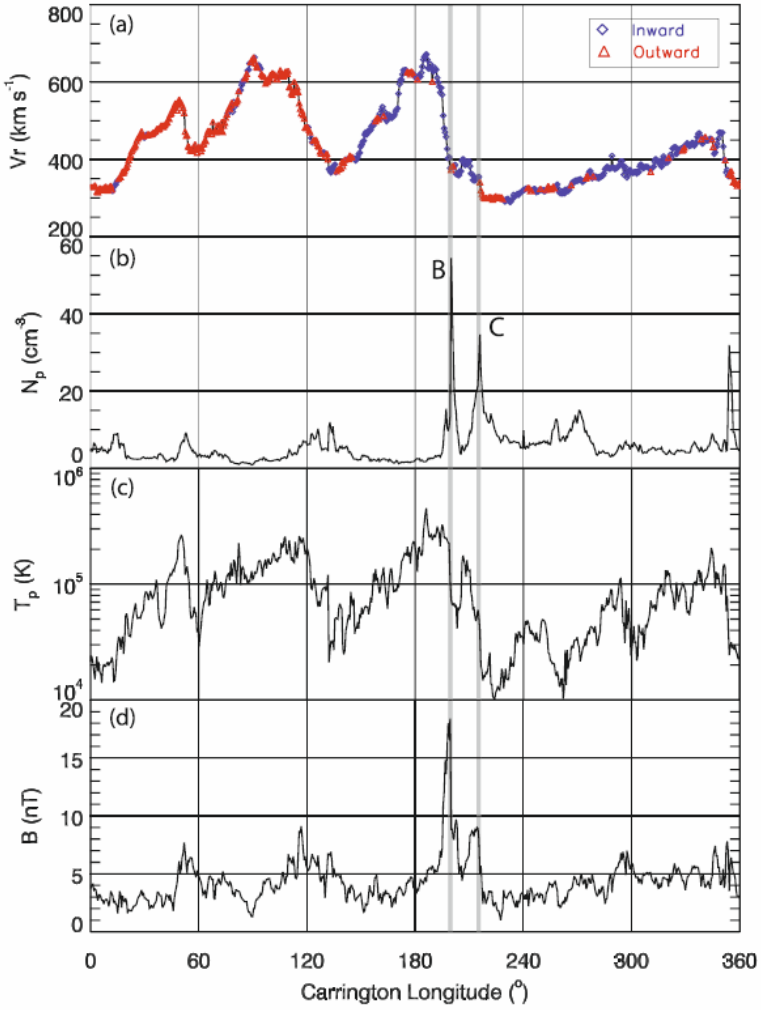




Source of slow wind

- **Is slow wind fundamentally transient?**
- **Streamers vs pseudo-streamers?**
- Key role of magnetic field as diagnostic





Riley and Luhmann

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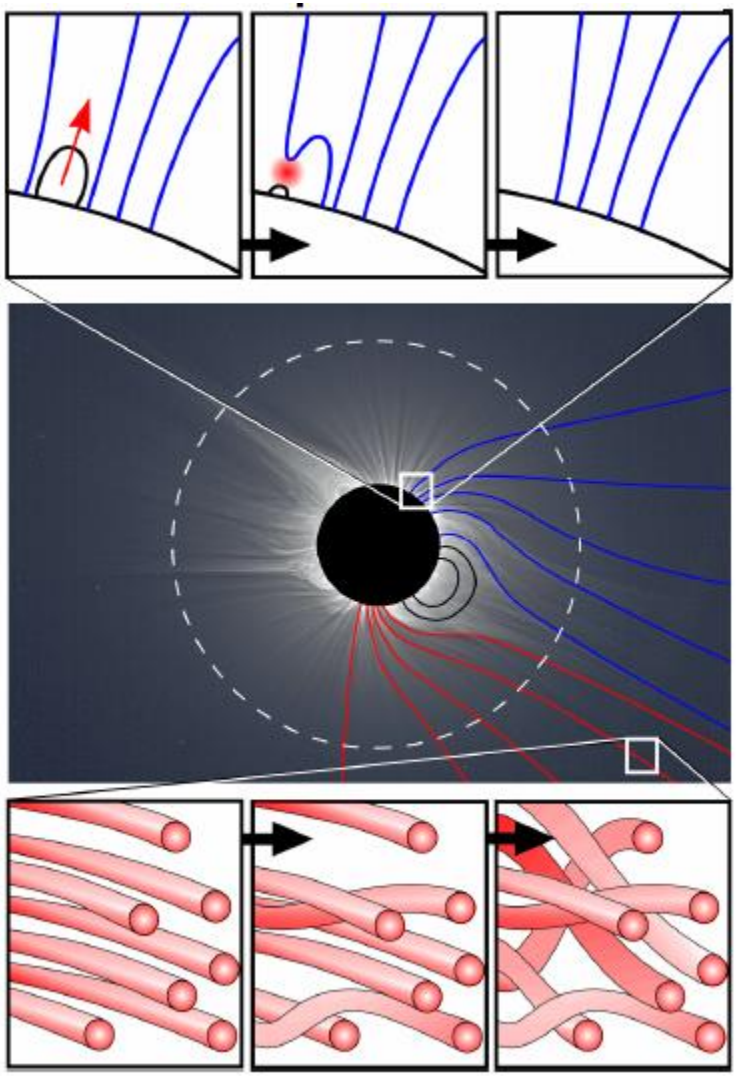
Magnetic field topology

- Interchange reconnection can change topology
- Bruno, Borovsky, others: evidence for flux tubes in solar wind

- **What is the small scale connectivity of the solar wind?**



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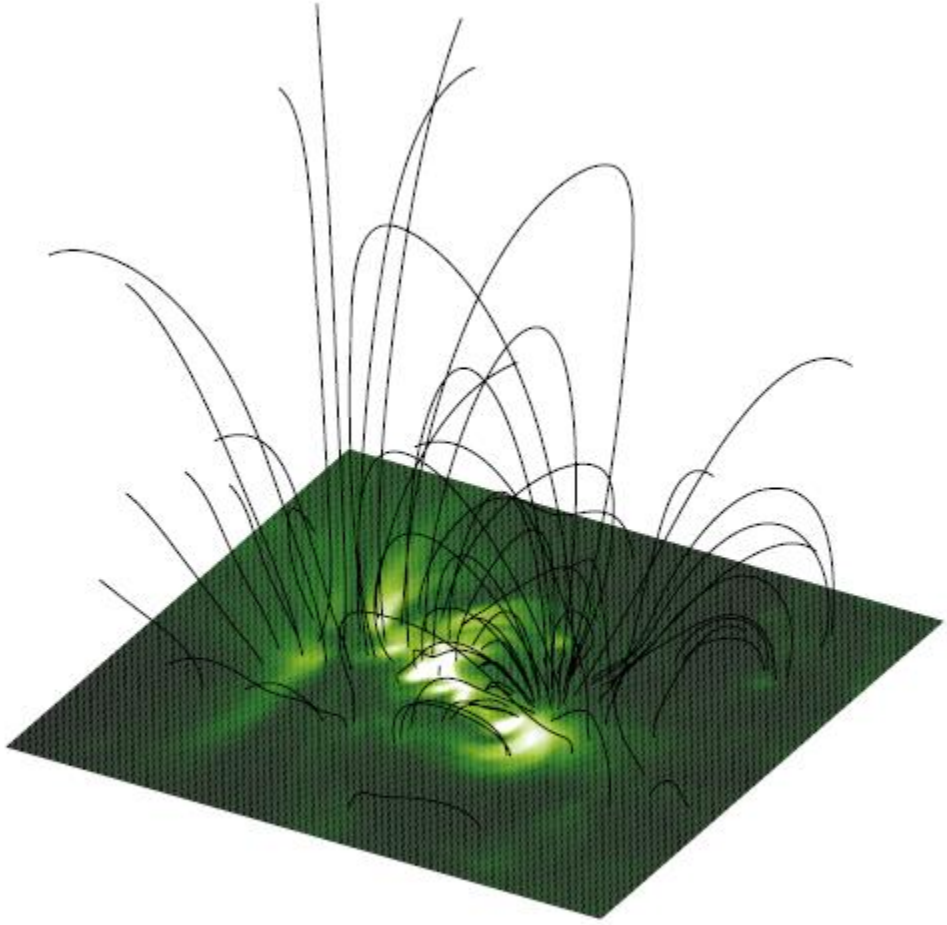
Coronal and heliospheric magnetic connections

- Hinode: abundant evidence for transient jets, rapidly changing connectivity around active regions
- **How does the complex, changing coronal field map into the heliosphere?**
- **What are the solar wind magnetic signatures of jets and chromospheric waves?**



Marsch et al., 2004

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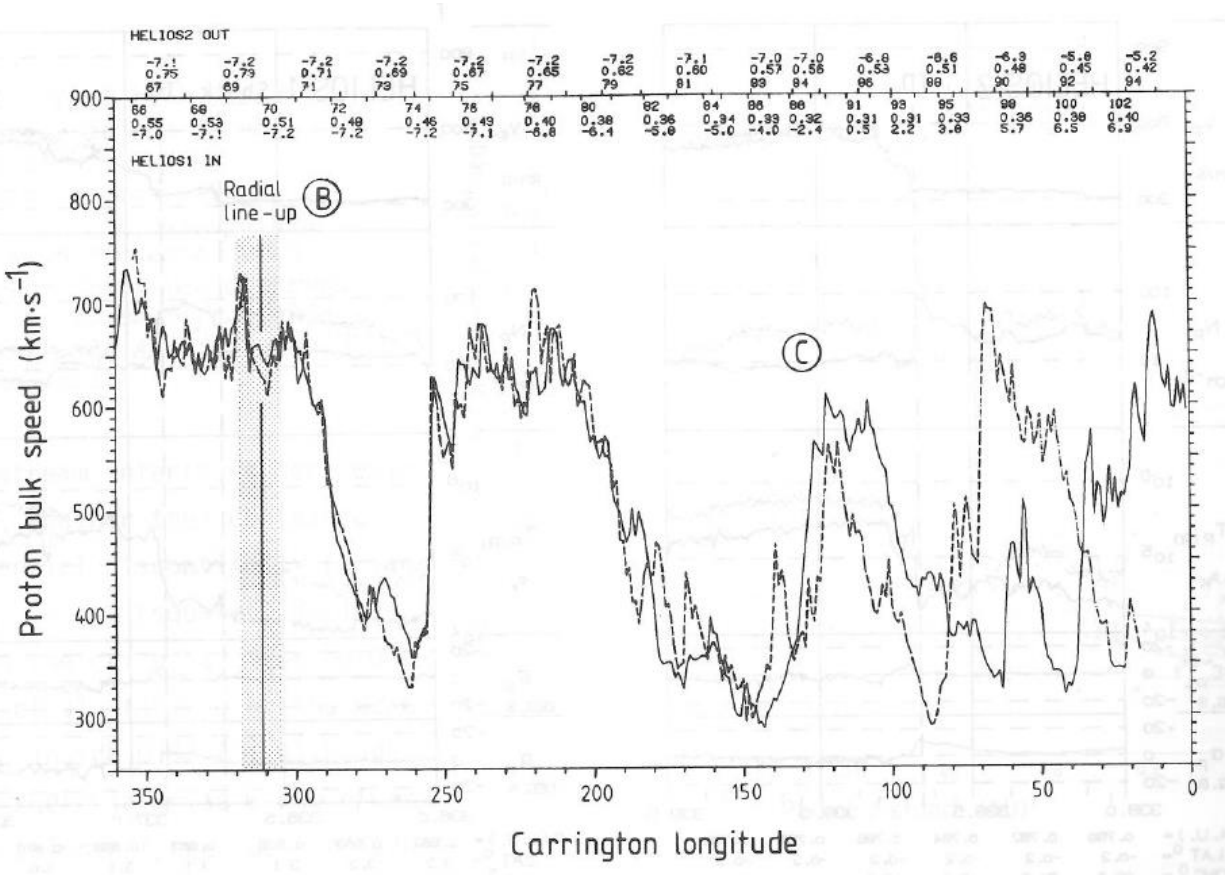
Radial, longitudinal and temporal scales

- **What determines the duration of a structure at a spacecraft?**

- CIR: longitudinal extent
- CME: radial extent

- Near-corotation
  - Stream-line size of blobs
- Close to Sun
  - Slight changes in source conditions, e.g. Coronal hole boundary motion?

- Orbiter, Probe: different orbits, different angular motion at same radial distance



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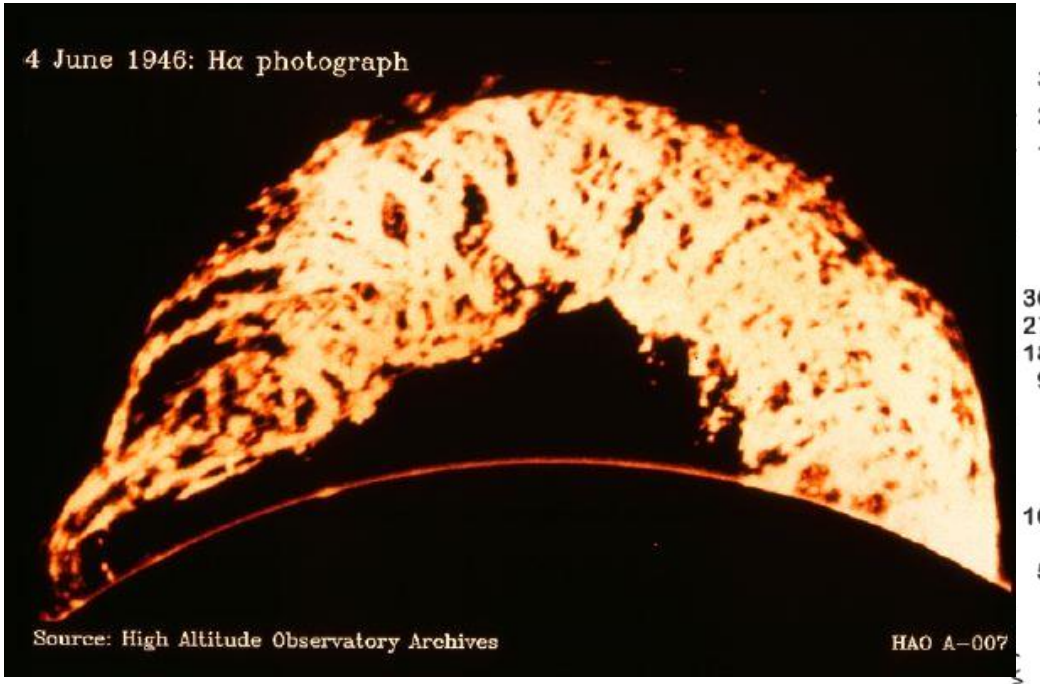
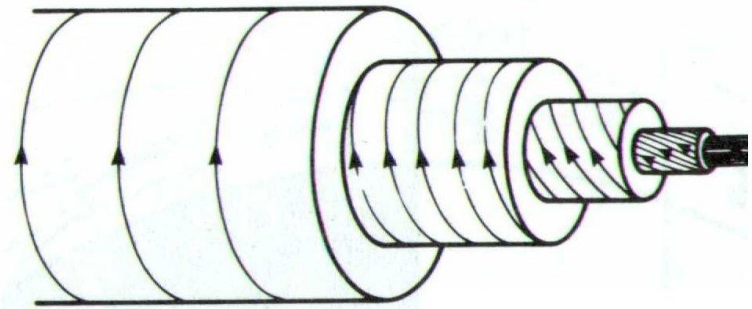
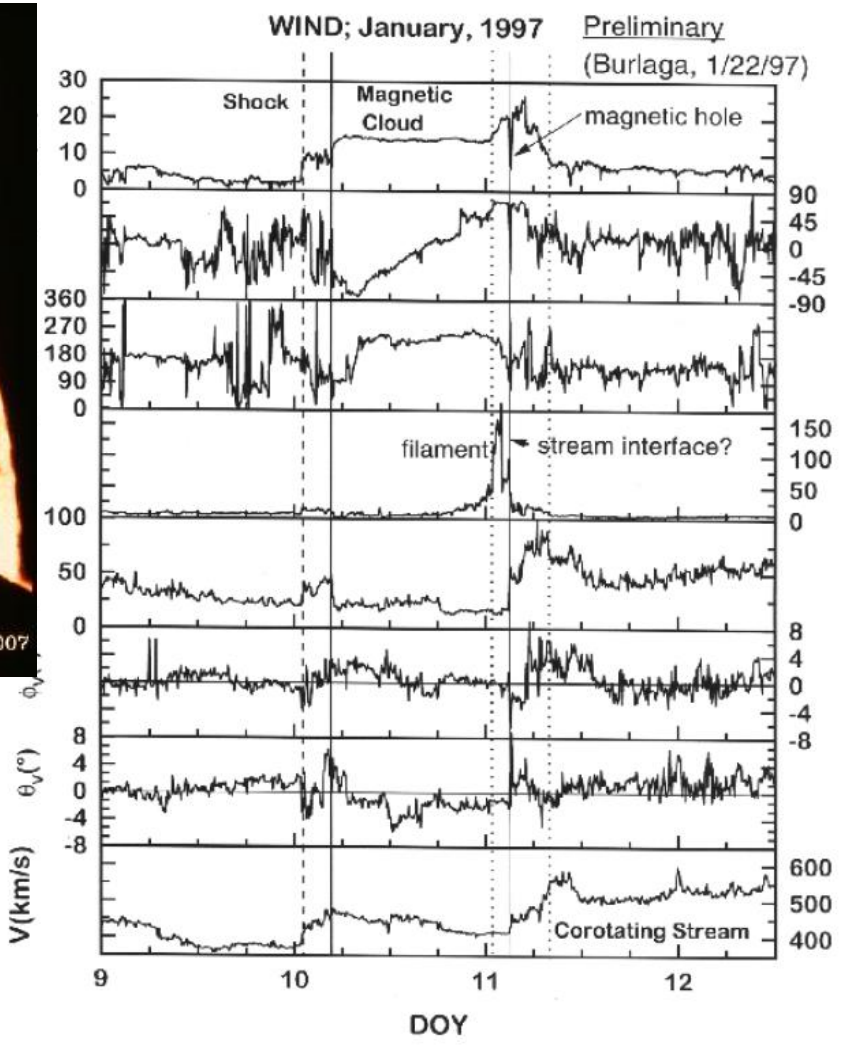
Flux ropes in coronal mass ejections







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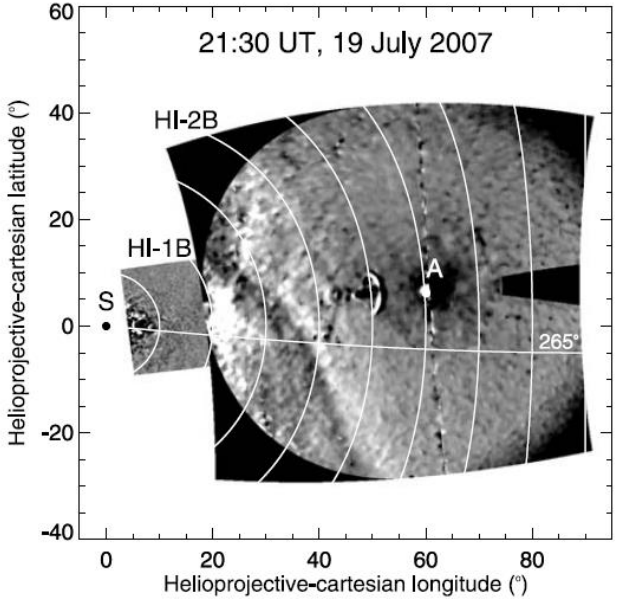
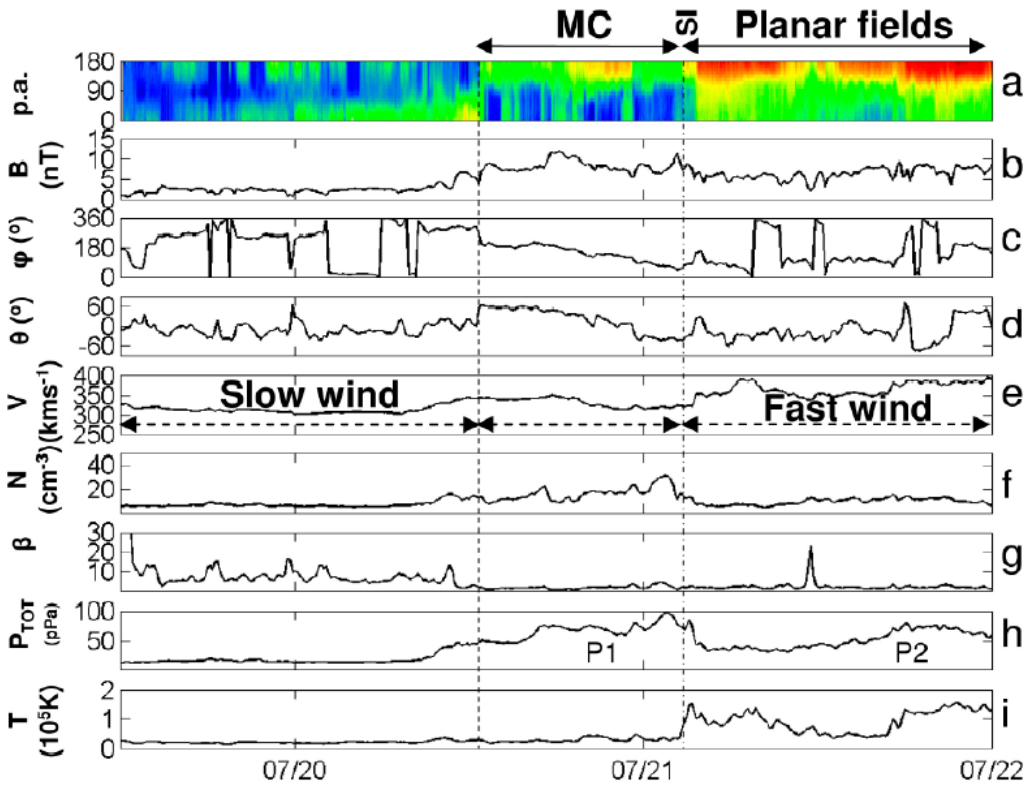
Linking coronal and heliospheric structures



- Rouillard et al., 2009
- STEREO HI-B transient
- Passes STEREO A as a CIR with embedded flux rope, connected to Sun
- **How do embedded structures evolve with distance?**



Rouillard et al., 2009

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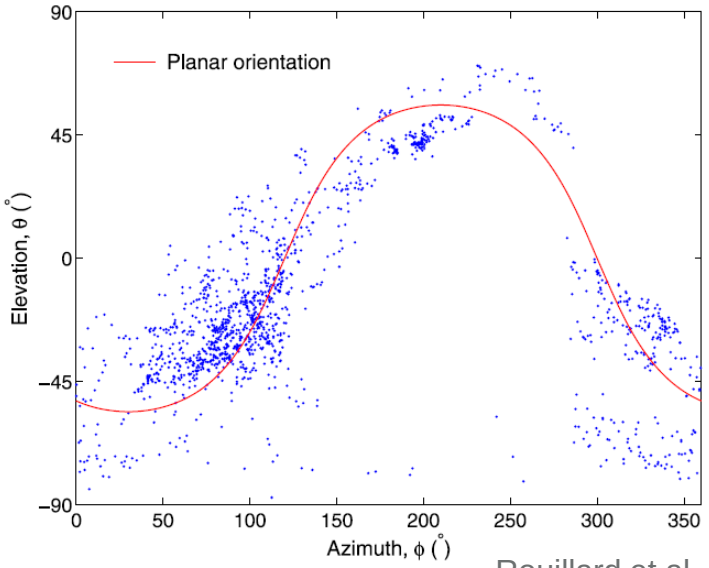
Magnetic field and particle propagation

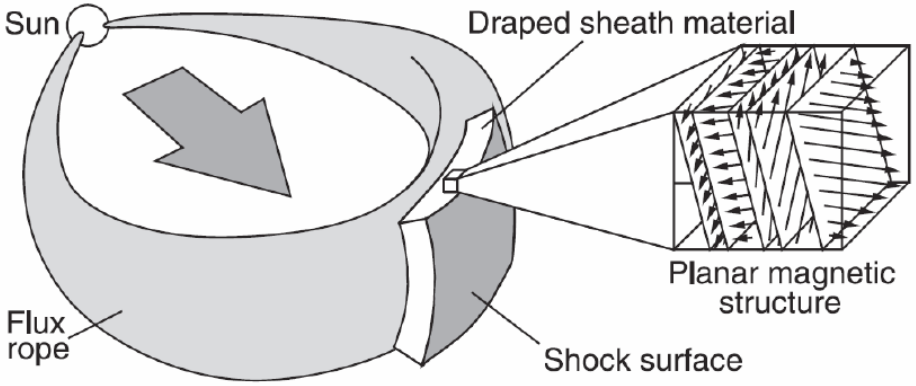
- Planar magnetic fields caused by compression
- Greatly reduce particle transport
- Compression develops from Sun to 1 AU

- **How do developing magnetic structures affect the propagation of particles into the heliosphere?**

- **What are the properties of near-Sun shocks?**



Rouillard et al., 2009



Jones et al., 2002

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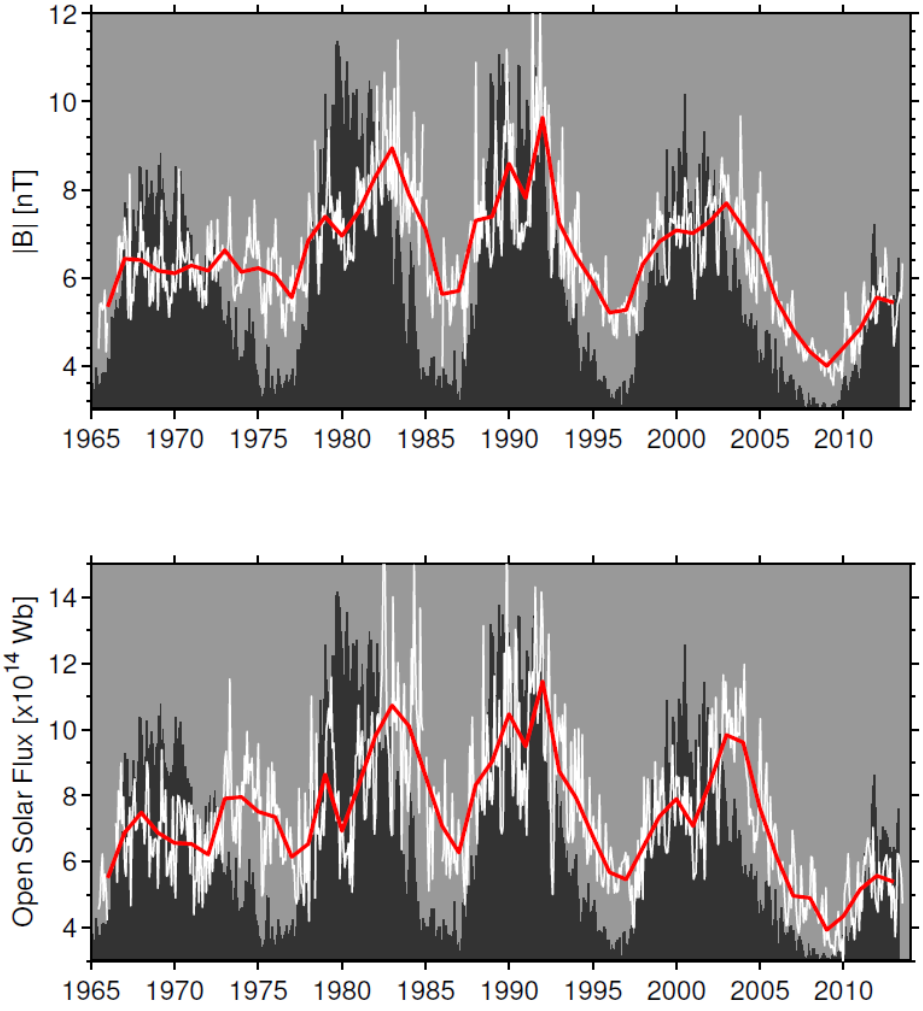
Magnetic flux and the solar cycle

- Magnetic field carried into the heliosphere
- Varies with solar cycle
- Must eventually disconnect from the Sun
- **How does magnetic flux close with solar distance?**



Owens and Forsyth

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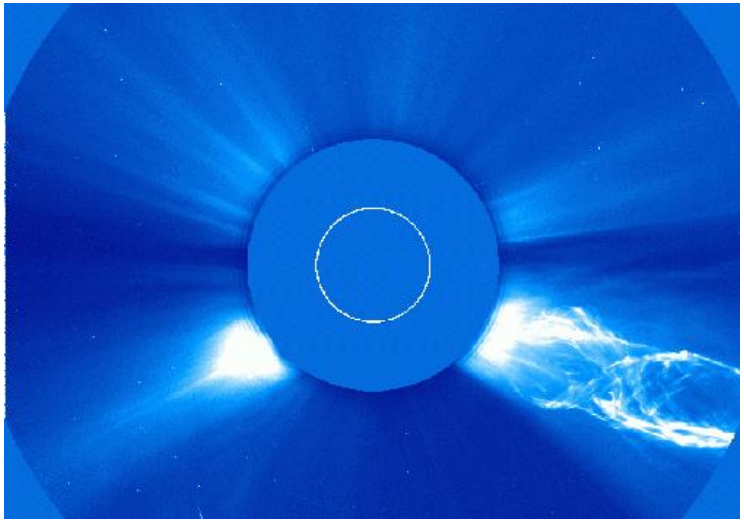
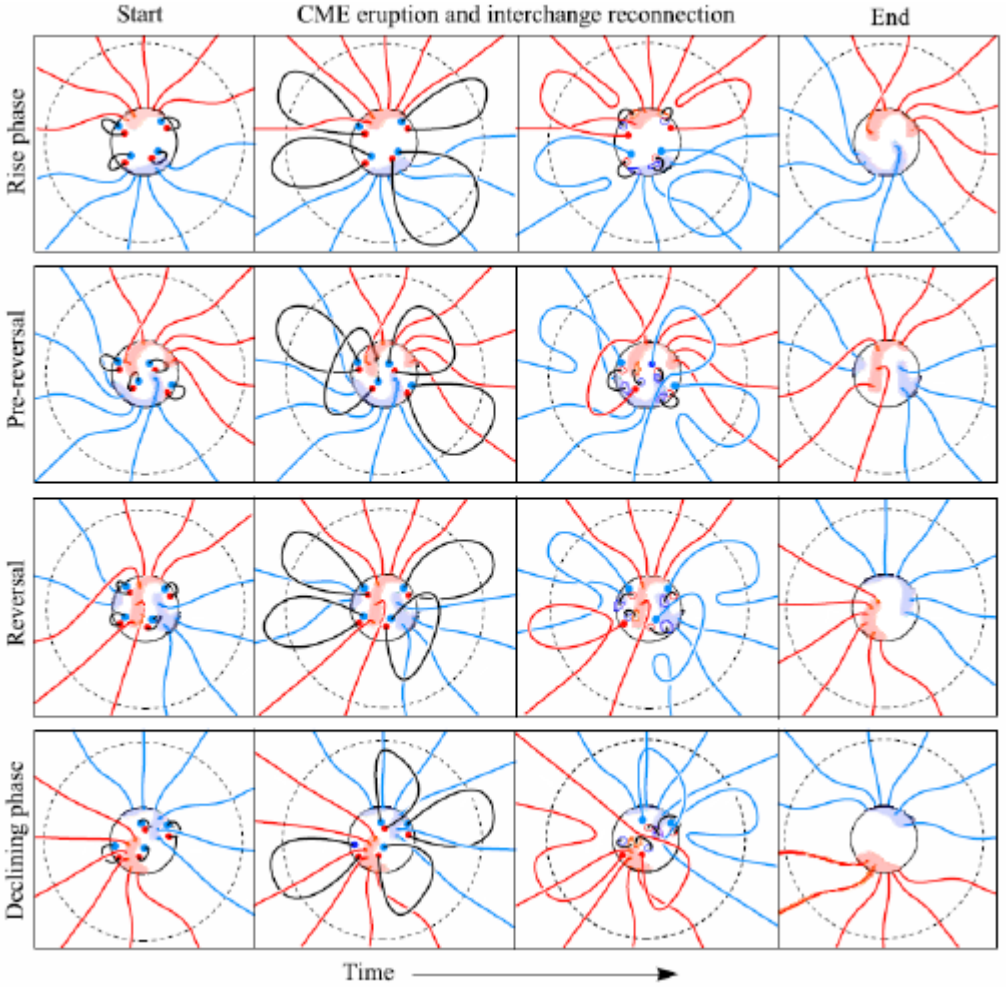
ICMEs, helicity and the solar cycle



- Magnetic clouds carry helicity into the heliosphere
- ICMEs from active regions have polarity rule (Bothmer and Schwenn) – migrate flux to poles
- **What is the role of ICMEs in the solar cycle?**



Owens et al., 2007

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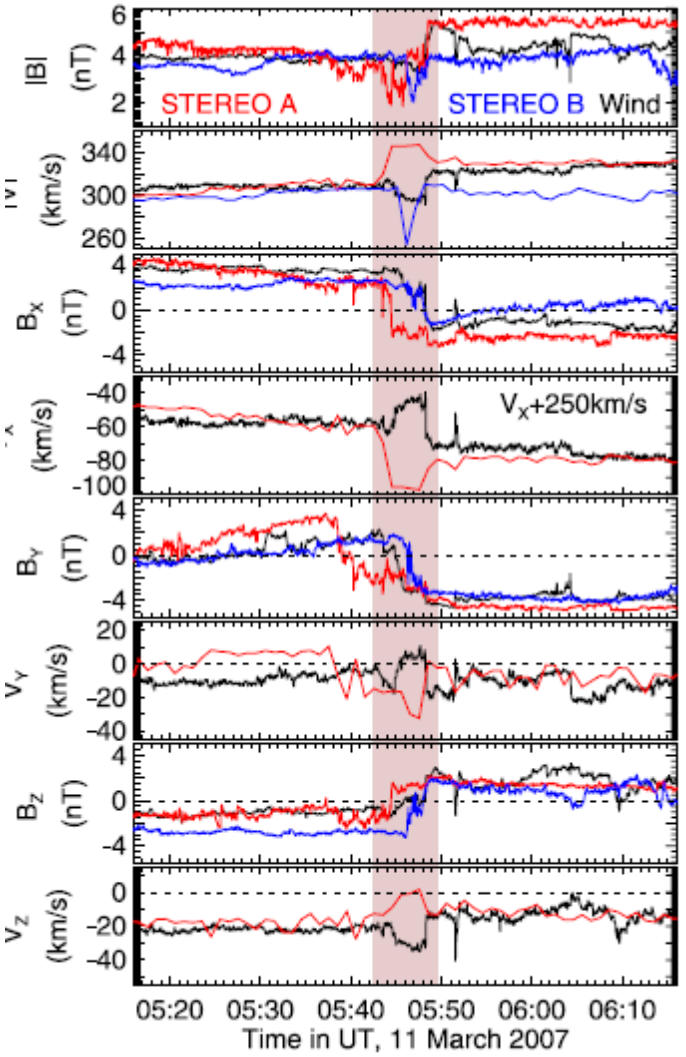
Ubiquitous reconnection

- Ample evidence for reconnection in the solar wind
- **How does magnetic flux disconnect from the Sun and inter-connect within the solar wind?**
- **How does this affect the energy budget of the solar wind?**
- **Is reconnection increasingly common with solar distance?**



Gosling et al., 2007

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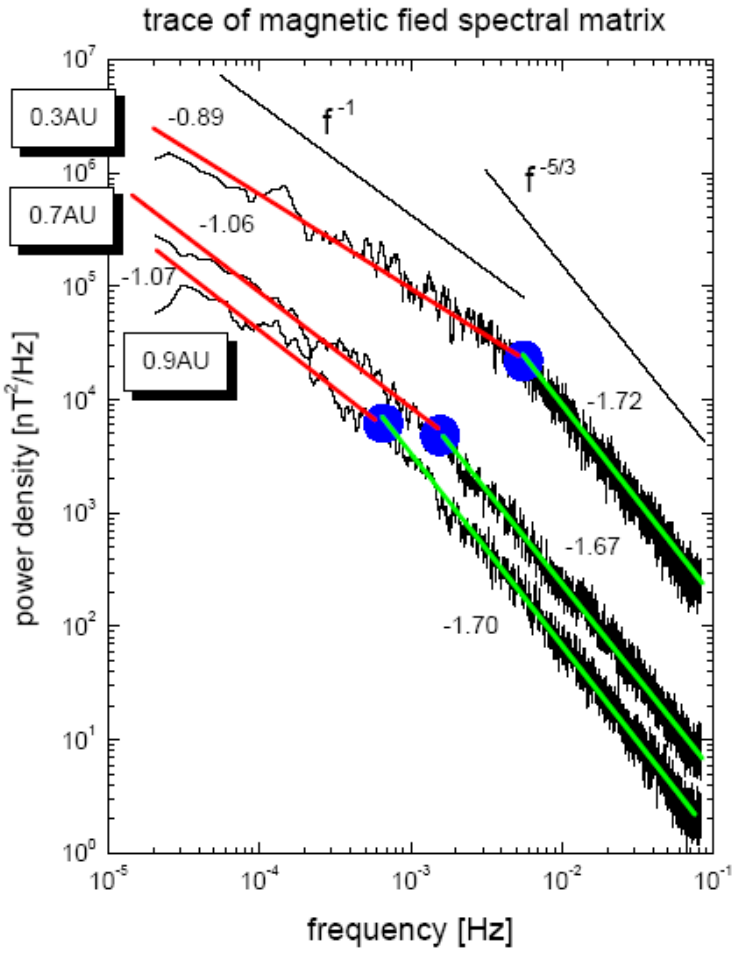
Waves and turbulence

- Ubiquitous waves and turbulence
- Evolving, dissipating turbulence

- **How is the wave population related to coronal conditions?**

- **What is the origin of the 1/*f* wave population?**

- **Is turbulence fully evolved in slow wind?**



Bruno and Carbone

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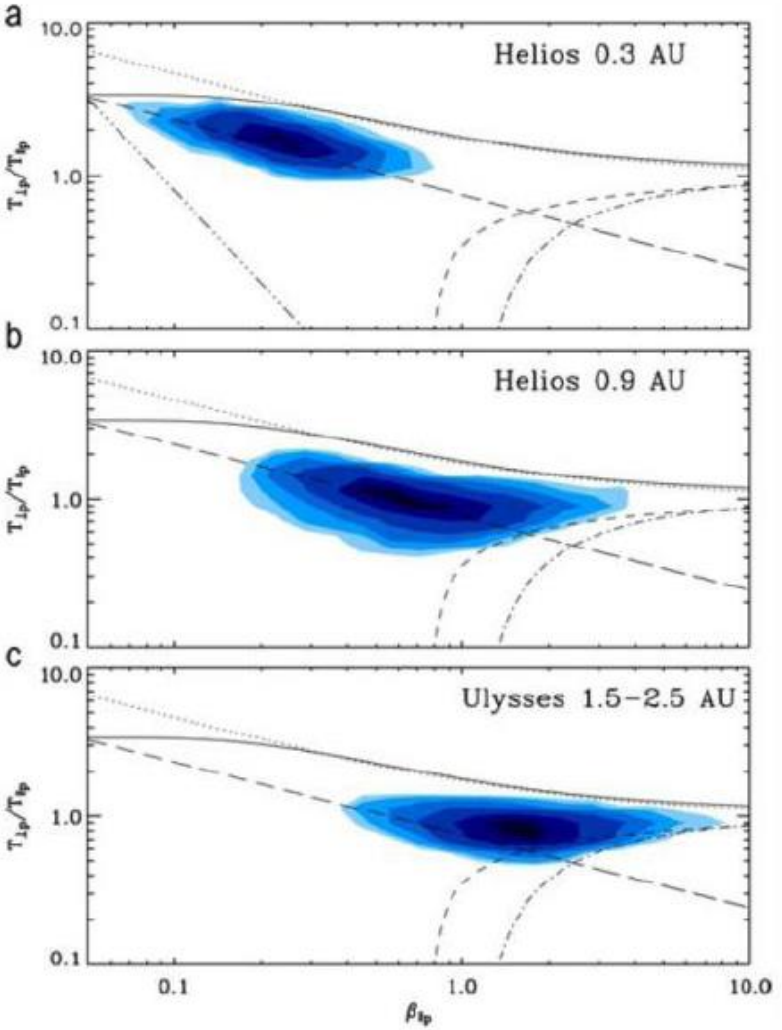
The role of kinetic instabilities

- Particle distributions evolve with radial distance
- Evidence for local generation of fluctuations (e.g. Bale et al.)

- Other local sources?
  - Beams
  - Dust/comet trails
  - Inner source

- **What is the energy budget of fluctuations in the inner heliosphere?**



Matteini et al., 2007

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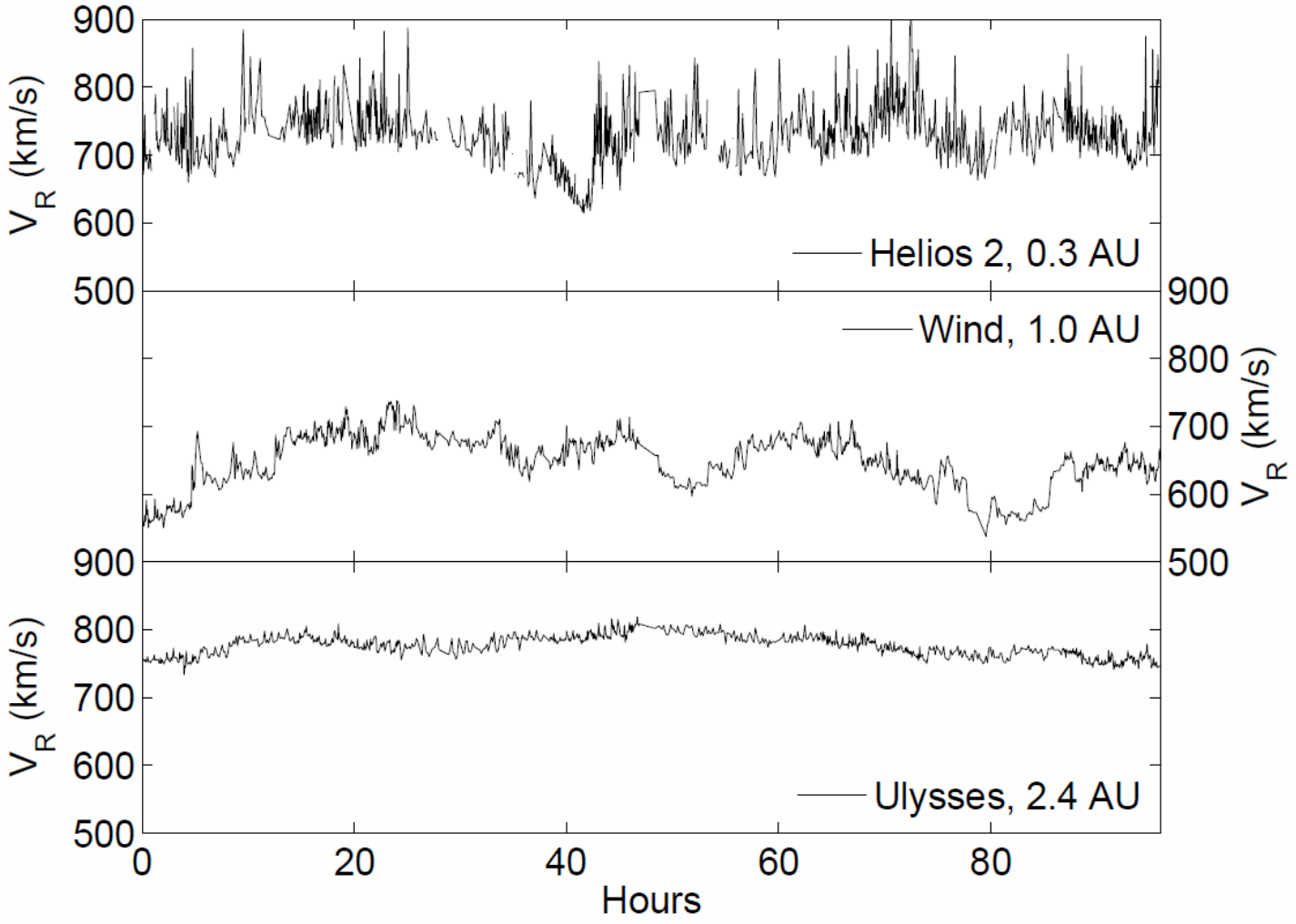
Solar wind fine scale structure



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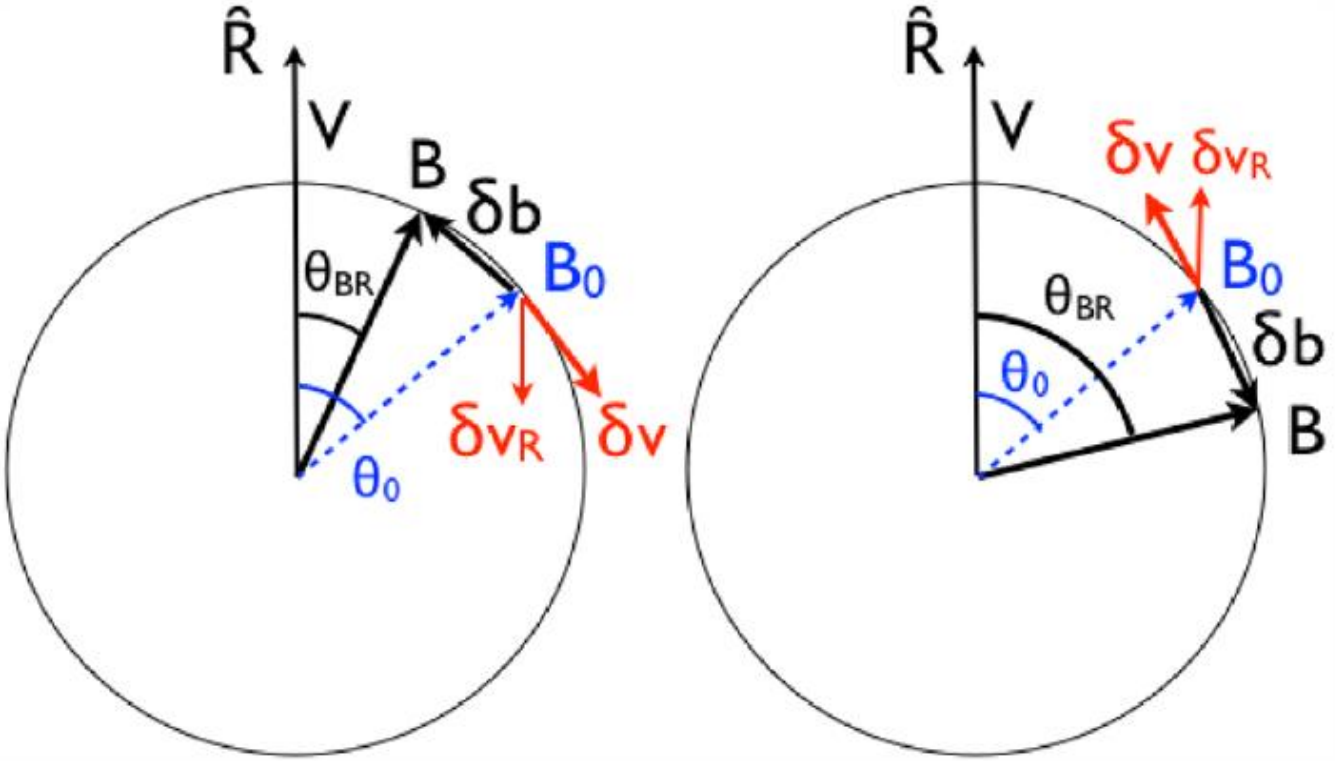
Alfven waves, field direction and velocity



$$\delta b_R = B_R - B_{R0} = B\cos(\theta_{BR}) - B_0\cos(\theta_0)$$

Matteini et al., GRL, doi:10.1002/2013GL058482, 2014

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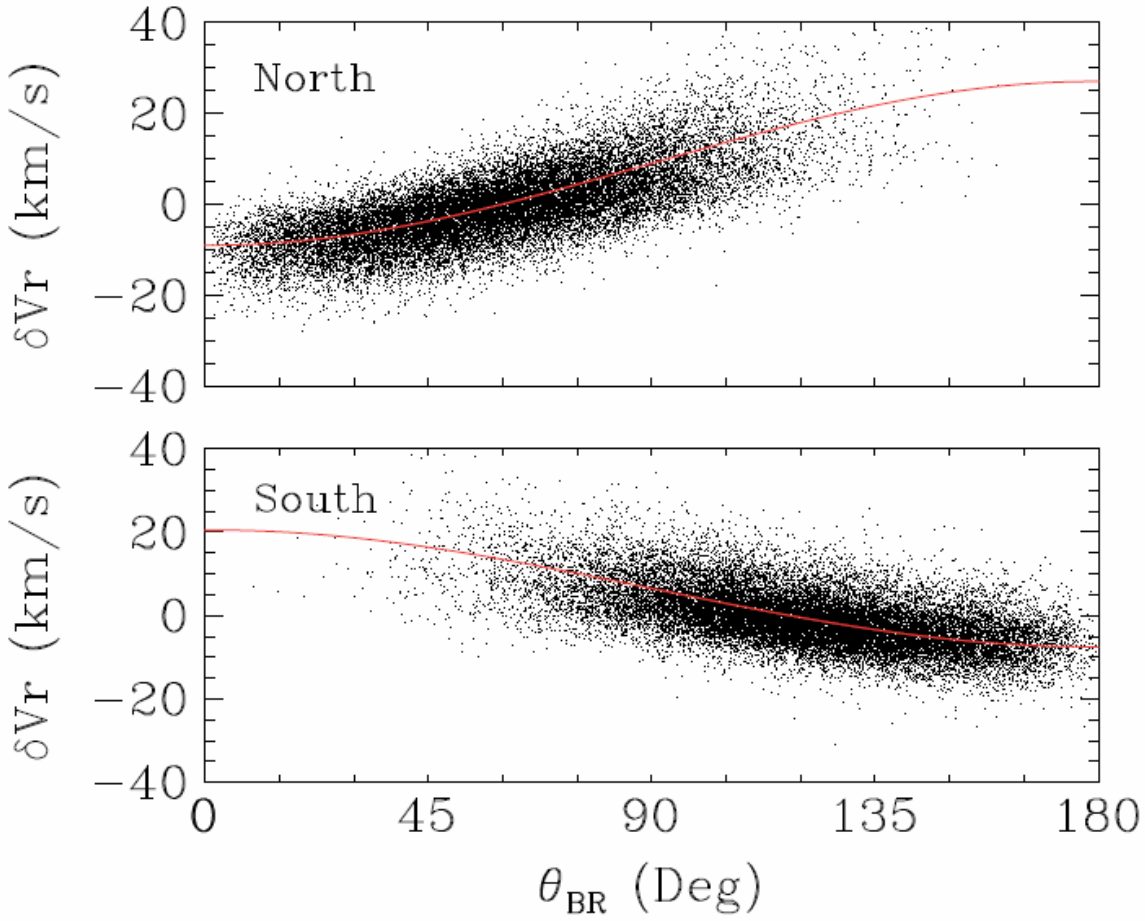
Ulysses high speed wind



$$\delta V_R = \pm V_{wave} \cos(\theta_{BR}) \mp V_{wave} \cos(\theta_0) .$$

Matteini et al., GRL, doi:10.1002/2013GL058482, 2014

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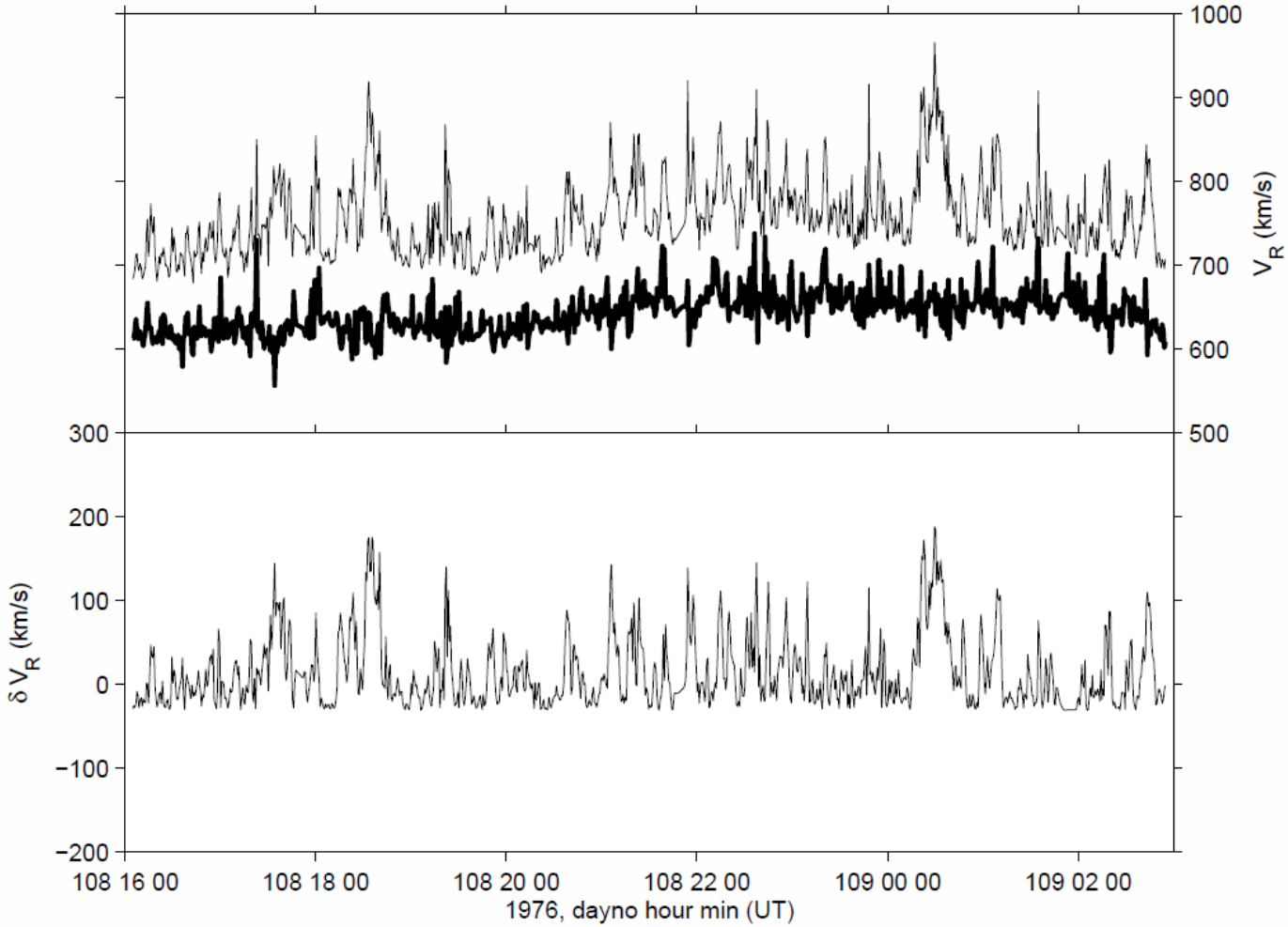
Correcting for the Alfven waves



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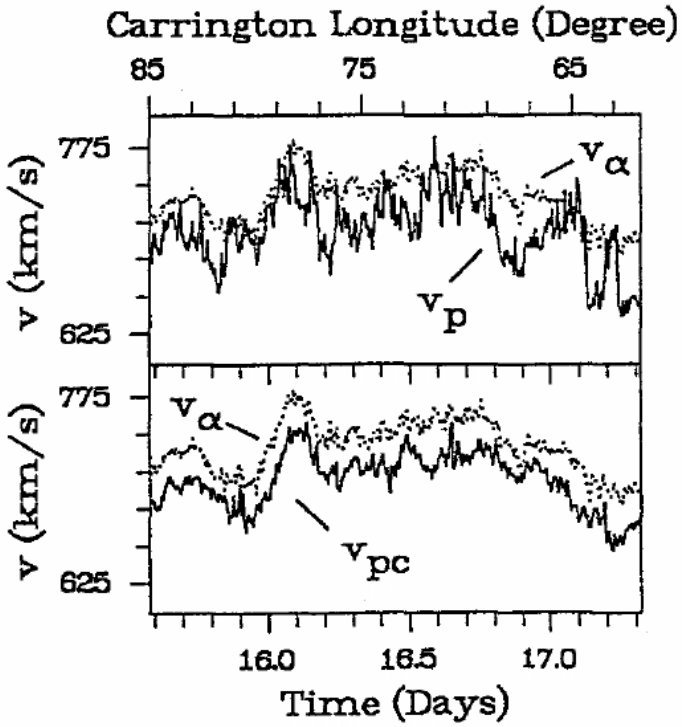
Re-inventing the wheel

Removal of the Alfvén-Waves Influence from the Proton Velocity

Since Alfvén waves influence the magnetic field and the proton velocity in high-speed streams most of the time /14/, this complicates the search for spatial plasma structures. As already described in /15/, it is possible to remove the influence of the Alfvén waves from the measured proton velocity $\vec{v}_p$. Hereby is $\vec{v}_p$ a composition of a velocity $\vec{v}_{pc}$ which is not influenced by Alfvén waves and a velocity $\Delta\vec{v}_A$ which is due to Alfvén waves:



$$\vec{v}_p = \vec{v}_{pc} + \Delta\vec{v}_A.$$

$\Delta\vec{v}_A$ results from

$$\Delta\vec{v}_A = \pm\frac{\Delta\vec{B}}{\sqrt{4\pi\rho}}$$

Thieme et al., Adv. Space Res., v9, (4)127, 1989

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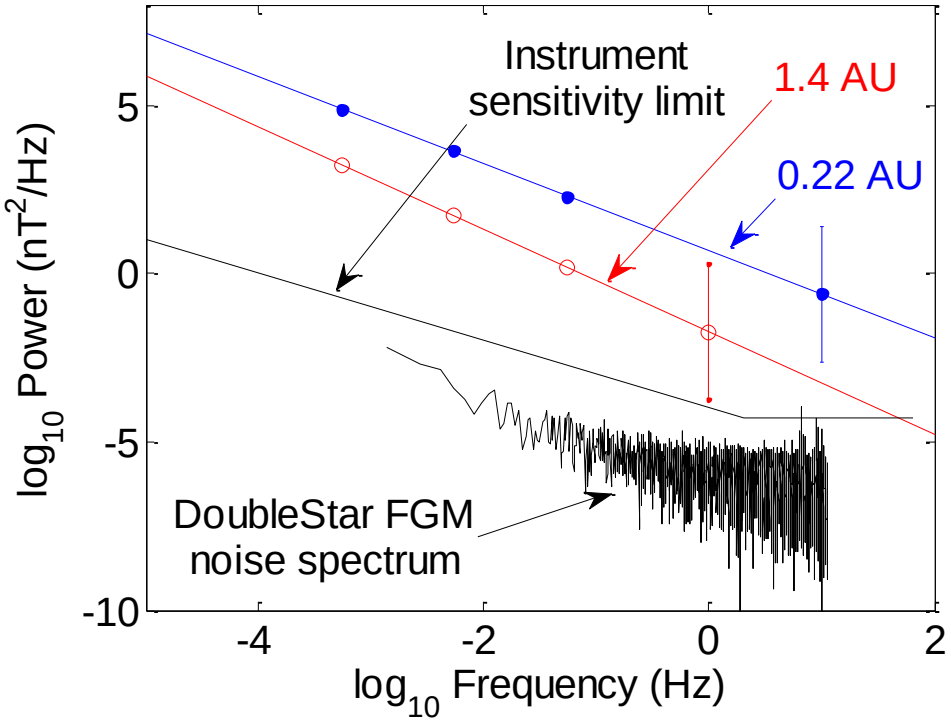
Solar Orbiter magnetometer: requirements

- **Time resolution**
  - Bulk plasma: 16 vector/s
  - Kinetic physics: 128 vectors/s burst
- **Low noise**
  - Order of magnitude below natural signal throughout the orbit
  - 10 pT $Hz^{-1/2}$ at 1 Hz
- **Absolute field**
  - Calibration: two sensors
  - Low and stable spacecraft and instrument magnetic fields



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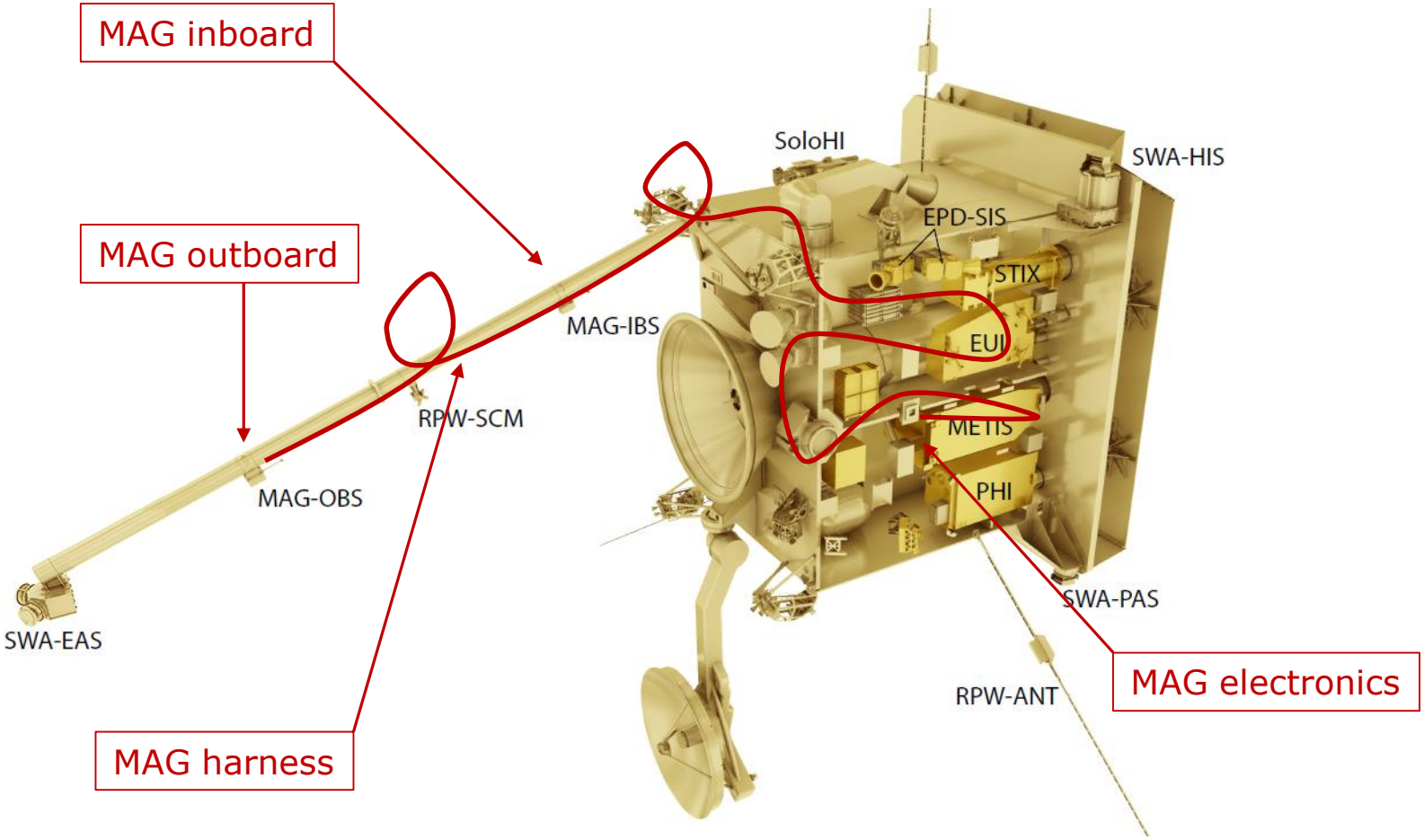
Solar Orbiter magnetometer: configuration



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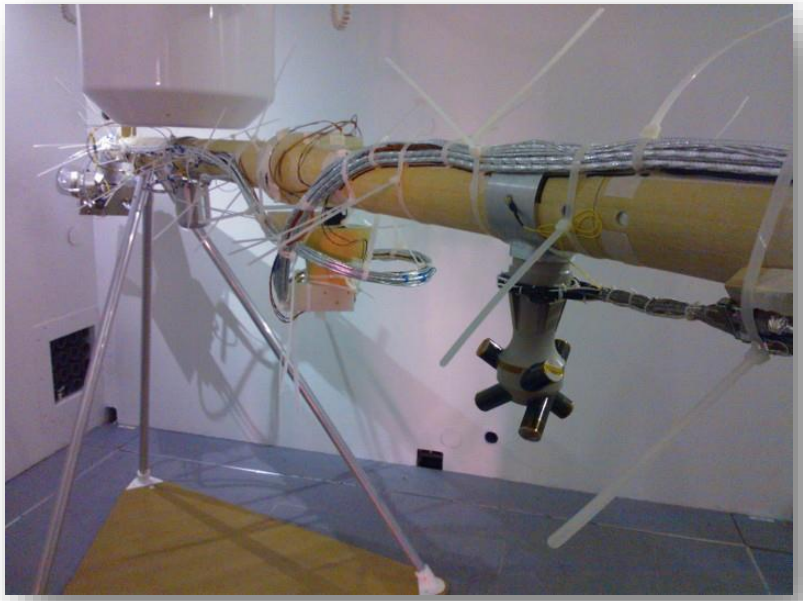
Solar Orbiter magnetometer: challenges

- Thermal
  - +80C to -190C on boom
- Mechanical
  - High vibration levels on launch
- Resources
  - Mass, power, telemetry
- Software
  - Reliability, low resource processor
- Magnetic cleanliness
  - Other instruments
  - Spacecraft sub-systems



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Solar Orbiter magnetometer: operational philosophy

- Always on
  - Vital to have 100% coverage
- Auto-ranging
  - Maximise precision as field magnitude varies
- Burst mode
  - 16 vectors/s most of the time: MHD, proton gyroscale
  - Burst mode: 128 vectors/s, ~ 1 hour per day
  - Trigger off RPW shock detection algorithm
  - Internal shock trigger (TBD)
- Low latency data
  - 1 vector every 8s within 24 hours
- Real time onboard data
  - To SWA for reduced data products

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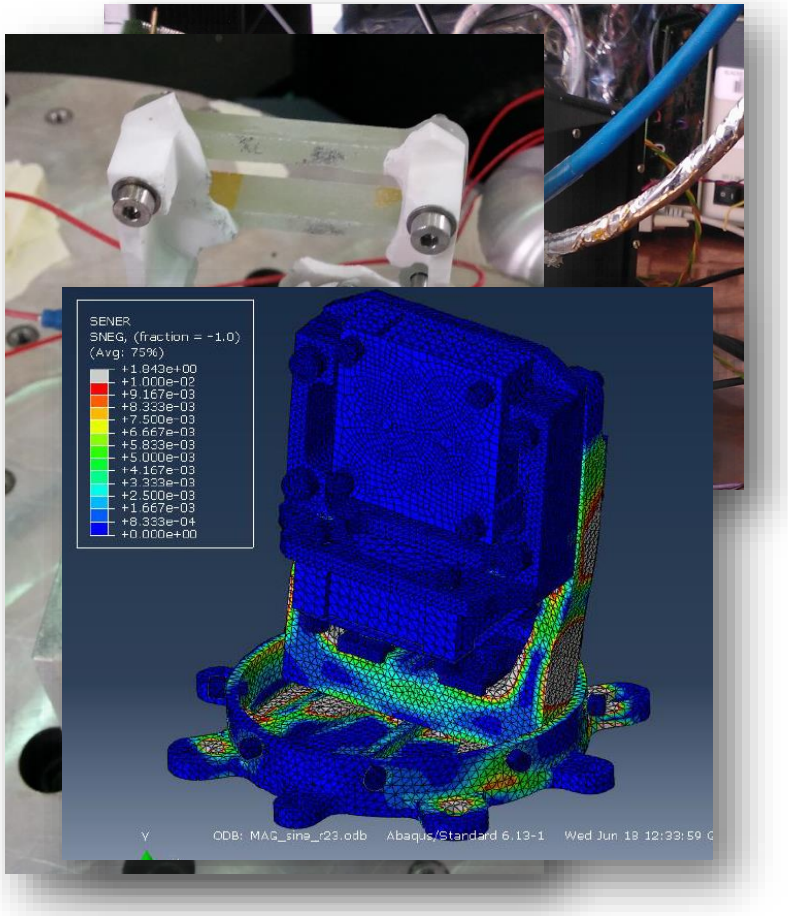
Solar Orbiter magnetometer: status

- Electrical model: final twiddles
  - Expect delivery to Airbus DS in November
- Sensors
  - Failed vibration test
  - Understand the issue, fixed
  - New test soon, expect to pass
- Software
  - Lots still to do
- Next
  - Qualification model
  - Final(!) electrical fixes
  - Near-identical to flight model
- Flight model
  - Delivery December 2015



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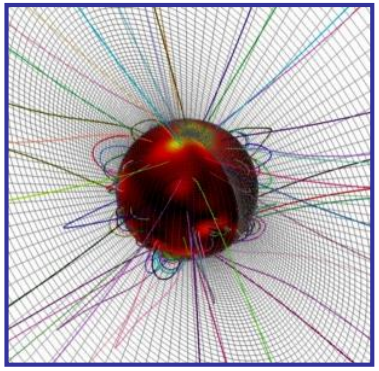
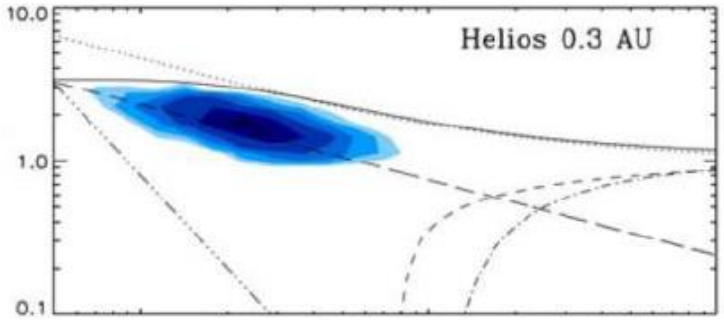
Summary

- How does the Sun's magnetic field connect into space?
  - Disconnecting flux from the Sun
  - Heliospheric current sheet and solar structure
  - ICMEs and the magnetic solar cycle



- How are the corona and solar wind heated and accelerated?
  - Origin of the slow solar wind
  - The evolving solar wind distribution
  - Dissipating turbulence



- How are particles accelerated and how do they propagate through space?
  - Developing shocks
  - Magnetic structures