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Magnetic field measurements at the L5 Lagrange point

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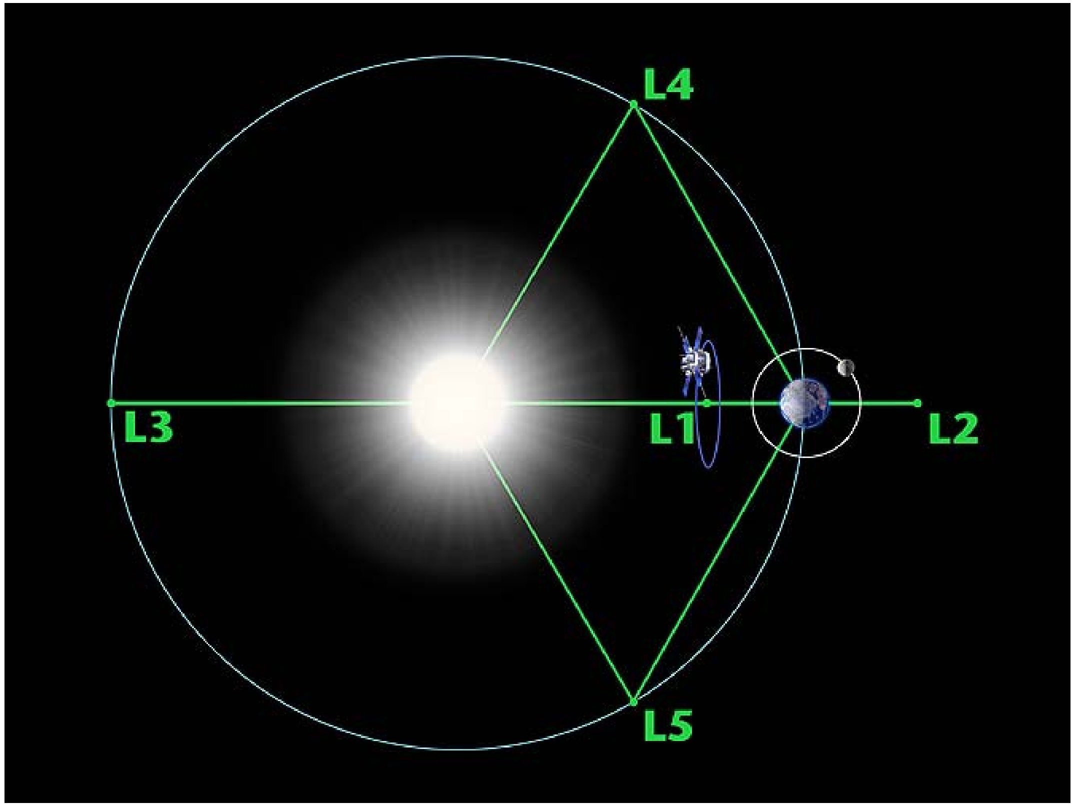
Science from an Operational Mission: An L5 Consortium meeting

BIS Conference Centre, London, 13 May 2015

A space weather monitor at L5

1. Imaging the surface – see what's coming over the limb
2. Imaging the corona and solar wind along the Sun-Earth line
3. **Measuring the solar wind in-situ**



The Parker spiral

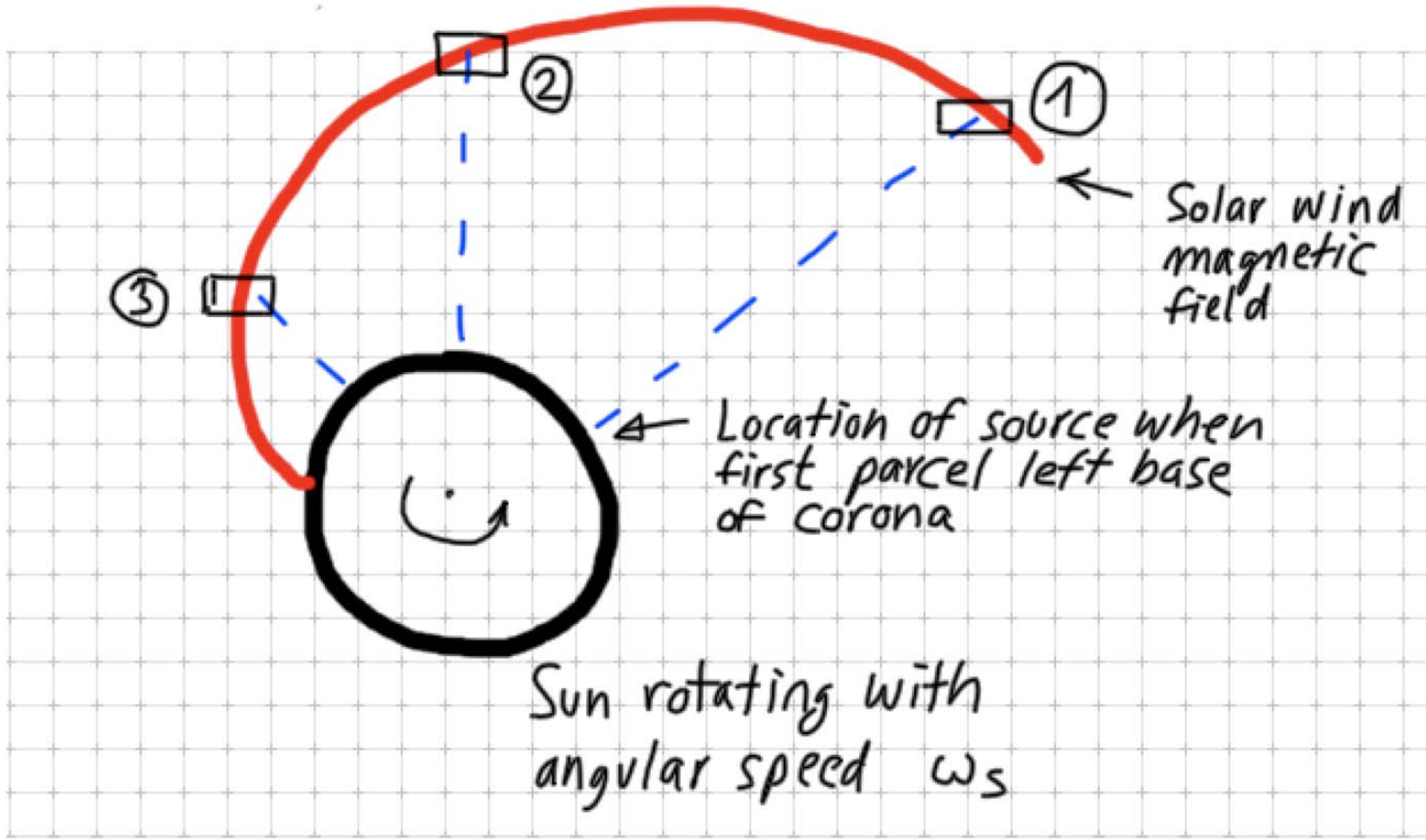


Image credit: I. Mueller-Wodarg

There are different types of solar wind

- Fast solar wind (v≈750km/s) comes from coronal holes
- At solar minimum, polar coronal holes dominate flow – fast wind over the Sun's poles
- Slower (v≈400 km/s), denser (≈2x) and more variable solar wind at low latitudes (from "streamer belt"
- Ecliptic plane: 7º to Sun's equator

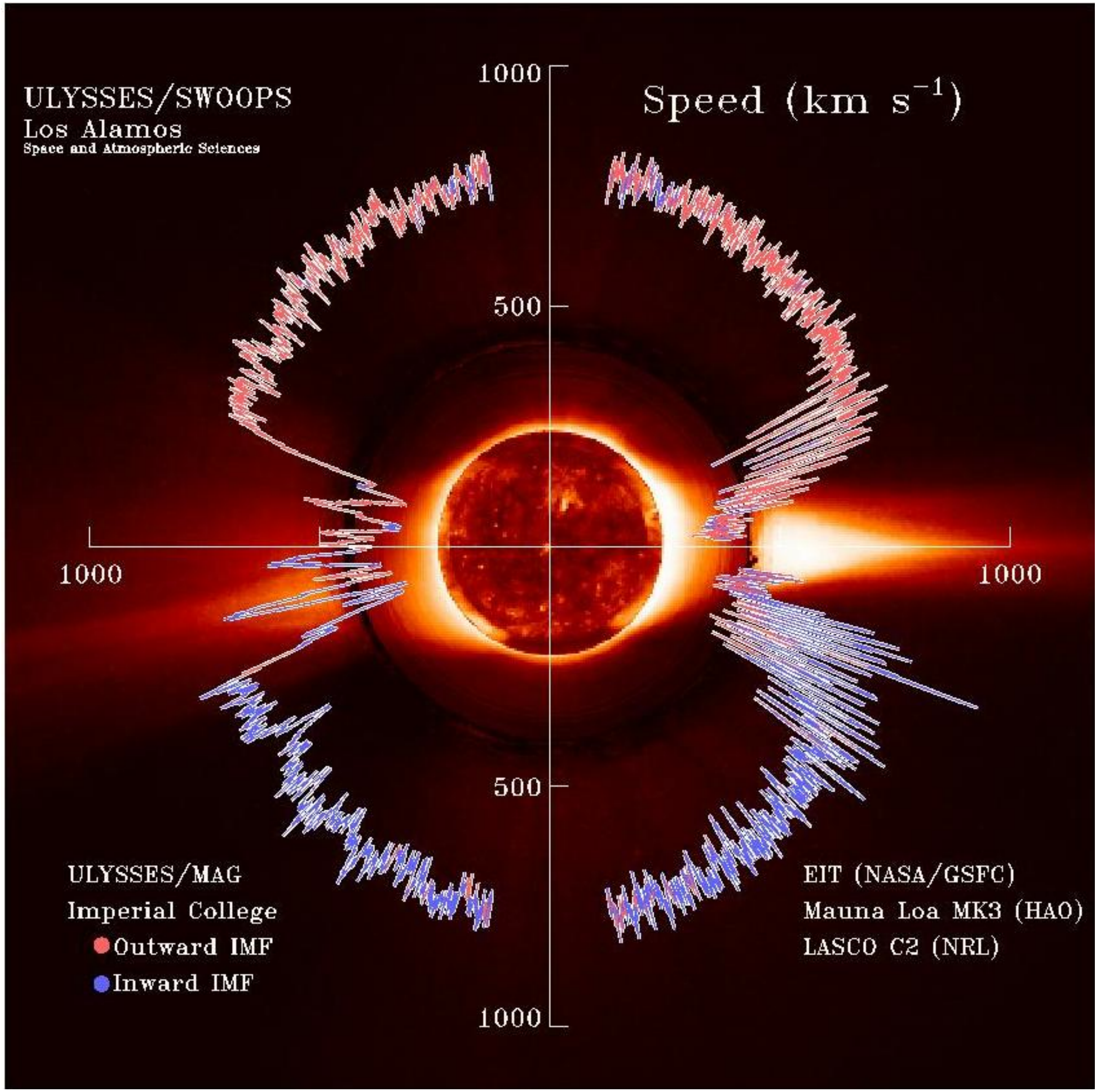


Image credit: McComas 1998

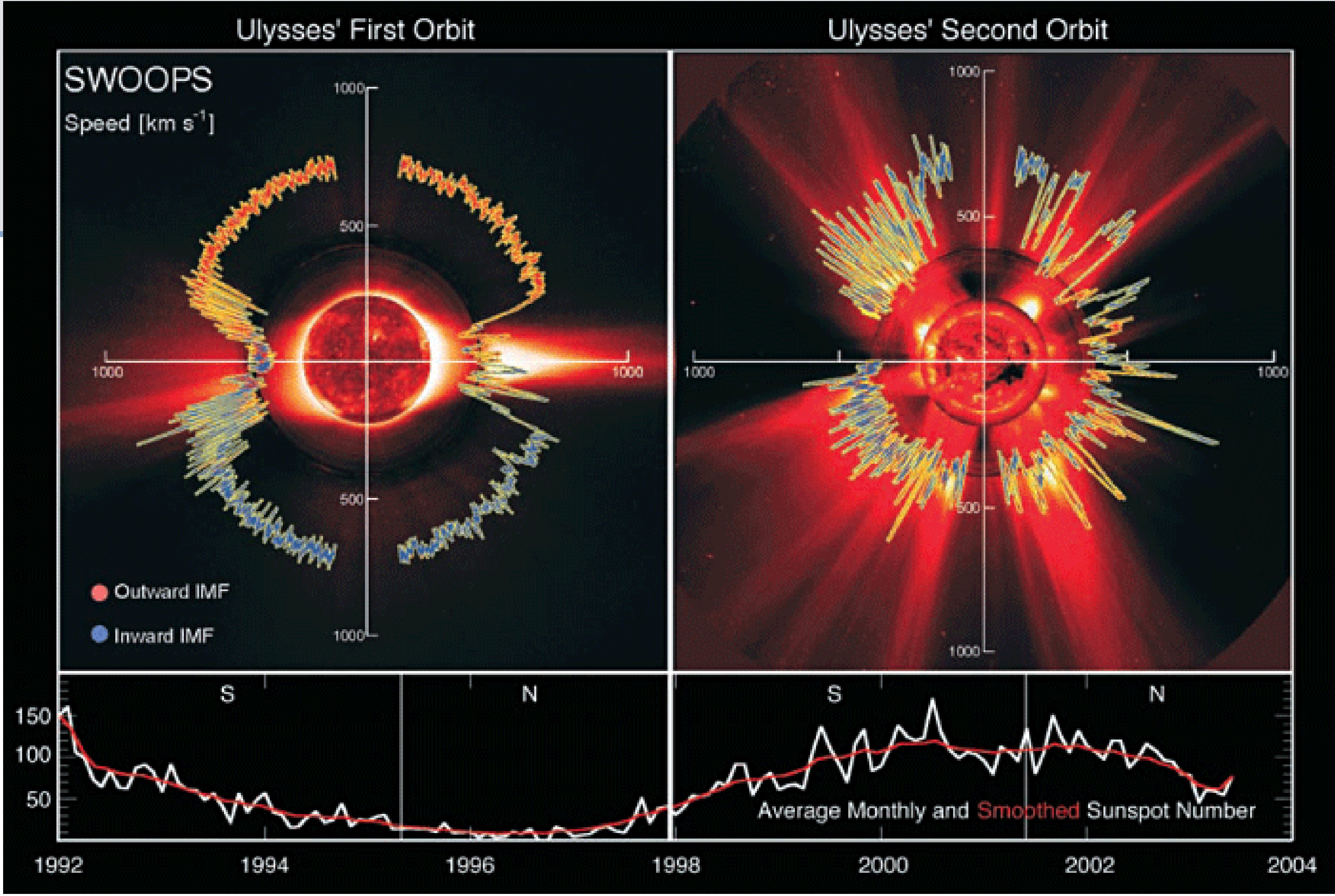
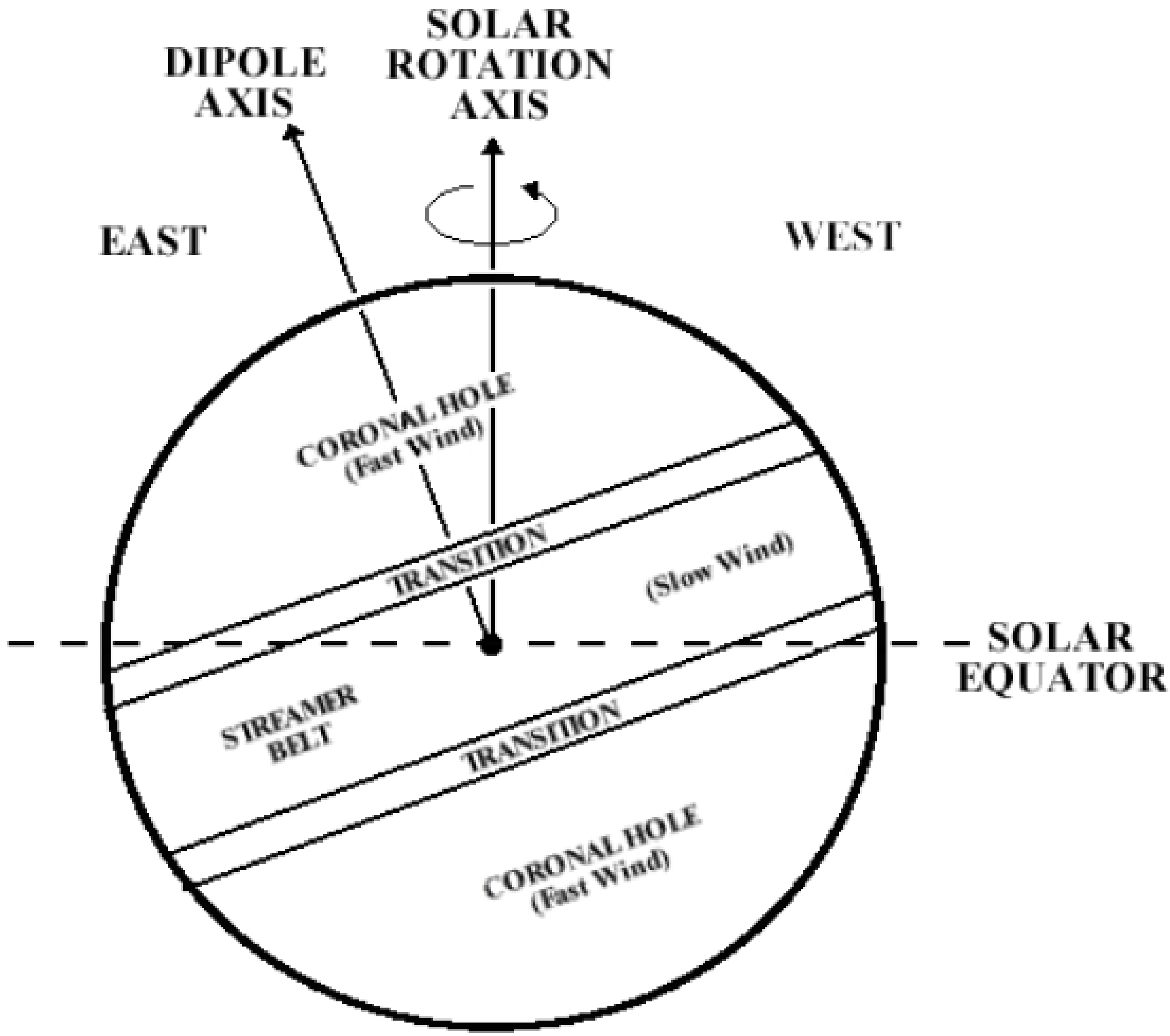


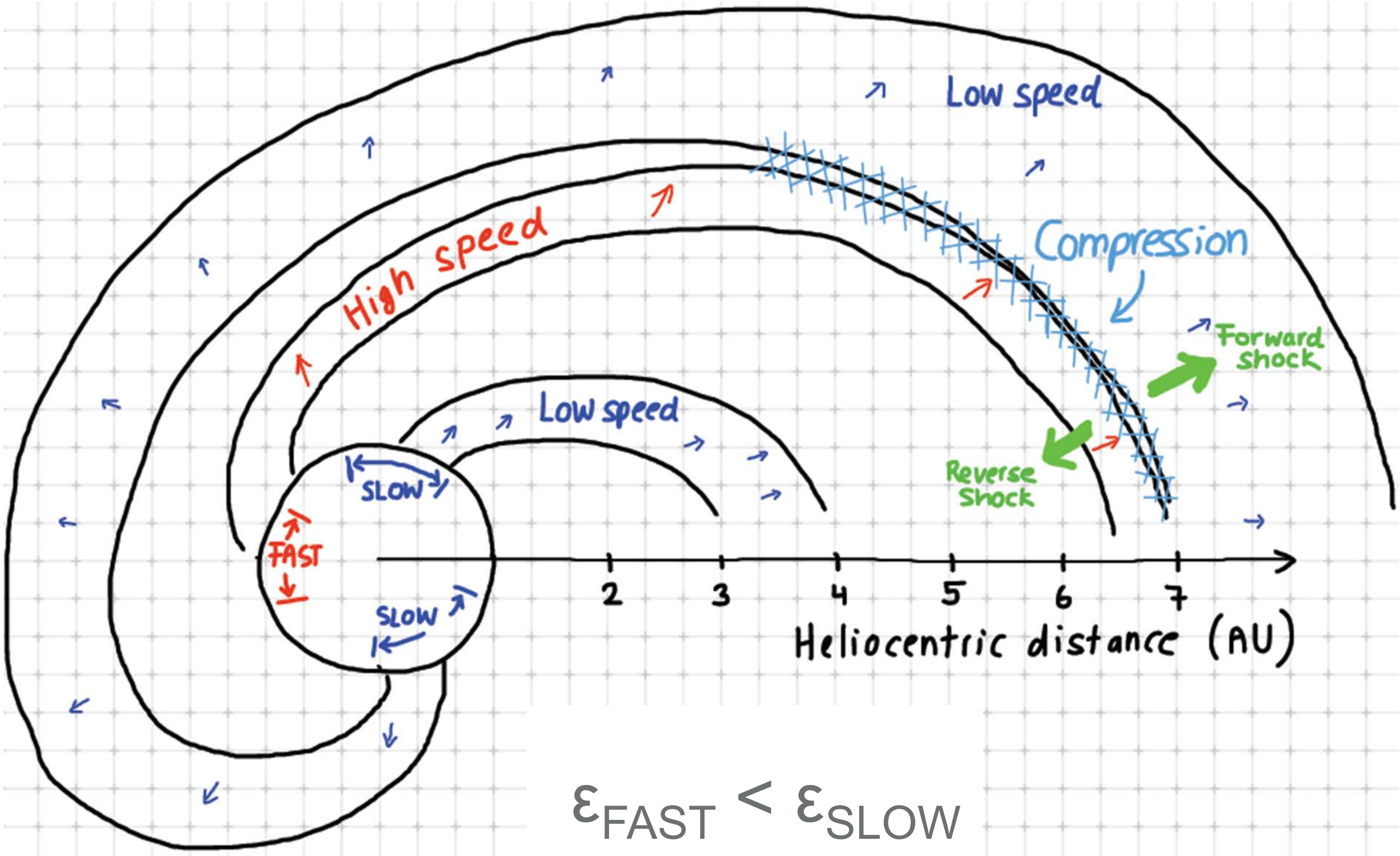
Image credit: McComas 2003

- Solar maximum: no dominant polarity
- Coronal holes occur at any latitude
- Fast and slow wind throughout – no latitude dependence in solar wind

Dipole orientation vs. solar rotation axis



Stream Interaction Regions (SIRs)



$$\varepsilon_{FAST} < \varepsilon_{SLOW}$$

Image credit: I. Mueller-Wodarg

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CMEs vs CIRs

- CMEs
  - Fast moving – bow shock
  - Compressed (enhanced) magnetic fields in sheath region
  - Smoothly rotating magnetic field in core often observed

- CIRs
  - Fast solar wind in trailing edge
  - **Contains large amplitude Alfven waves with extended intervals of southward IMF**

- Both can exhibit
  - Fast flow
  - Southward IMF
  - **CME storms tend to be stronger**

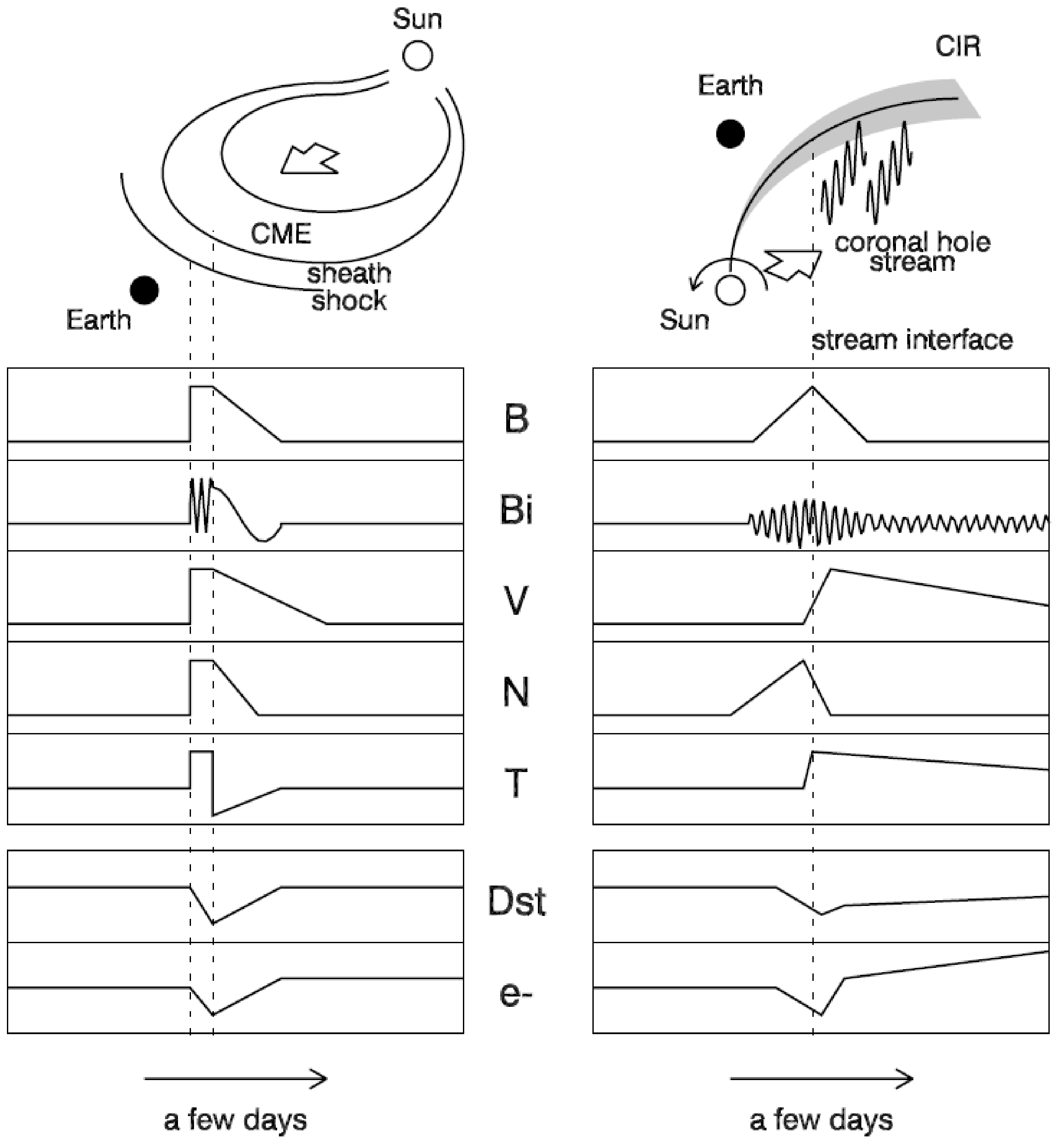

Image credit: Kataoka and Miyoshi 2006

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Image credit: H. Hietala
Hietala et al. 2014, Kilpua et al., 2015
doi: 10.1002/2015GL063542
doi: 10.1002/2014GL059551

Not all storms are created equal

Storm list 1995–2013

Dst < -50 nT: 398 storms → **193** suitable for the study

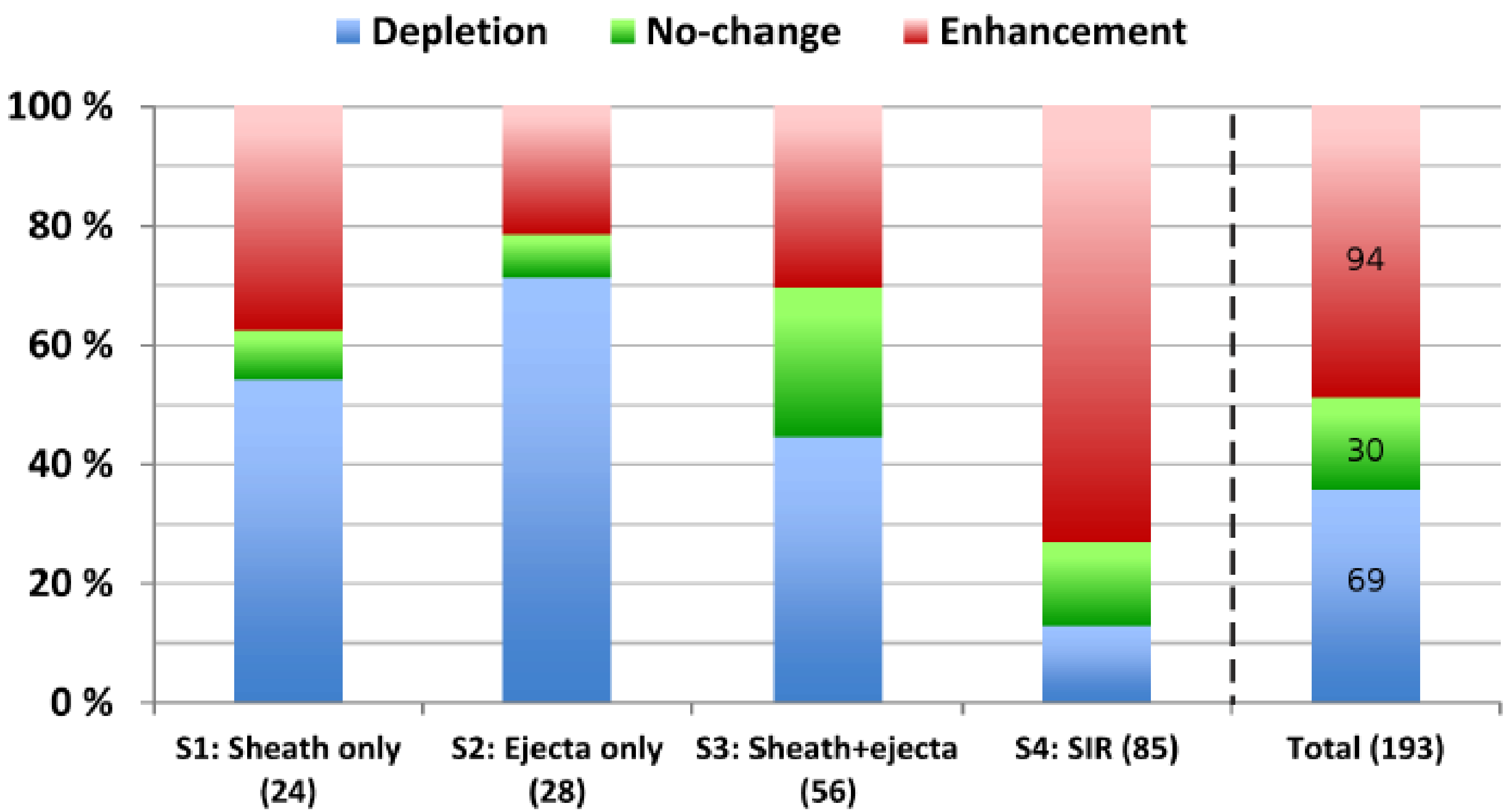
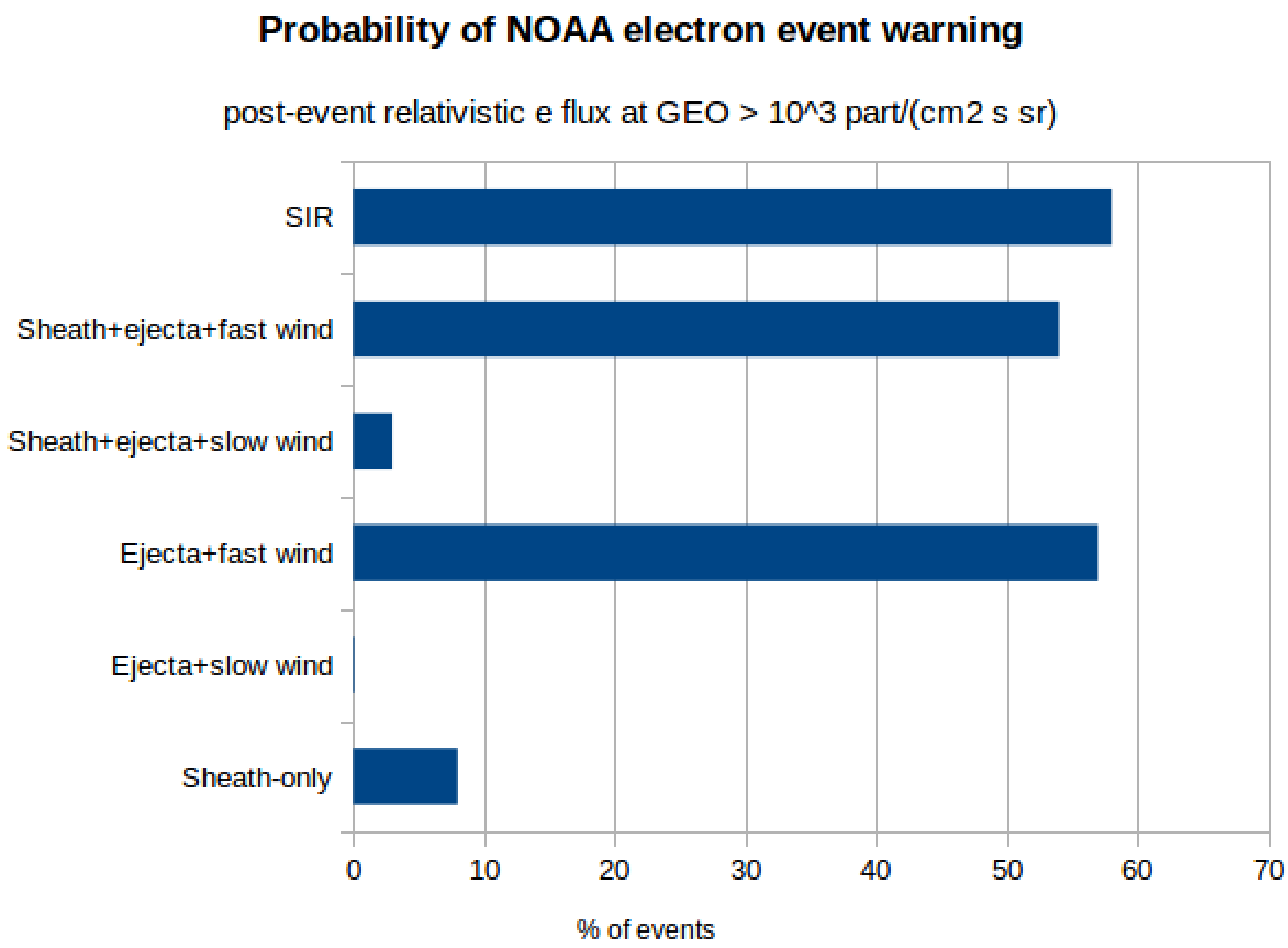


Image credit: H. Hietala
Hietala et al. 2014, Kilpua et al., 2015

Implications for space weather forecasting



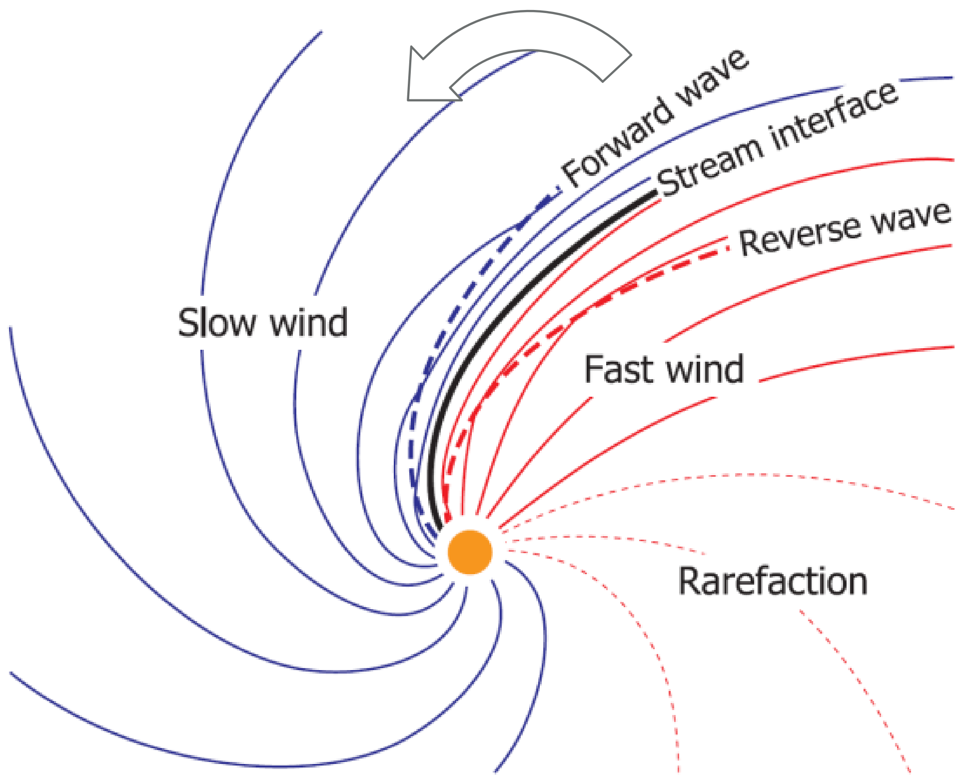
In situ measurements at L5

Stream interaction regions (SIRs):

- “co-rotate” with the Sun
- can be known as Co-rotating Interaction Regions (CIRs)
- cause geomagnetic activity (storms and substorms) *depending on their magnetic field structure*
- are stronger at solar minimum

Magnetic field observations at L5:

- provide 4 - 5 day warning of geoeffective SIRs
- constrain solar wind models and forecasts



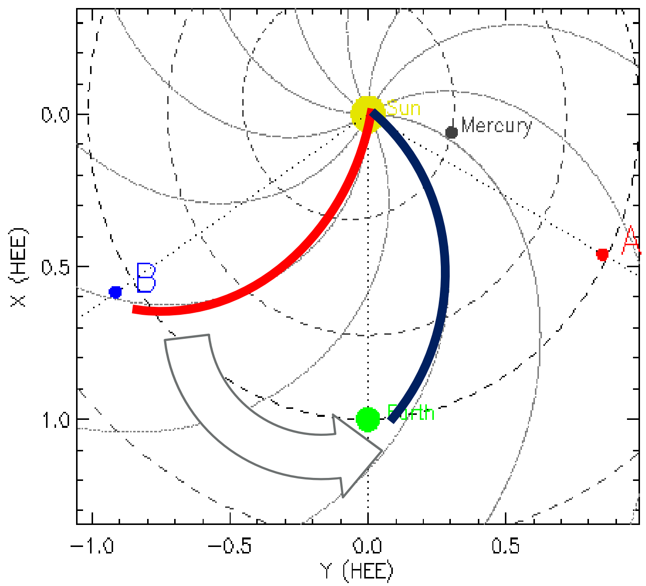
SIRs are formed by fast wind running into slow wind

(Owens & Forsyth 2013)

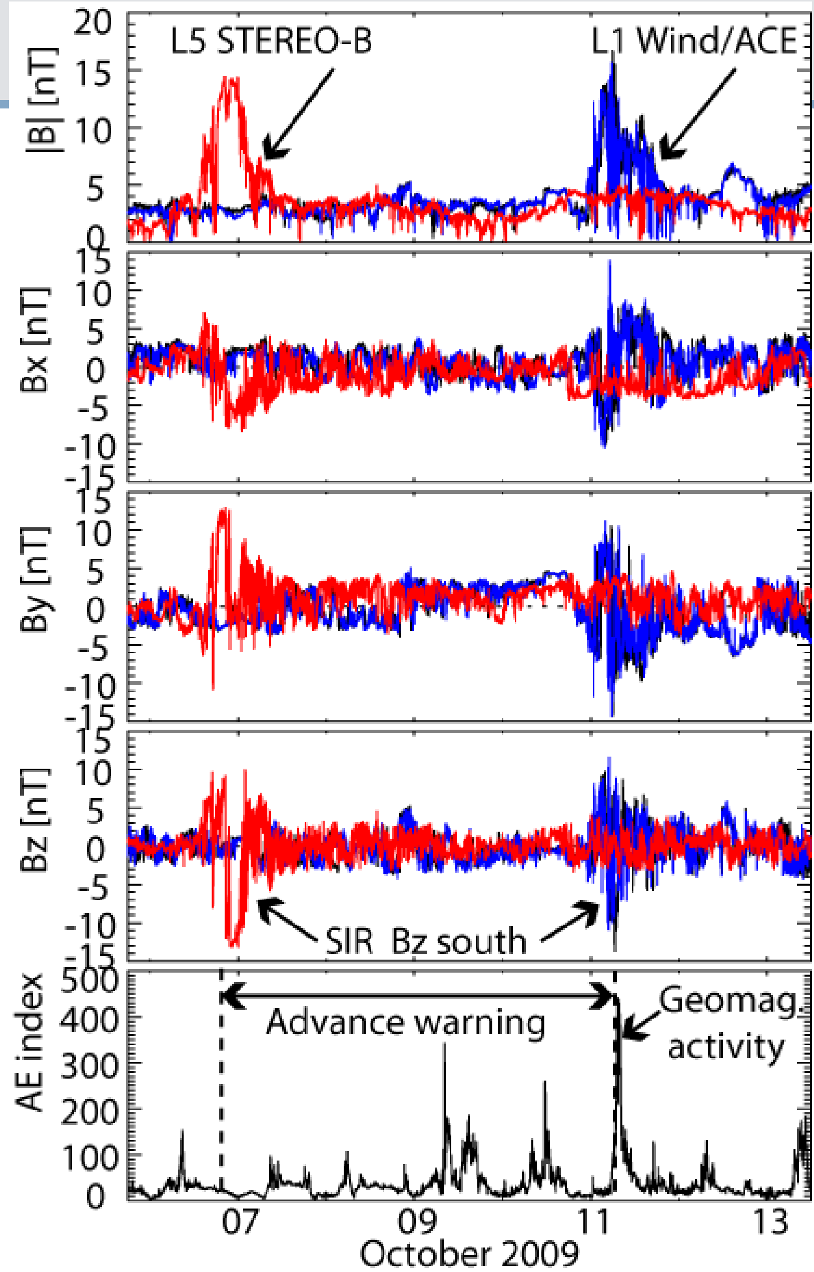
In situ measurements at L5

- October 2009, STEREO-B at L5
- Bottom panel: AE index (auroral electrojet). Geomagnetic activity on 11 October
- Similar solar wind observed on 6 October by STEREO-B at L5
- More than four day warning

STEREO-B proof of concept
October 2009



STEREO-B proof of concept



Material courtesy Chris Russell UCLA

Interplanetary Field Enhancements (IFEs)

Characterized by

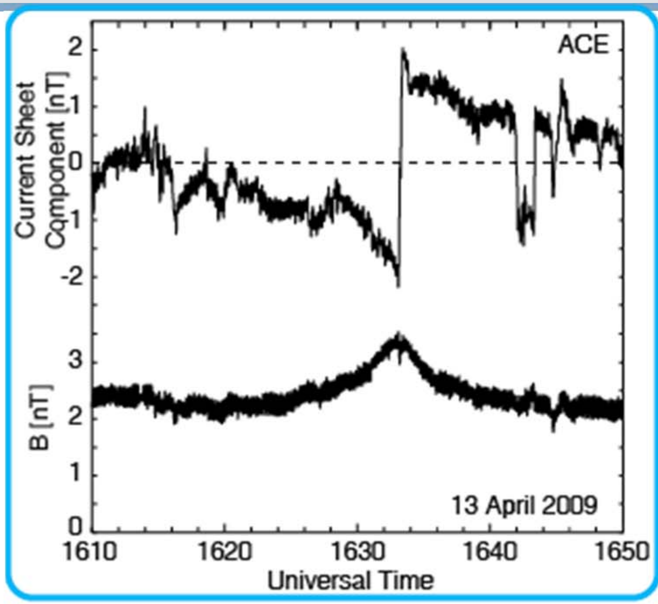
- Enhanced field strength
- Central current sheets

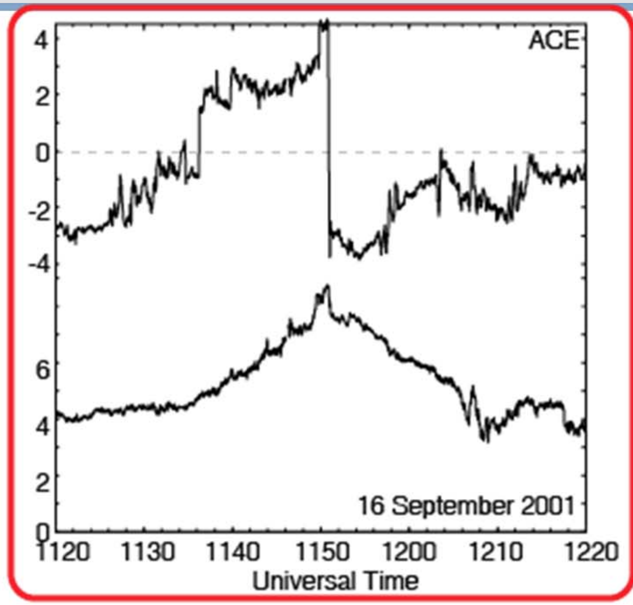
Duration: 5 minutes to ½ day

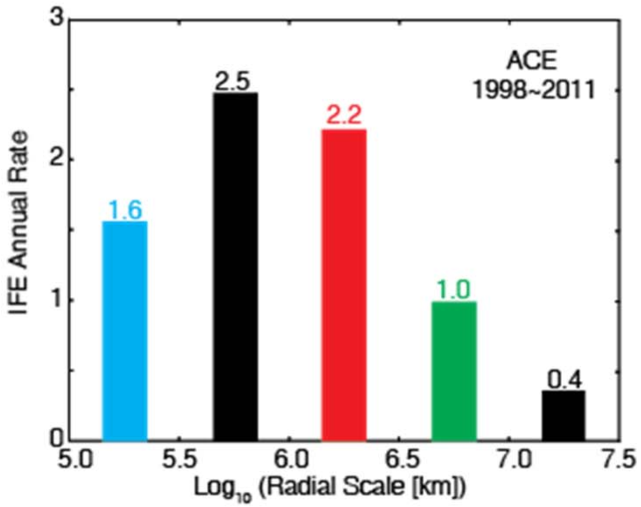
Velocity ≈ Vsw (based on multi-s/c obs)

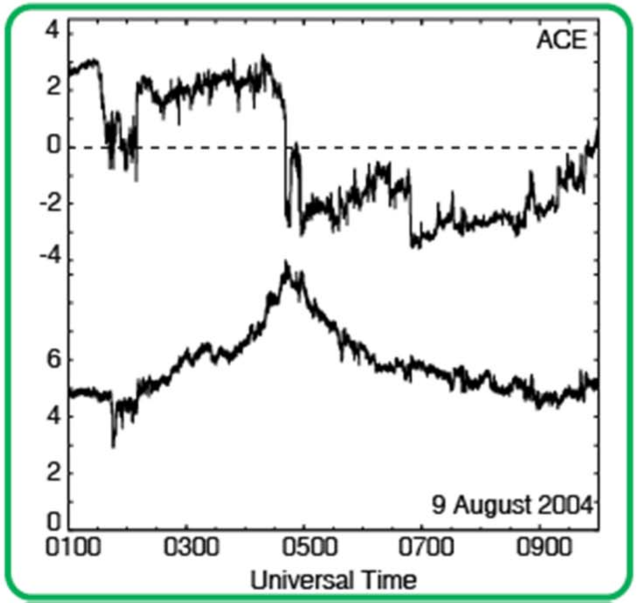
Annual rate is ~8 at 1AU

Radial scale= Duration × Vsw









Interplanetary Field Enhancements (IFEs)

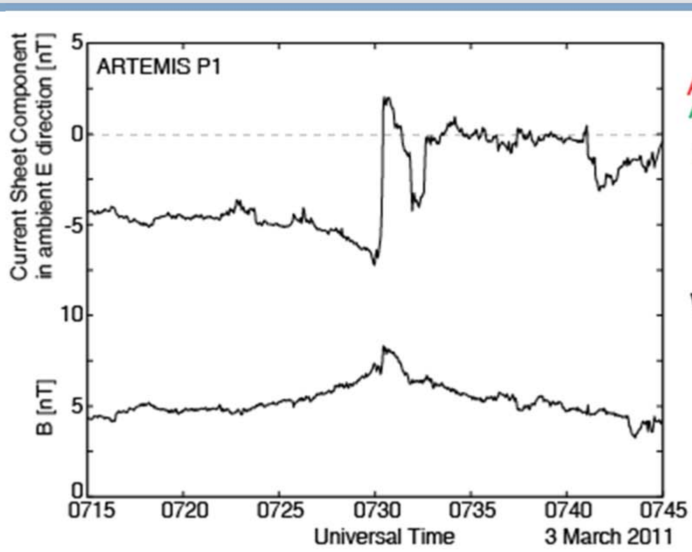
- What are they?
  - Obstacle travelling with the solar wind
  - The only reasonable candidate is **coherent body of fine scale charged dust**
  - Source: rock-rock collisions ie small meteroids into larger meteoroids
  - Can in principle occur much more often but are too small to be seen telescopically
  - Magnetic field measurements give rate of occurrence versus duration.

- Why are these important?
  - NEOs have been hit in the recent past and material was eroded/broken off and is co-orbiting with the main asteroid
  - While we know where the NEO is, the material that was broken away from the NEO can be ahead of or well behind the NEO now and it is dangerous down to sizes of about 10m
  - **These IFEs are our only way of finding these regions of abundant rocks in Near Earth Orbits**

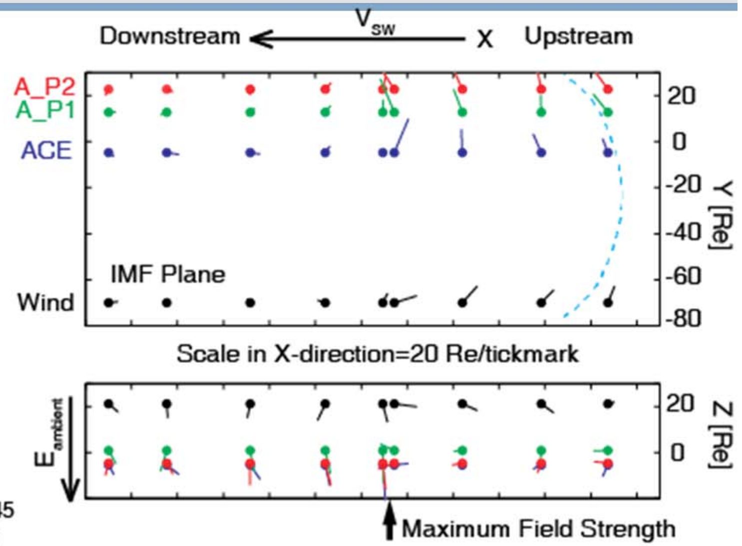
- **Need multiple observing points around the Sun for good statistics**

IFEs: Charged Dust Clouds Picked Up by the Solar Wind

- This IFE was detected by ACE, Wind, ARTEMIS P1, ARTEMIS P2 and Geotail simultaneously.
- A strong current sheet in the ambient E direction (Figure a)

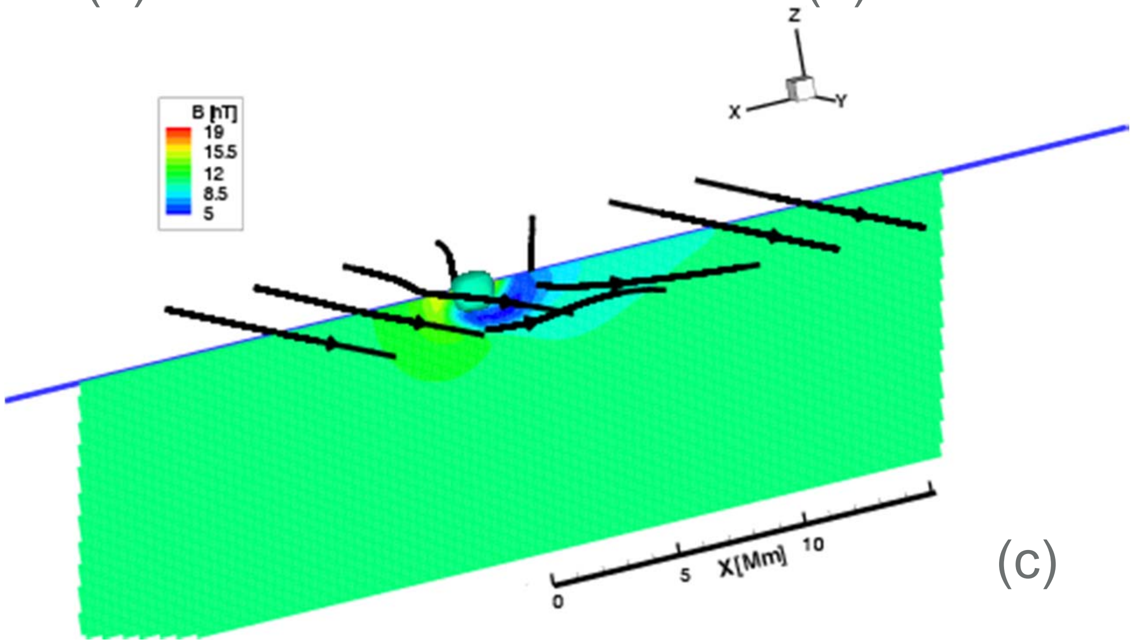


(a)



(b)

- The reconstructed magnetic field geometry shows a draping signature in the upstream and a bending signature in the downstream (Figure b).
- In a simulation modeling solar wind picking up charged dust cloud, we see similar draping and bending signatures in the magnetic field lines (black lines in Figure c).



(c)

Designing a magnetometer: step 1

Measurement requirements

Interplanetary Magnetic Field	Obs cycle	Obs latency	WMO cycle	WMO lat	L5 cycle	L5 Latency
Bx, By, Bz & |B|	1min	3 min	1-60 sec	1-15 min	~1sec-1min	~1-3min

- Operational capability implies that the instrument must exhibit high reliability and the instrument must provide continuous data flow 24/7 for at least 10 years, at the specified accuracy.

The requirements are not set by the science community

Designing a magnetometer: step 2

Sensor technology

- Magnetoresistive or Fluxgate?

- For top level science missions that require high reliability and accurate measurement over decade(s) long investigations, a fluxgate magnetometer is the obvious choice.

- **Heritage is key** to demonstrate operational levels of reliability:
- Cluster, Ulysses, Cassini, and DoubleStar
- Solar Orbiter and JUICE

Solar Orbiter magnetometer (EM)

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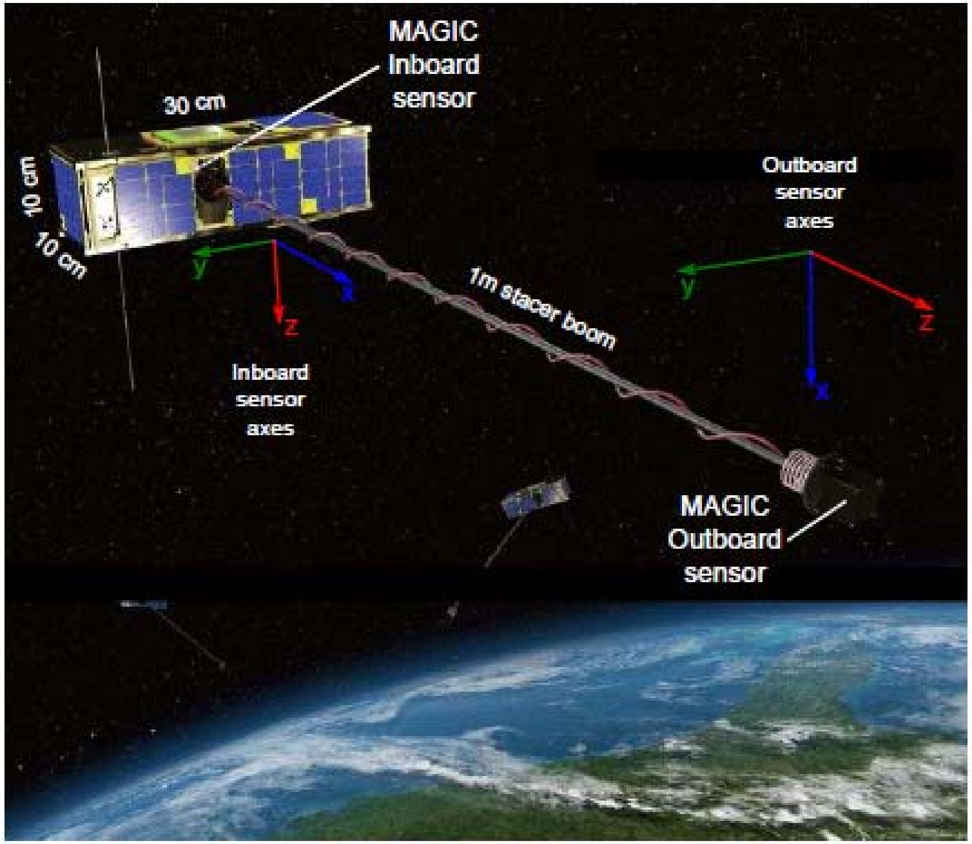
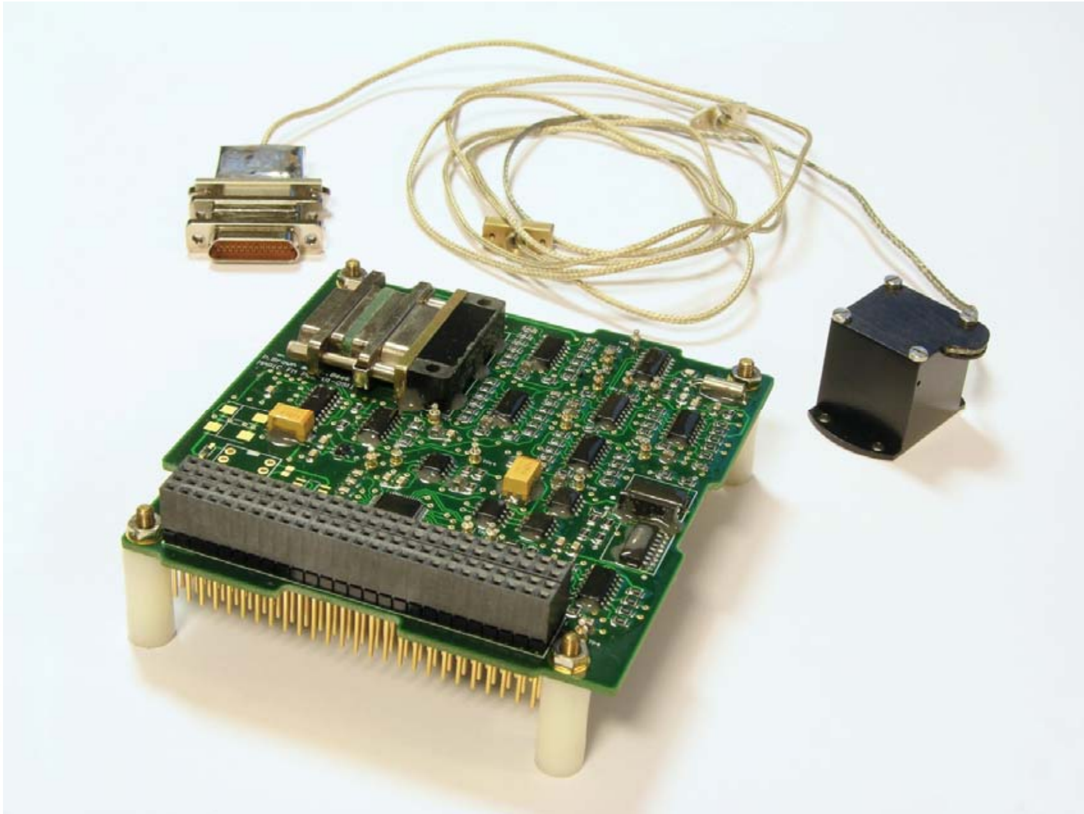
But for some applications a *lower resource payload* may be appropriate

Magneto-Resistive magnetometer sensor technology





The MAGIC of CINEMA: First in-flight science results from a miniaturised anisotropic magnetoresistive magnetometer

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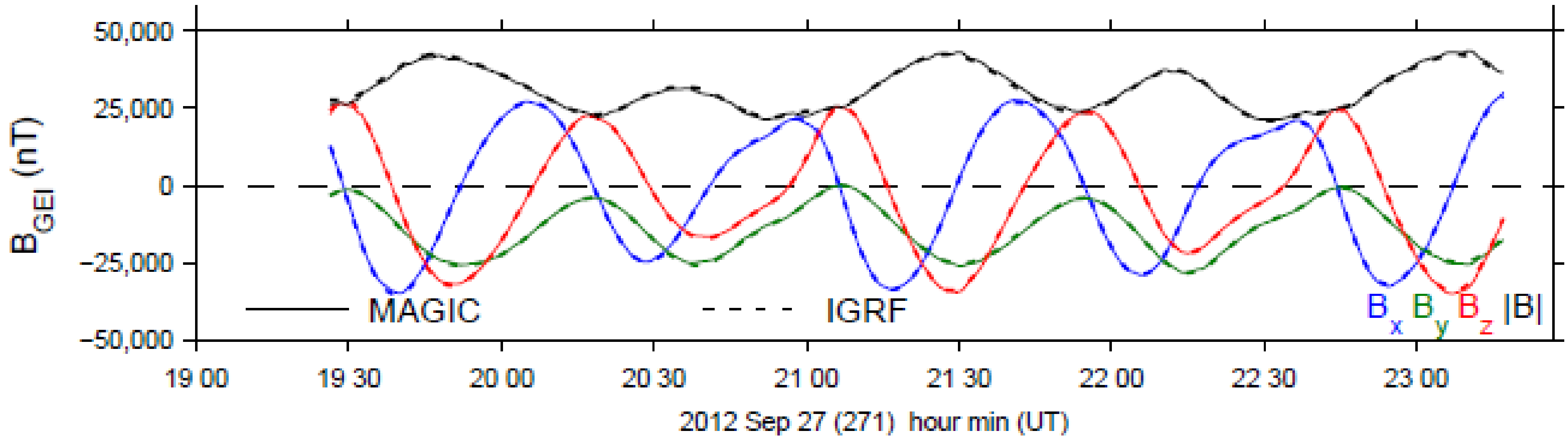
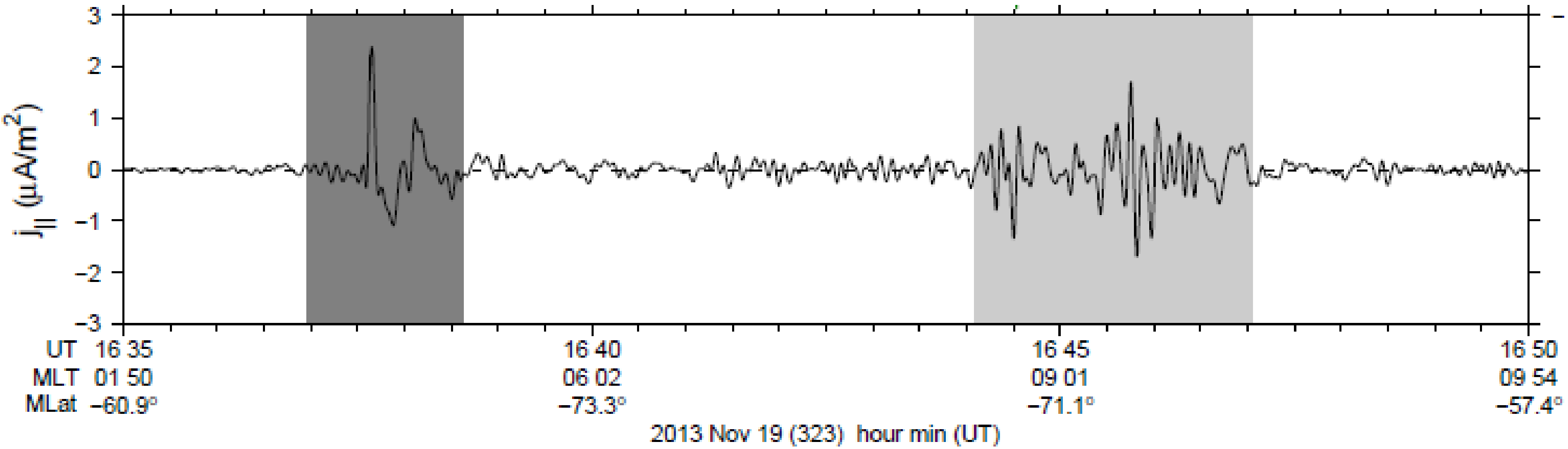
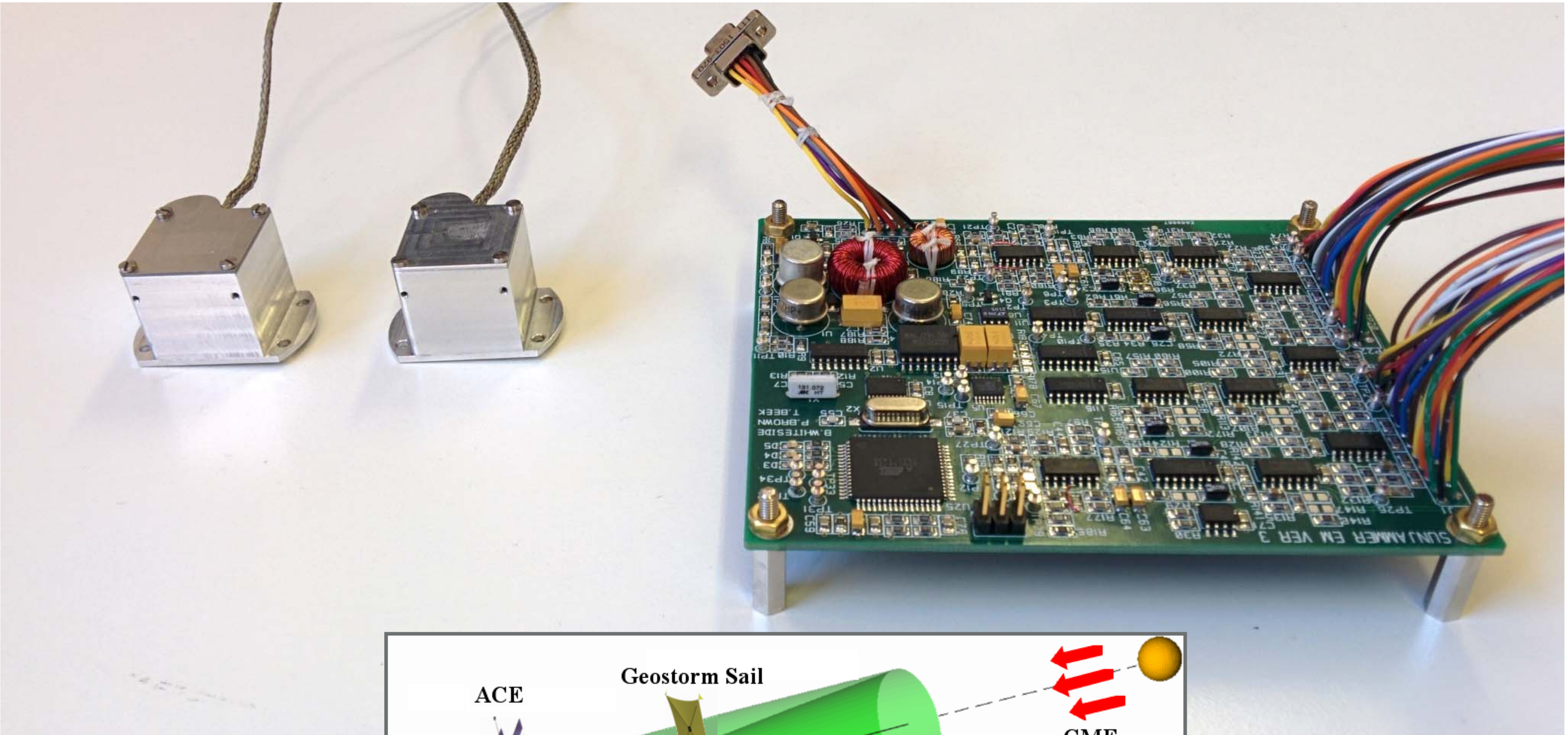
Archer et al., Ann. Geophys., 2015

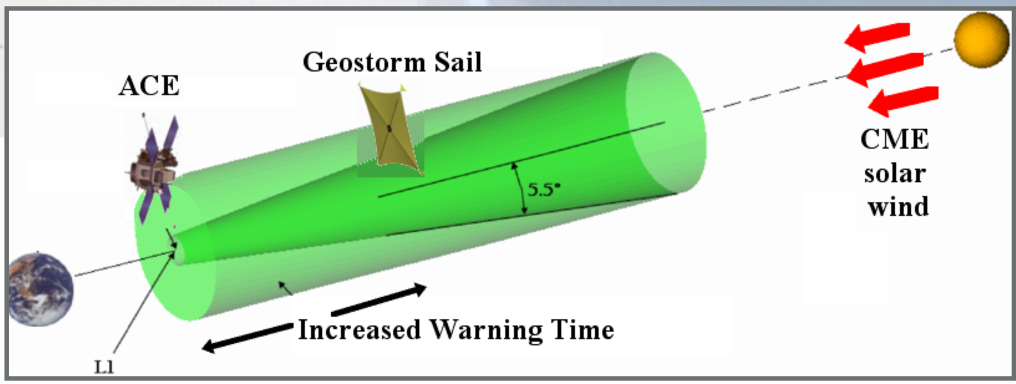
Magneto-Resistive magnetometer sensor technology





Sunjammer Engineering Model





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Designing a magnetometer: step 3

Instrument concept

- Fully redundant: duplicate electronics and two sensors
- Sensors located in a magnetically clean and quiet environment
- Operational requirements for minimal data latency are more stringent than science requirements (where a delay of months for calibrated data can be acceptable)
- **Place the sensors on a (long) boom**

Designing a magnetometer: step 4

How long should the boom be?

- Important to note that the instrument provider does not define the boom length!
- A requirement on the magnetic environment at the sensor is placed which the spacecraft manufacturer must meet
- Key issue: **real time operations**. We cannot spend 1 year decontaminating the data (e.g. Venus Express)
- Therefore a longer boom may be needed than is the case on a science mission (and no other instruments on the boom!)

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The end result: Magnetometer (MAG) technical details

- Operational = continuous data flow 24/7 for more than 10 years
- Concept: fully redundant dual sensor fluxgate
- Here uses same sensor and drive electronics as Solar Orbiter: maximises heritage
- Radiation tolerant, undergoing qualification
- Meets and far exceeds measurement requirements
- Very high reliability and heritage

Instrument capabilities	
Measurement	|B|, Bx, By, Bz
Time resolution	1 vector/s
Measurement Range	± 0.1 – 100 nT / axis
Relative accuracy	0.1 nT
Absolute accuracy	1.0 nT

Instrument properties	
Power	6 W
Mass (inc. harness)	5.5 kg
Volume (electronics/ sensor)	16.5 x 16.5 x 17 cm 12.5 x 12.5 cm
Data rate	0.25 kbit/s
Instrument accommodation	Sensors mounted on s/c provided 5m boom
Thermal environment (operational/ non-op.)	-80degC to +70degC -120degC to +90degC

Summary

- In situ measurements off the Sun-Earth line are crucial to understand the properties of the solar wind for operational space weather purposes

- The magnetic field is a crucial measurement:
  - Geoeffective structure (SIRs, CIRs)
  - Data assimilation into forecast simulation models (e.g. ENLIL; CME sheath regions)
  - Space weather at other planets?
  - NEOs

- Operational requirements are different from science requirements
  - They are not easier to meet (require a cleaner magnetic environment)
  - They are not necessarily cheaper to meet (high reliability, long lifetime)

- High heritage instrumentation from top-level science missions means that magnetic field instruments are ready and available for operational deep-space space weather missions.