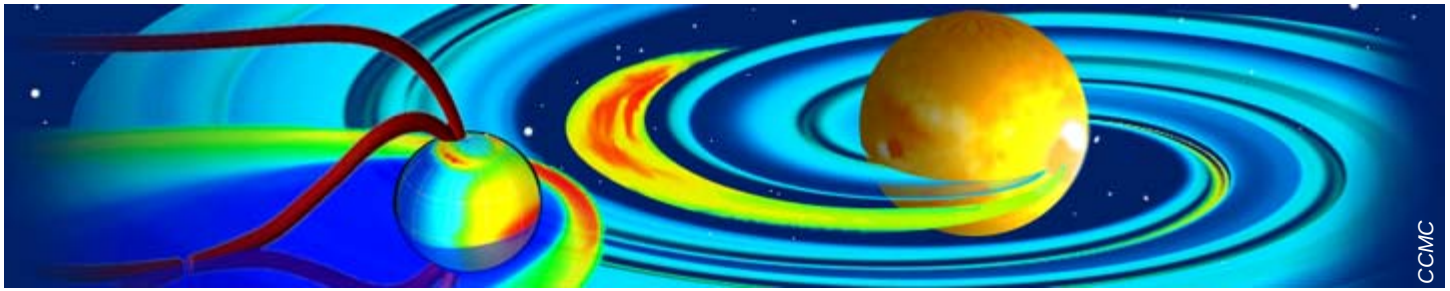
centre for fusion, space and astrophysics

CFSA

THE UNIVERSITY OF WARWICK

Signatures of Outflowing Transients Adjacent to the Heliospheric Current Sheet

Multi-spacecraft Observations



Claire Foullon *(1,2)*

In collaboration with:

B. Lavraud*(3)*, **C.J. Owen***(2)*, **A.N. Fazakerley***(2)*, **R.M. Skoug***(4)*

(1) Univ. Warwick, UK, (2) MSSL/UCL, UK, (3) CESR/CNRS, France, (4) LANL, NM USA

With thanks to: **PIs from STEREO, ACE, Wind and Cluster**

The HCS passage near Earth is a relatively well predicted recurring phenomenon, but…

Two properties:

1) Structured HCS

2) Main orientation can be highly distorted *[e.g. Villante et al., 1979]*

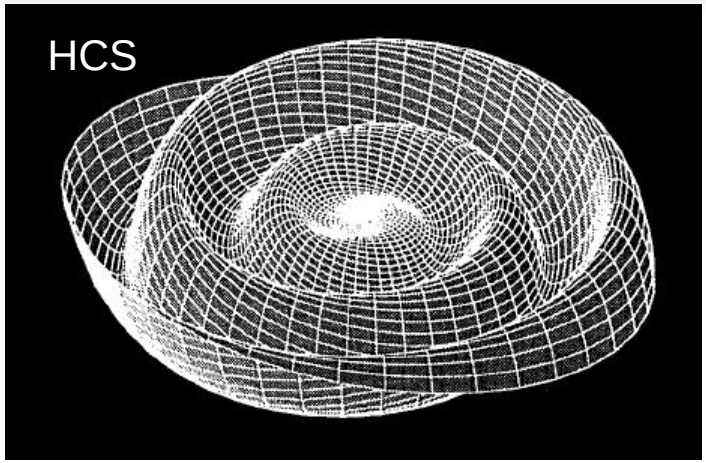
Main new results (with STEREO & multi-s/c):

(1) Substructures caused by outflowing transients

(2) Distortions likely related to those transients

What are the in-situ signatures of those transients?

Motivations



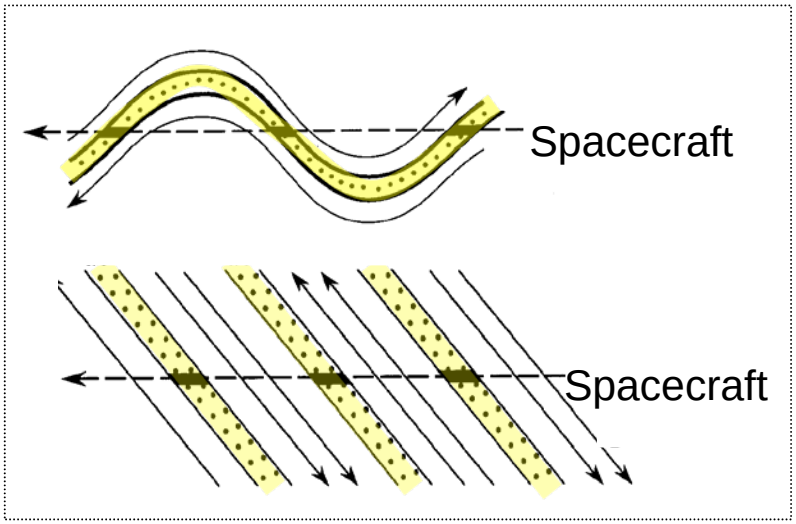
[Jokipii and Thomas, 1981]

Multiple current sheet crossings in the solar wind

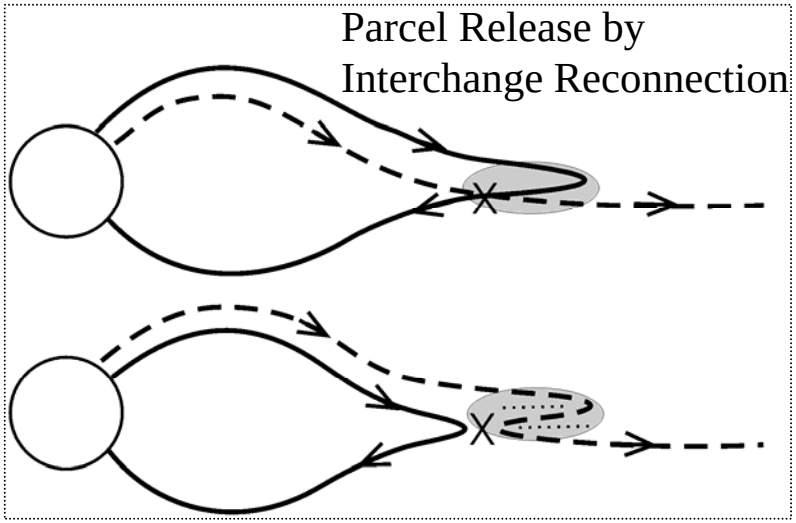
- High-beta plasma sheets
- Passage of the HCS

Multiple crossings near the HCS:

- Waves?
- Multiple current sheets?



[Smith, 2001]

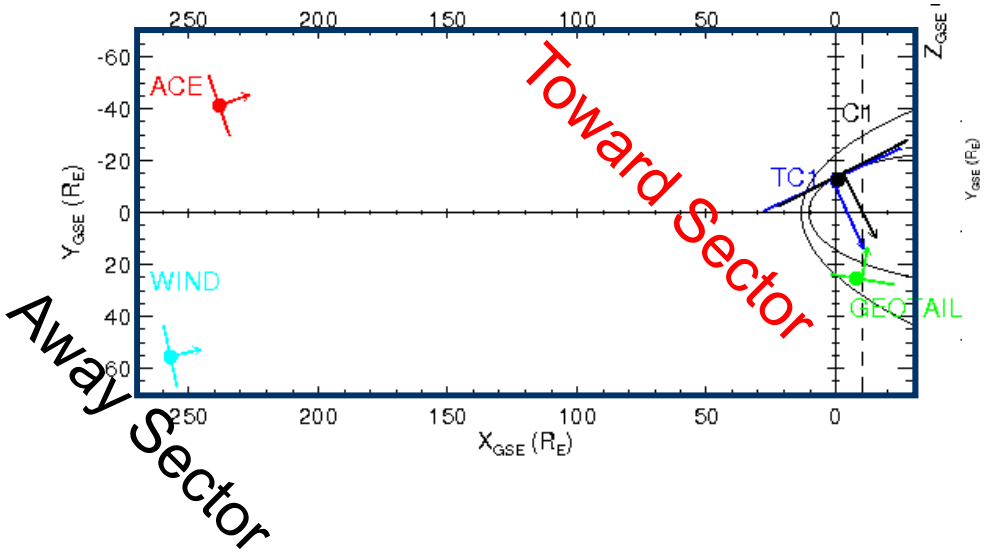


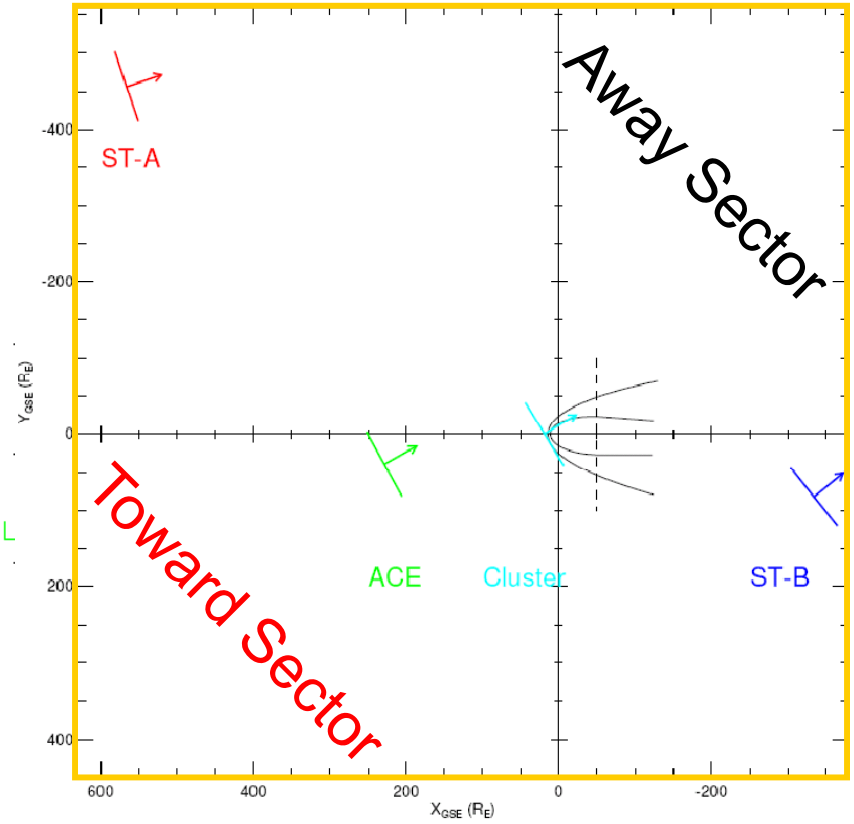
[adapted from Wang et al. 1998, modified by Crooker et al. 2004a]

Crooker et al. (2004a): interchange reconnection creates field inversions

Multi-spacecraft studies of HCS substructures in the solar wind

Two complementary sector crossings during the recent solar minimum



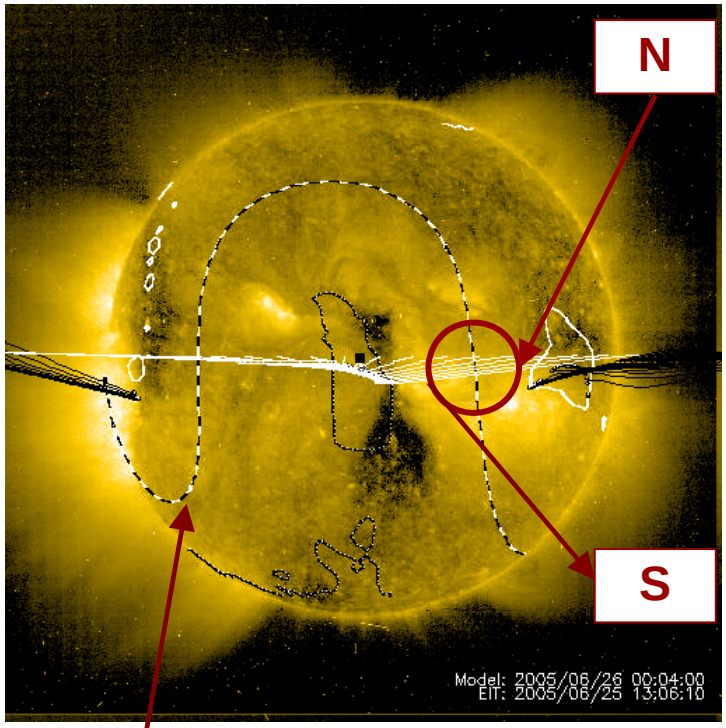


June 27, 2005 HCS: 2 s/c near L1, 96 R_E across the Sun-Earth line: Wind and ACE (+ 3 s/c in the nightside magnetosheath).

March 04, 2007 HCS: good spatial and cross-scale coverage, spanning 550 R_E across and 900 R_E along the Sun-Earth line: ST-A,-B, ACE, 4 Cluster.

Multi-spacecraft studies of HCS substructures in the solar wind

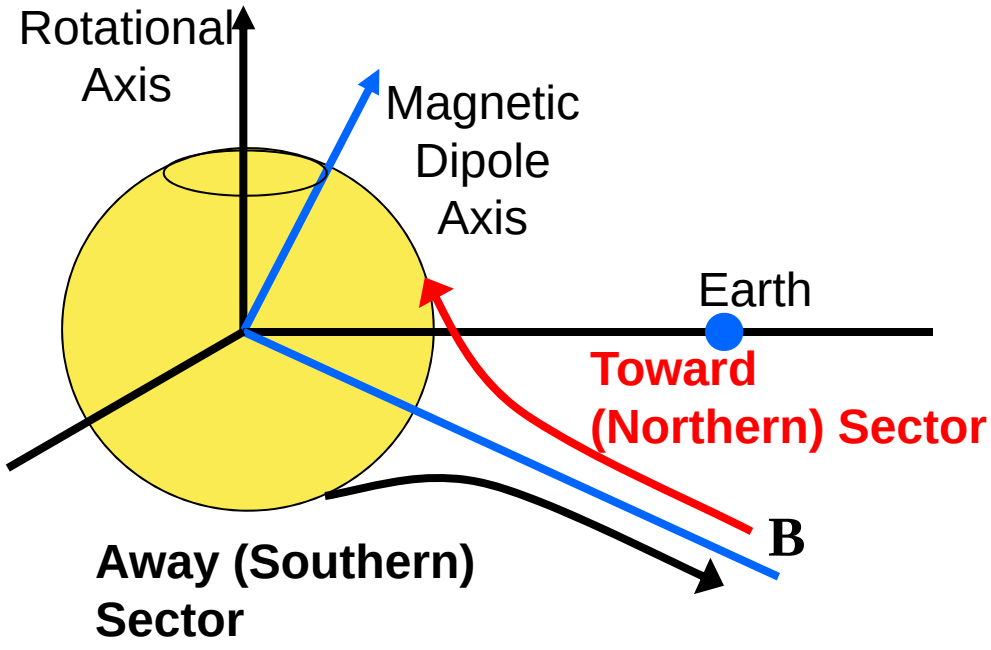
Two complementary sector crossings during the recent solar minimum



HCS

EIT 284 A 2005/06/25 13:06

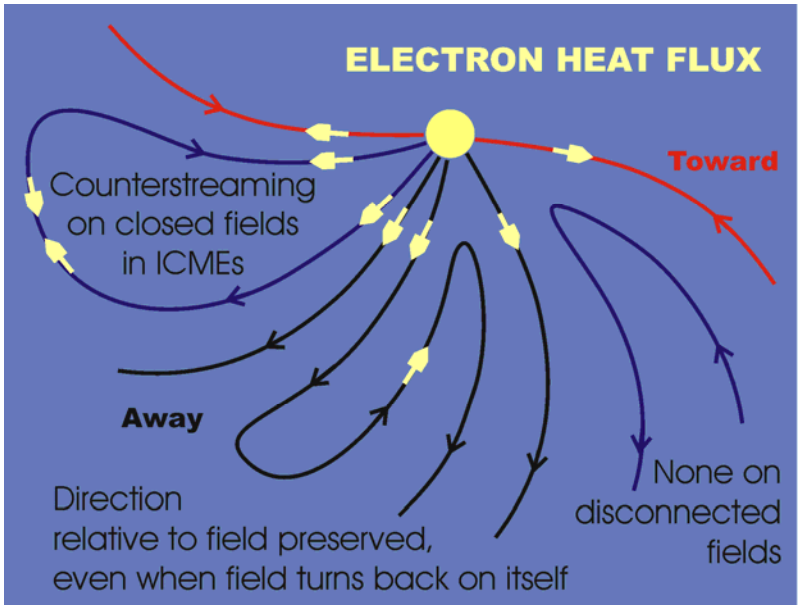
VSL Solar and Heliospheric Weather model

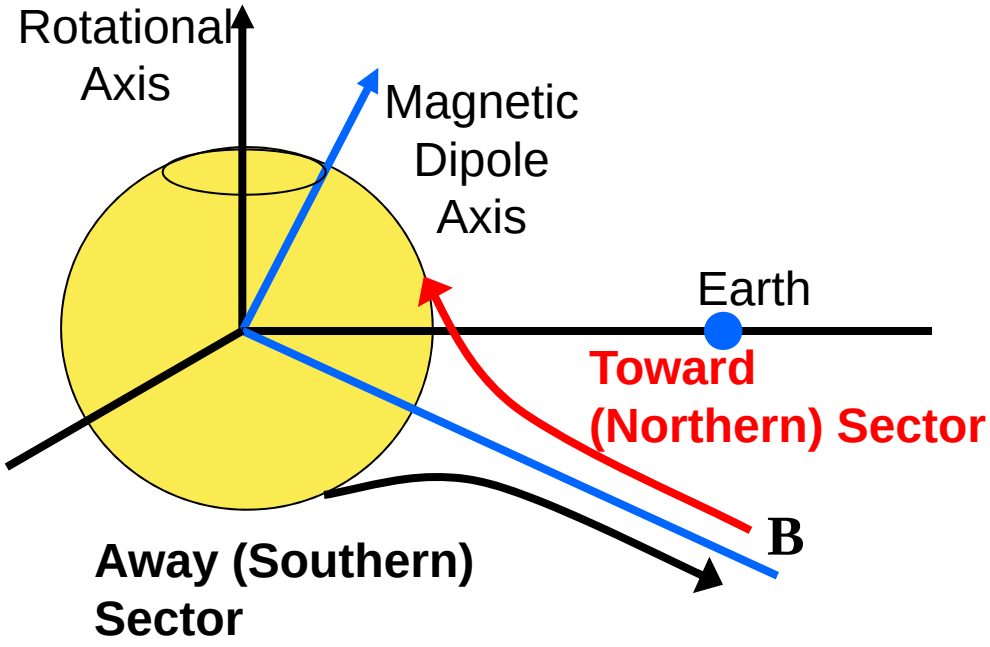


In this period near solar minimum, the **toward sector** (sunward IMF) is connected to the northern solar magnetic hemisphere, and the **away sector** (anti-sunward IMF) to the southern hemisphere.

Multi-spacecraft study of substructures in the solar wind

Attempt to resolve spatial scales and temporal variations

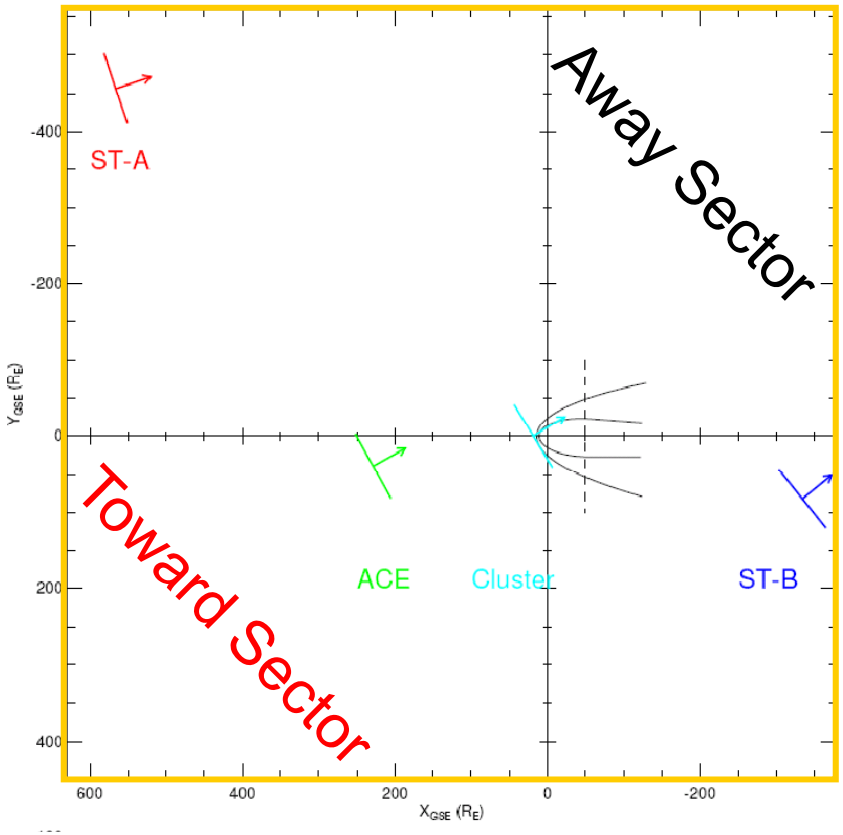




To correctly identify the HCS crossing(s), we use suprathermal electrons as sensors of magnetic topology.

Part I

March 04, 2007 HCS



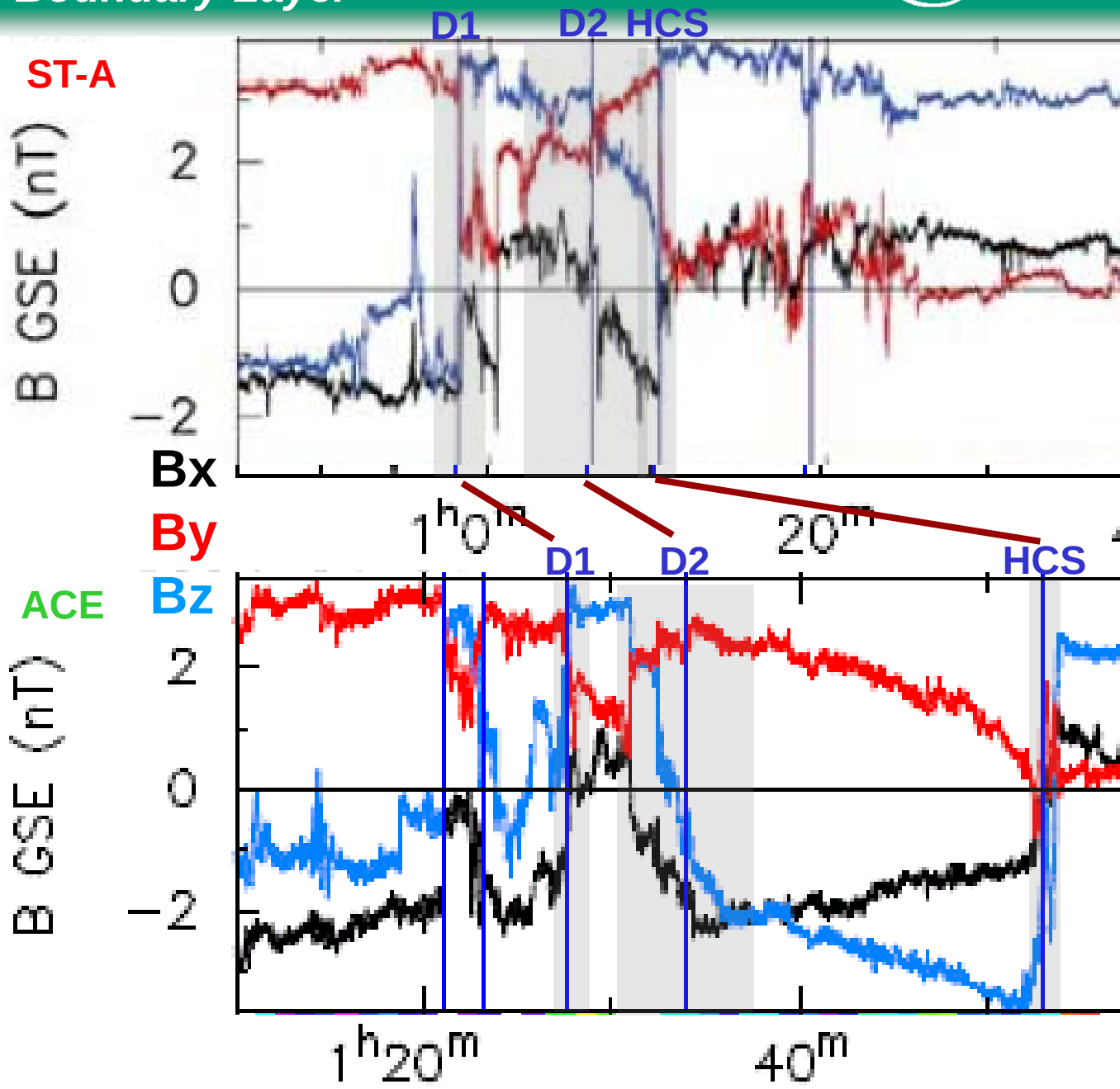
Foullon et al. 2009,
Solar Physics 259 (1), p. 389

Overview: Sector Boundary Layer

WARWICK

The leading edge of the sector boundary appears layered.

Two to four major magnetic field reversals are detected before the HCS, depending on the observing spacecraft.



Overview: Sector Boundary Layer

WARWICK

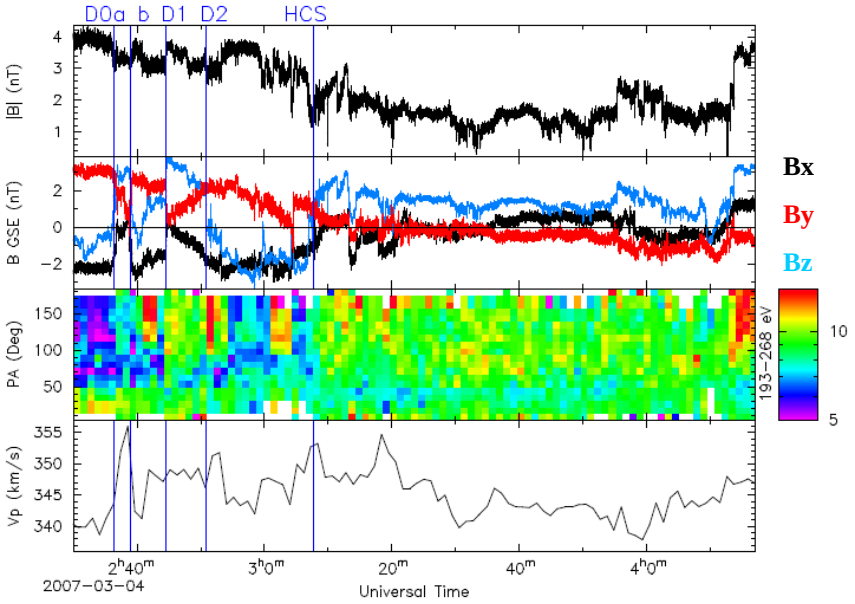
The leading edge of the sector boundary appears layered.

Two to four major magnetic field reversals are detected before the HCS, depending on the observing spacecraft.

Accelerated plasma within the field reversal regions: interpreted as Alfvénic fluctuations (B, V-components).

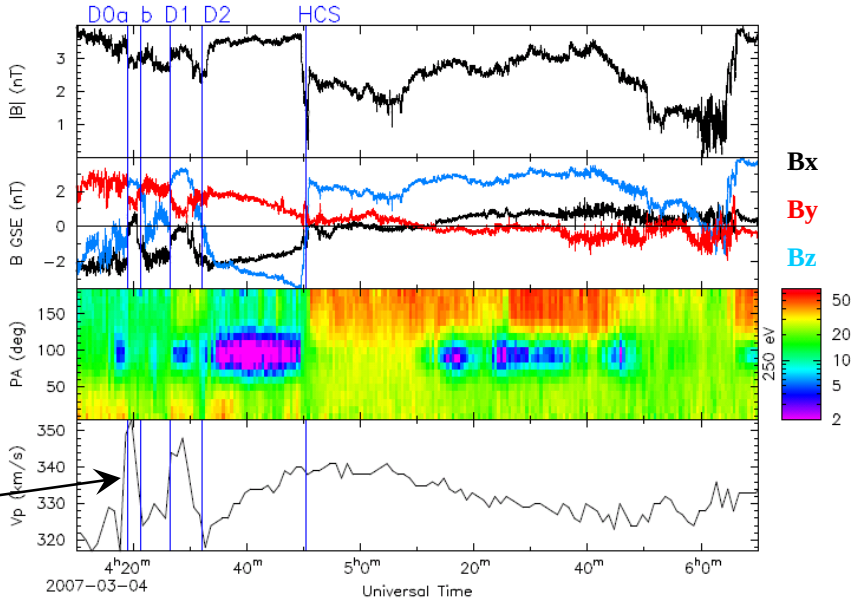
Cluster

Injections due to field-line connections to the bow shock



ST-B

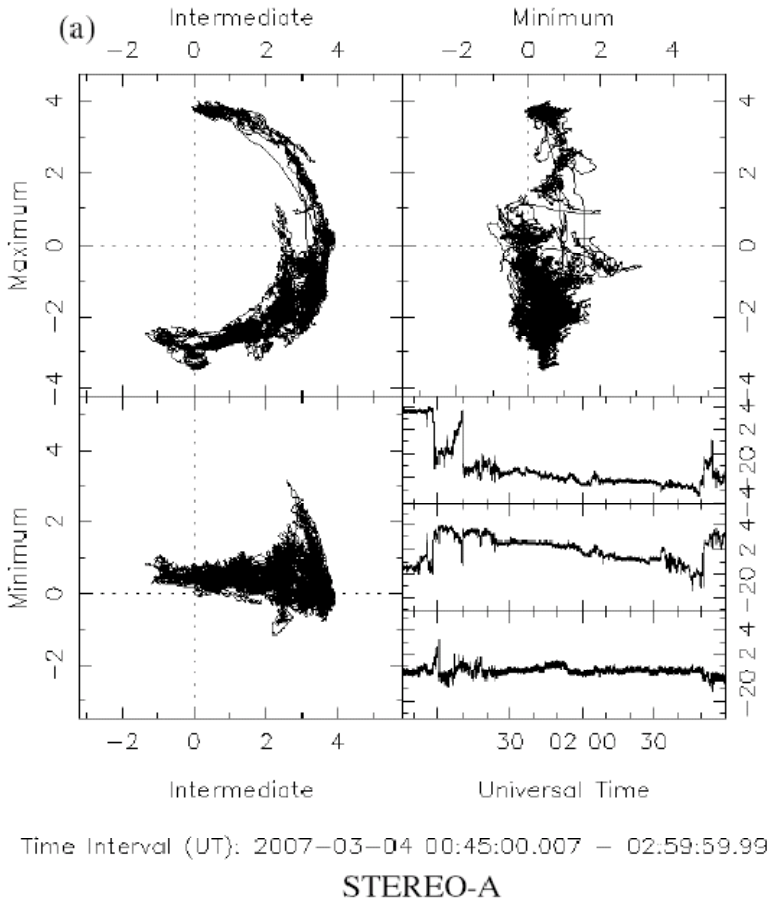
Ion foreshock (solar wind slowed down)



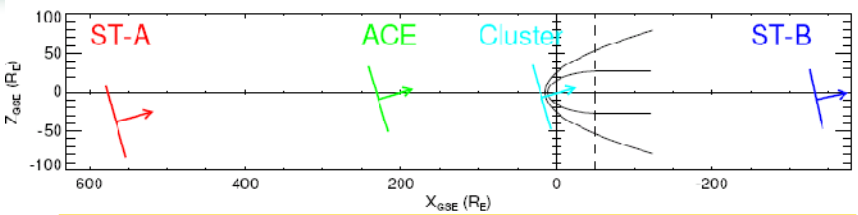
Analysis: A Layered Planar Structure

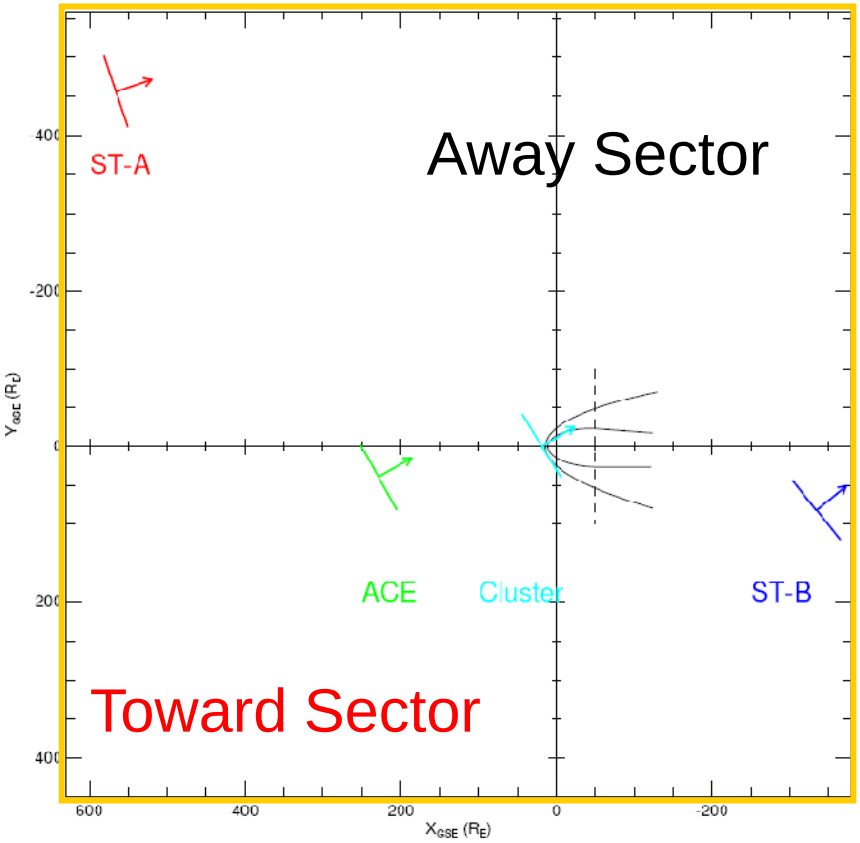
Orientation estimates of all current sheets using various analysis methods

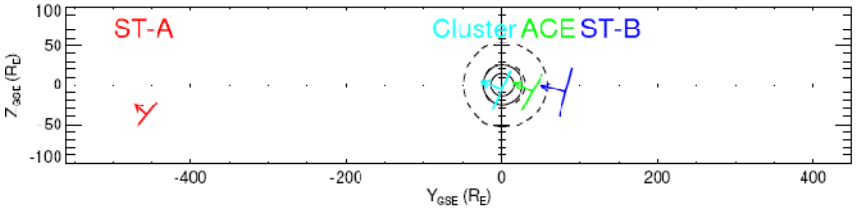
MVA, MVABN , Cross-product



SBL: planar structure







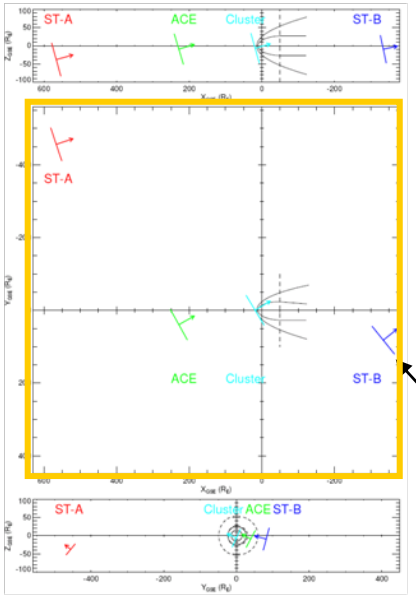
Analysis: A Layered Planar Structure

WARWICK

Orientation estimates of all current sheets using various analysis methods

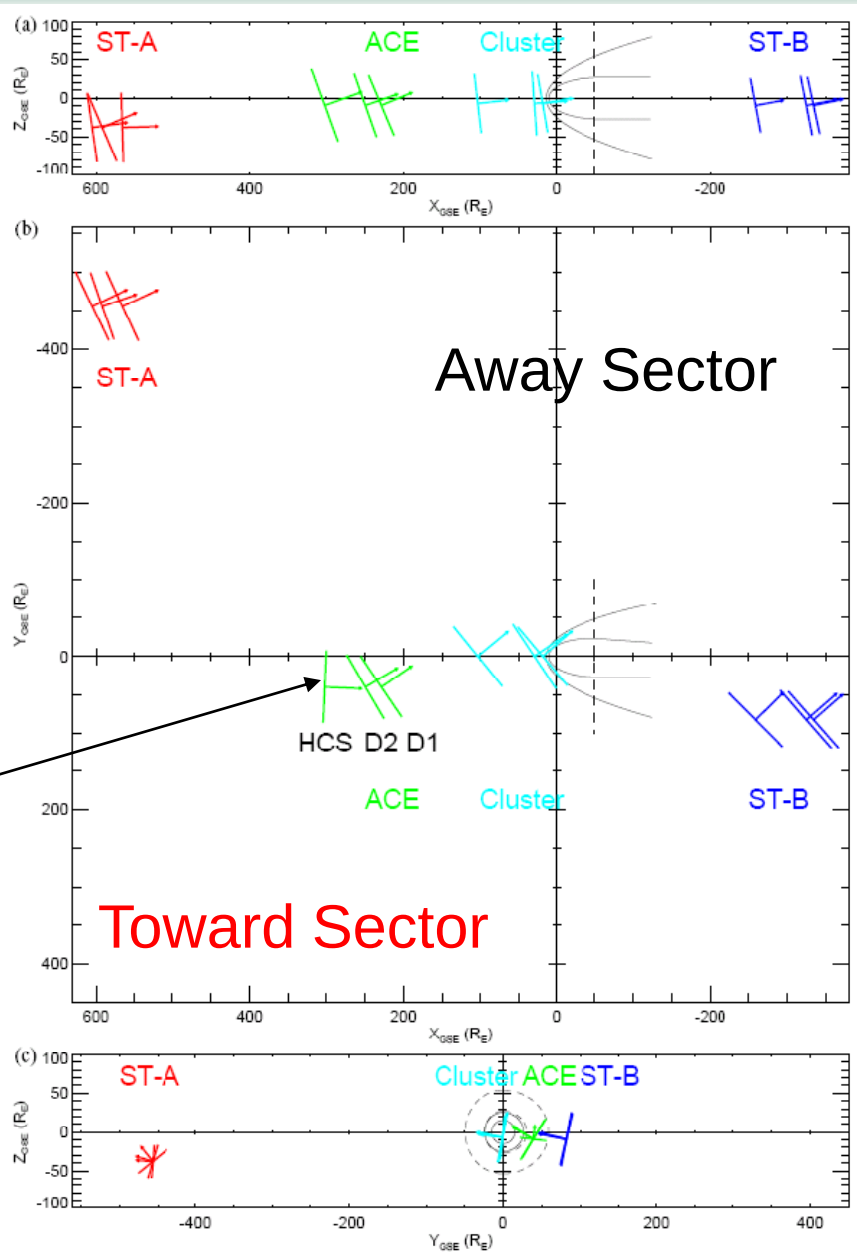
MVA, MVABN, Cross-product and 4-s/c discontinuity analysis (Cluster)

- a multi-layered current sheet structure, quasi-parallel to the HCS,
- embedded and curving together along the planar magnetic structure of the sector boundary.



Occasional deviations from the planar structure on the broad scale

SBL: planar structure



Discussion: Transient Outflowing Loops

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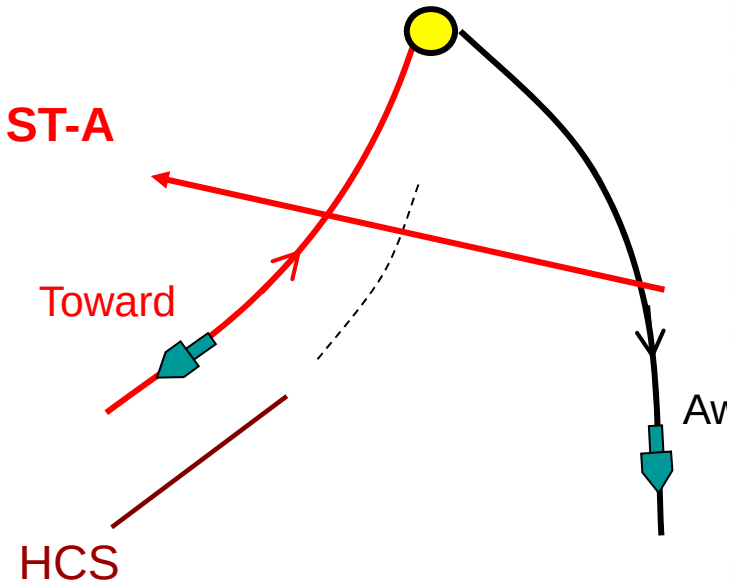
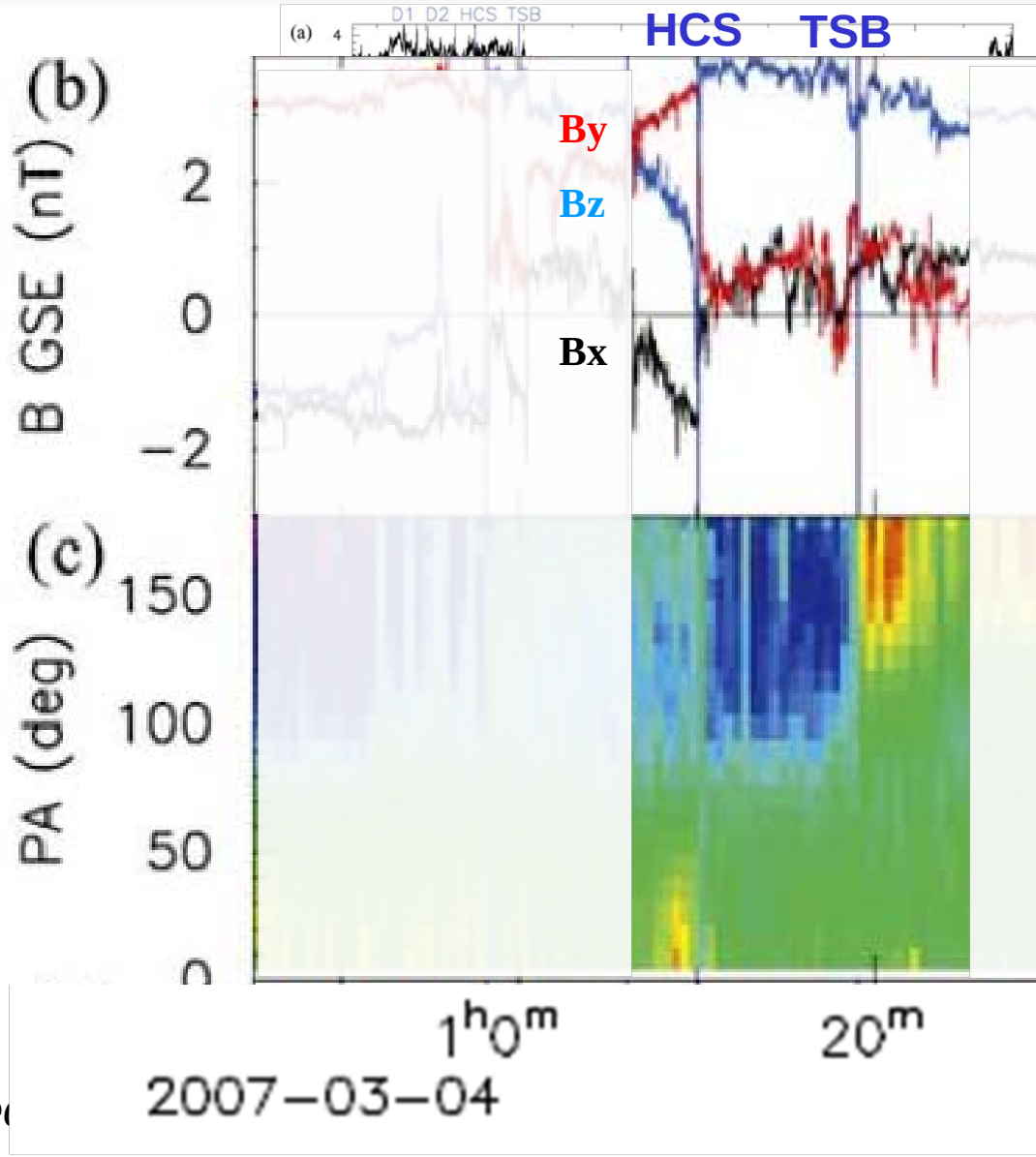
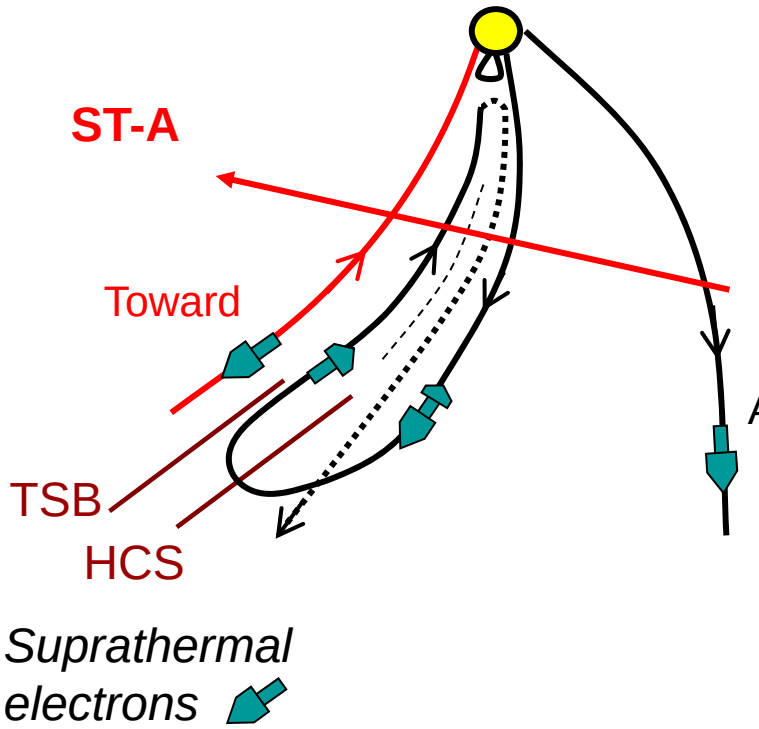


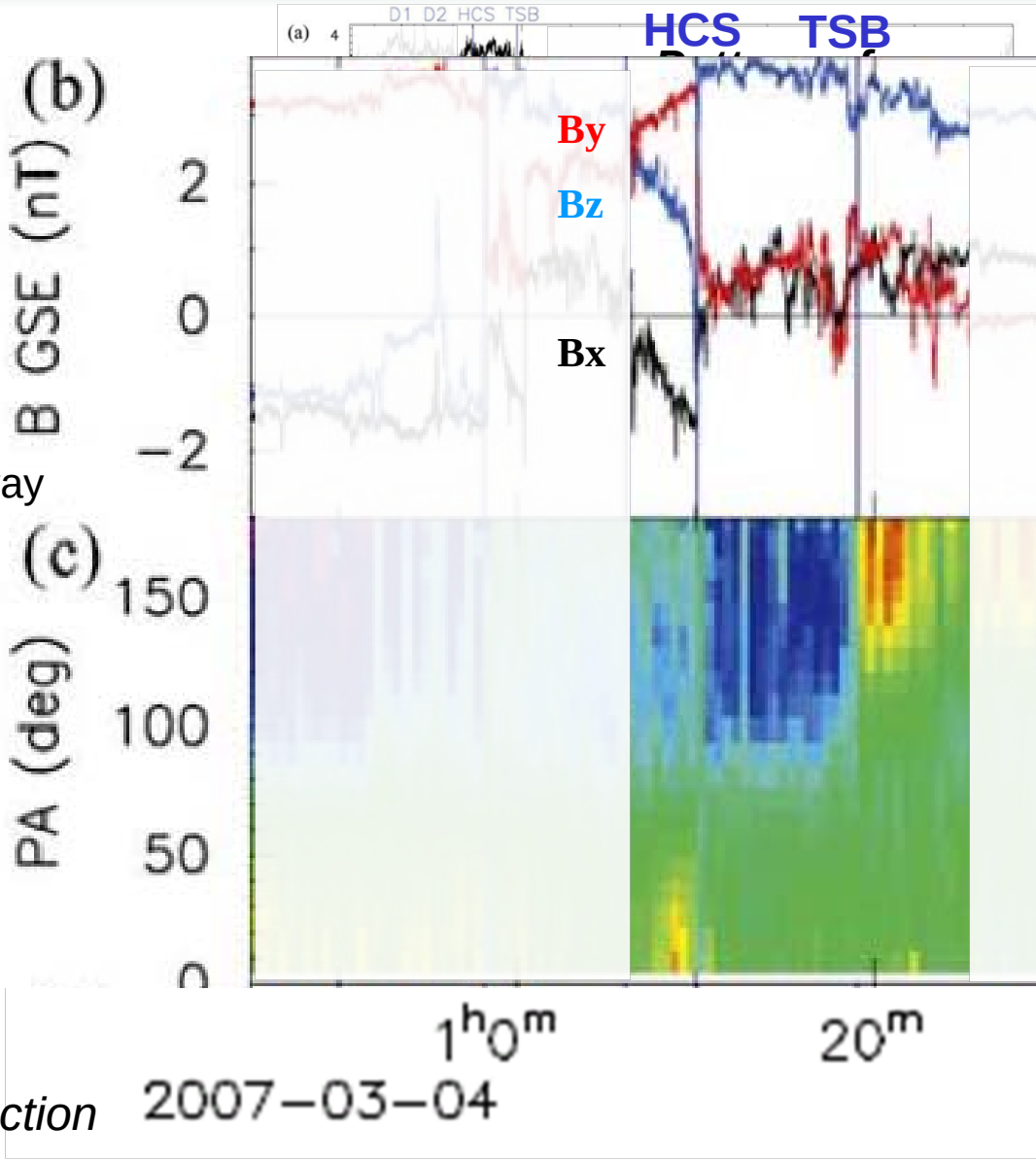
Suprathermal electrons



- *Simplified geometry: SBL cross-se*
- *Connection to the Sun as default*

Discussion: Transient Outflowing Loops

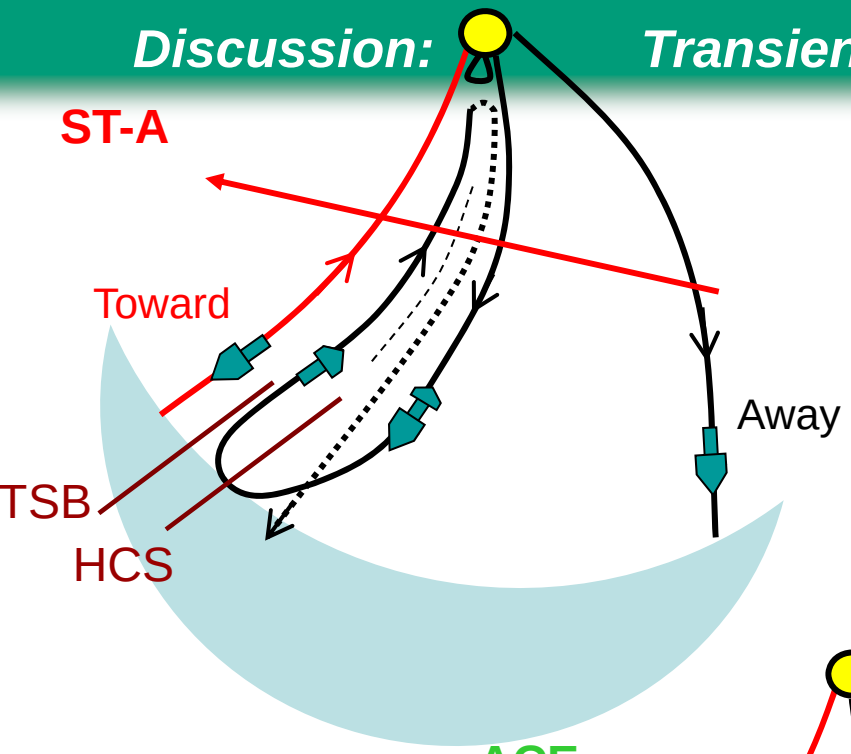


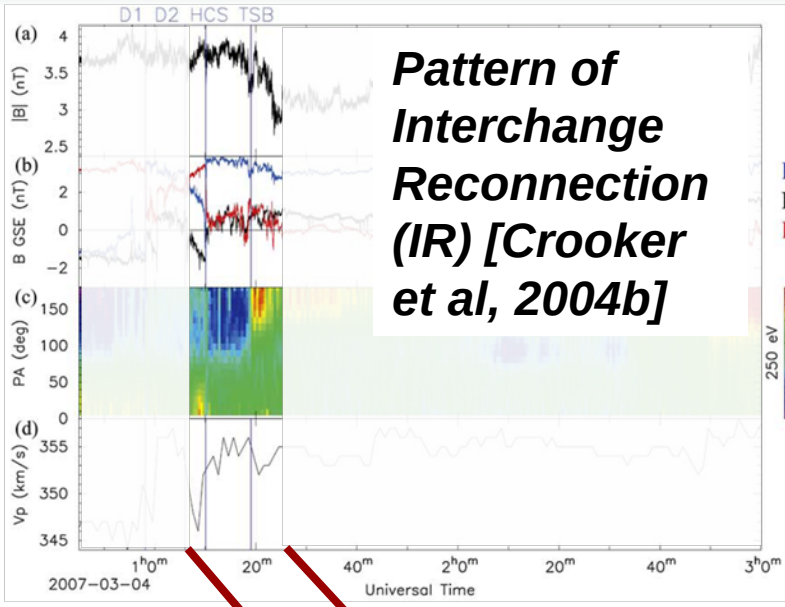


- *Simplified geometry: SBL cross-section*
- *Connection to the Sun as default*

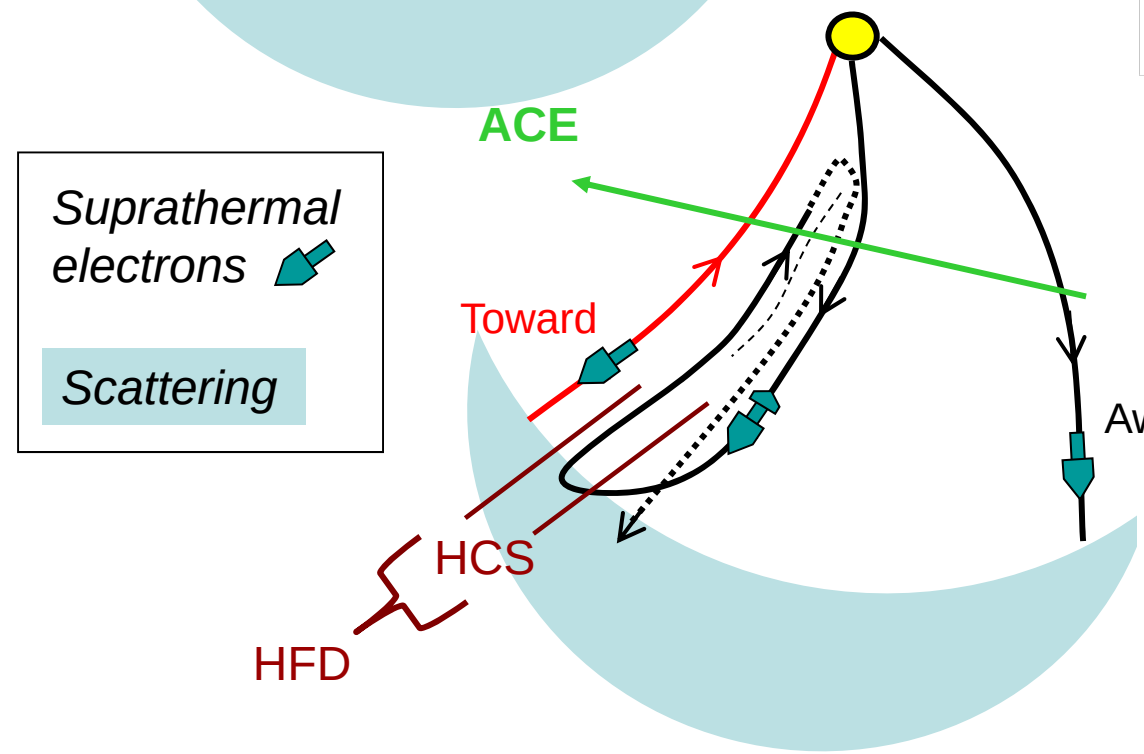
Discussion: Transient Outflowing Loops

WARWICK



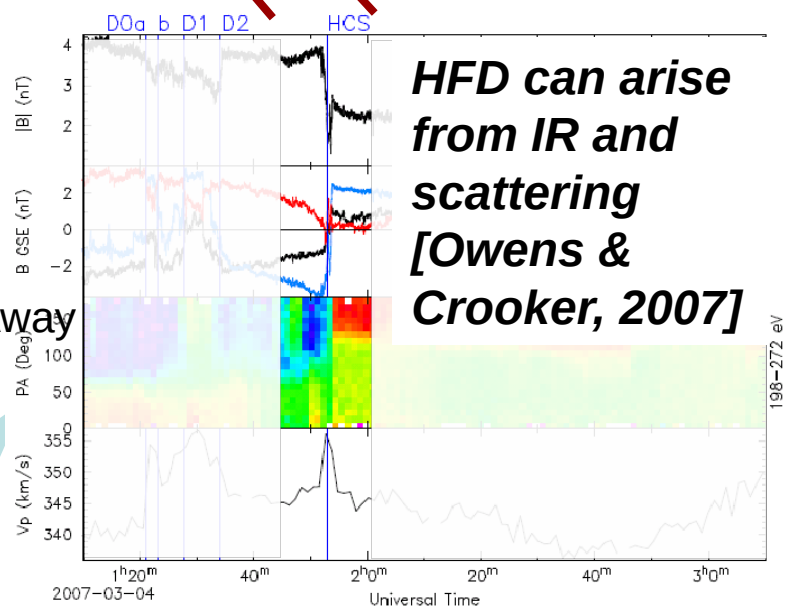


Pattern of Interchange Reconnection (IR) [Crooker et al, 2004b]



Suprathermal electrons

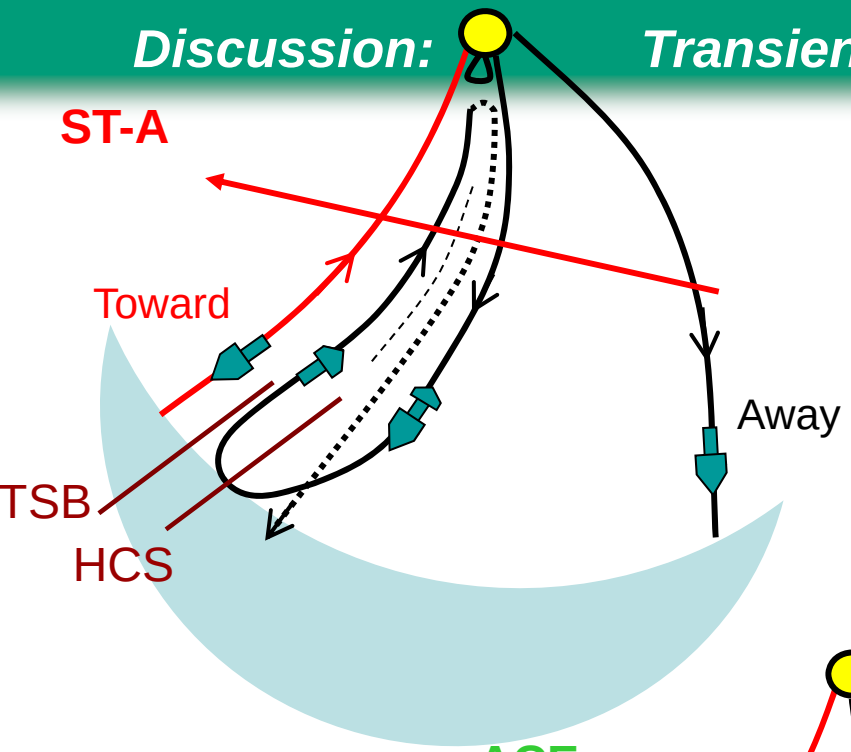
Scattering

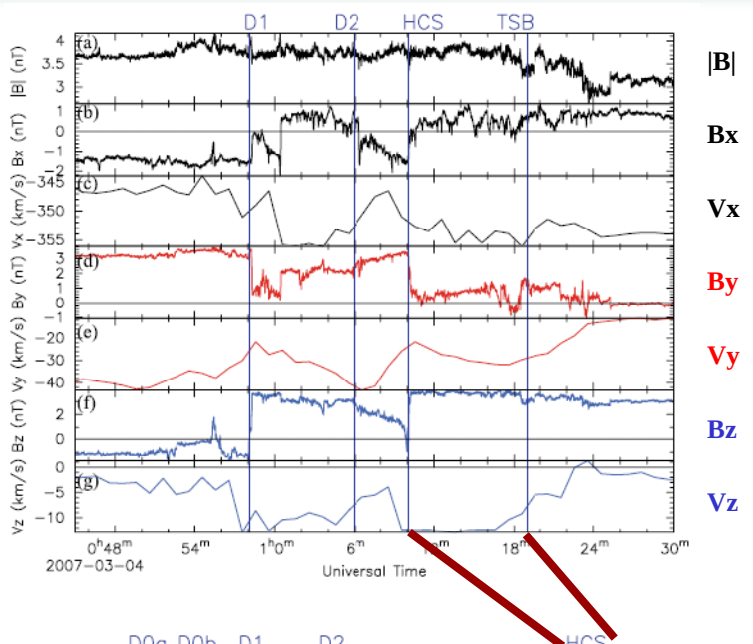


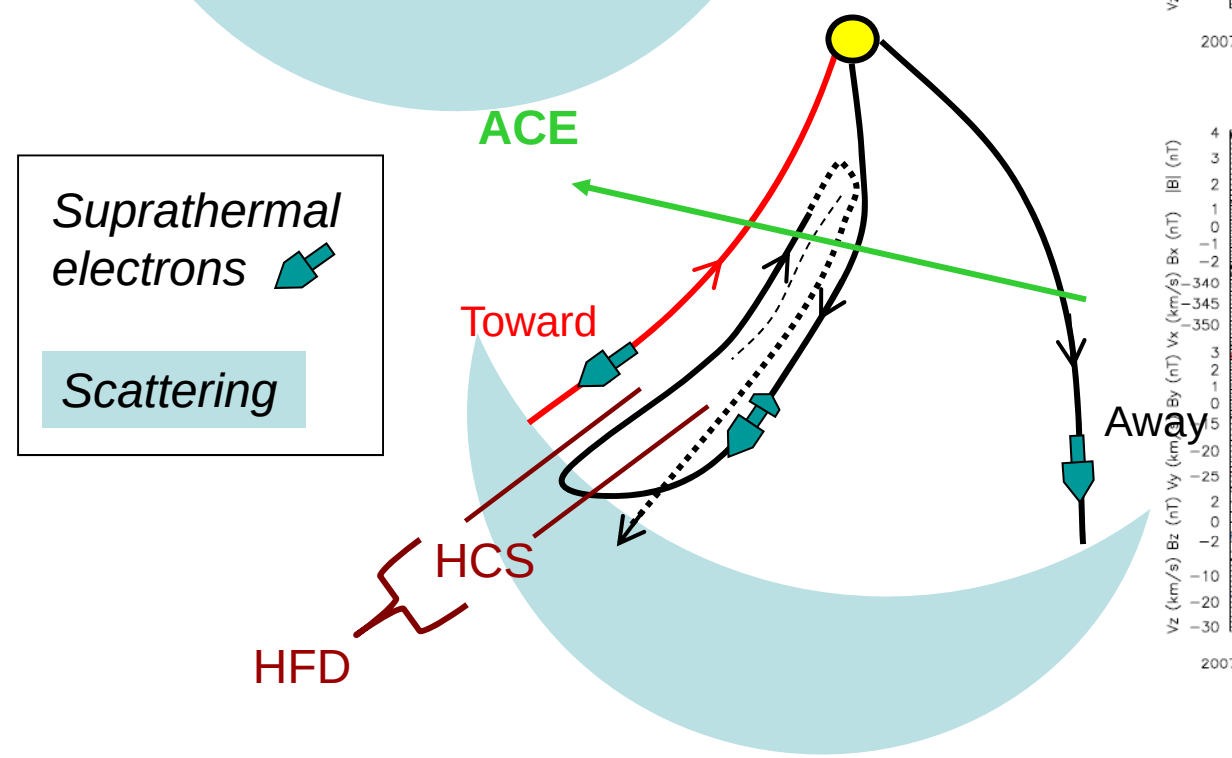
HFD can arise from IR and scattering [Owens & Crooker, 2007]

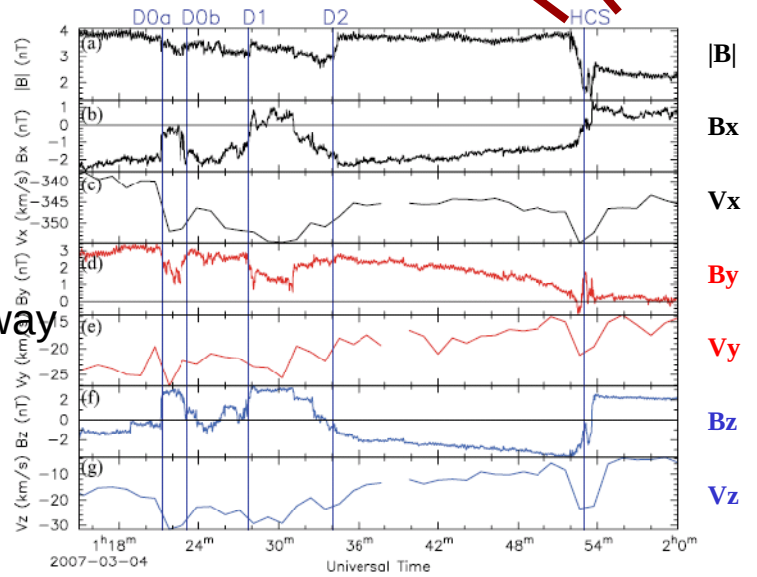
Discussion: Transient Outflowing Loops

WARWICK









Discussion: Transient Outflowing Loops

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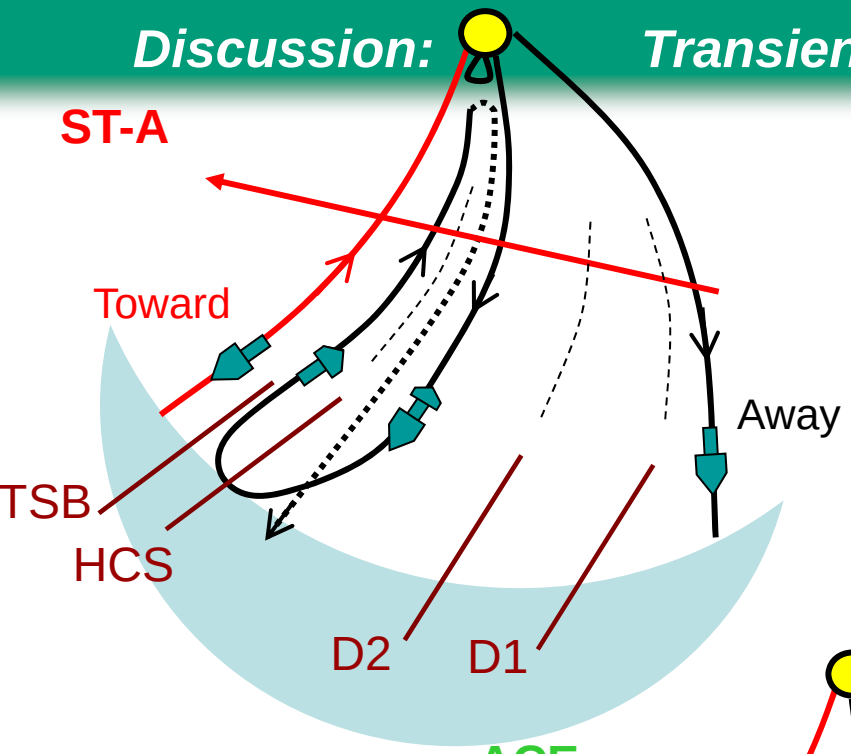
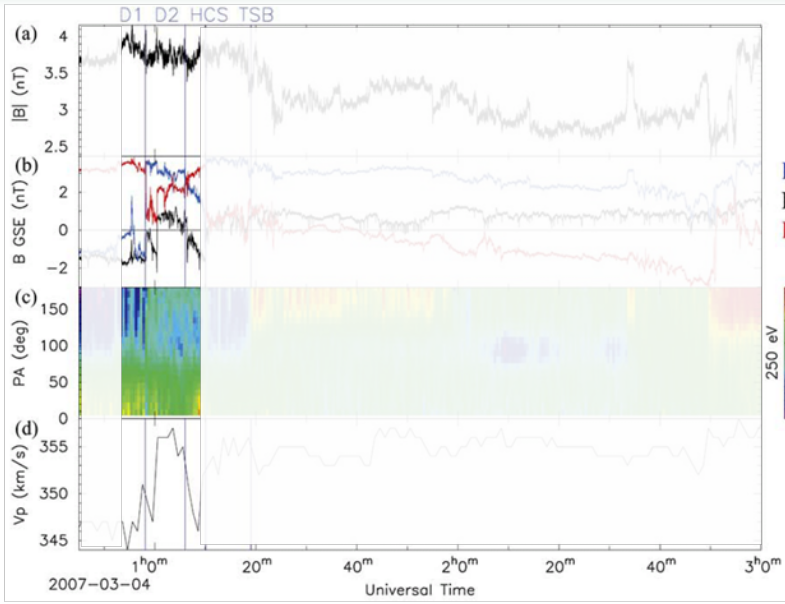
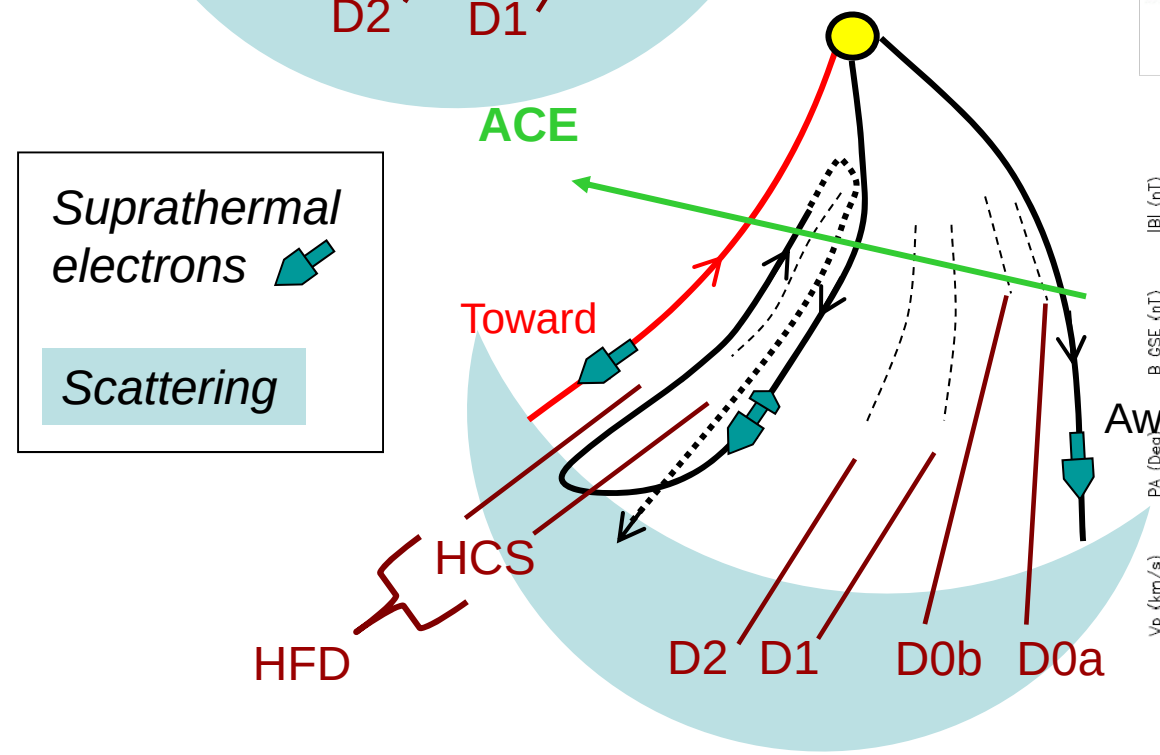
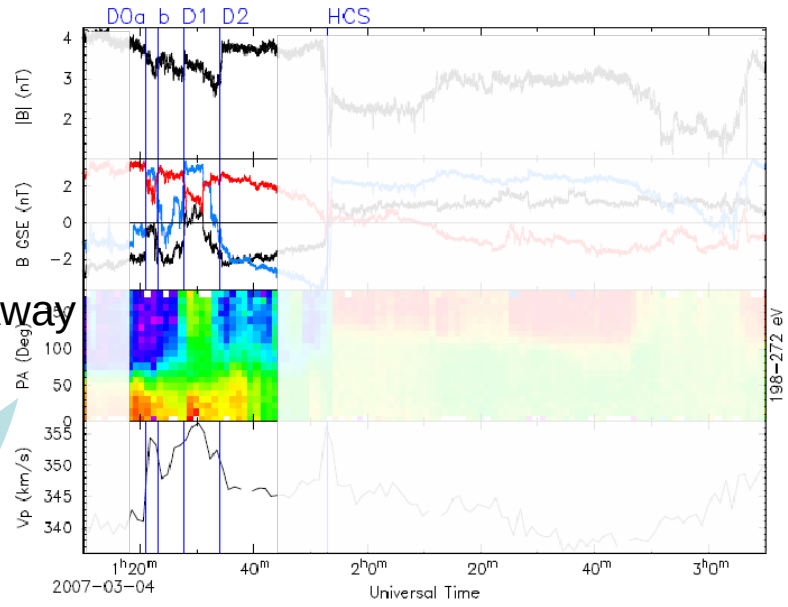






Suprathermal electrons

Scattering



Discussion: Transient Outflowing Loops

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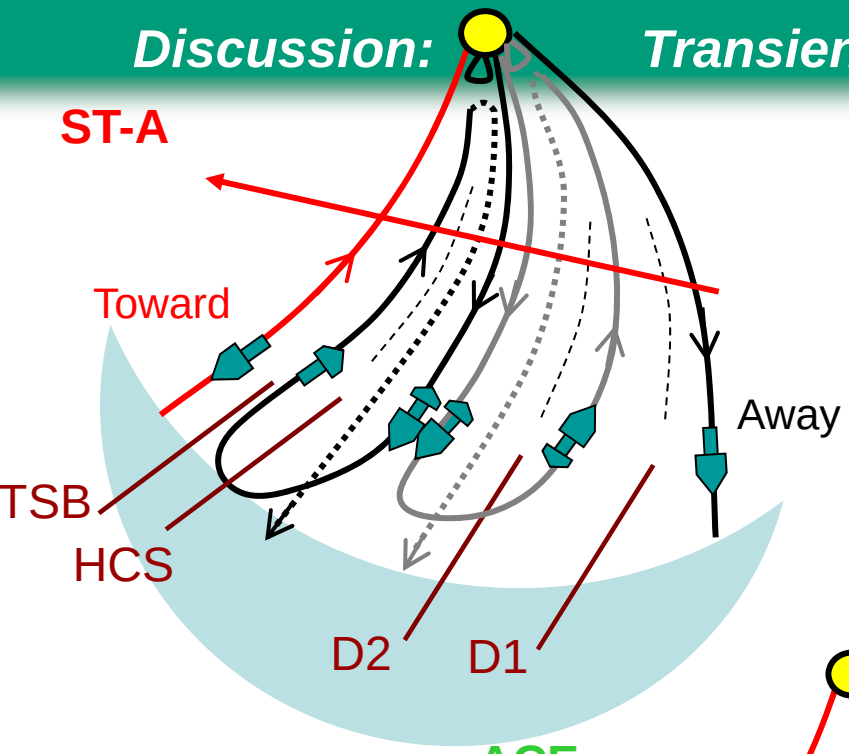
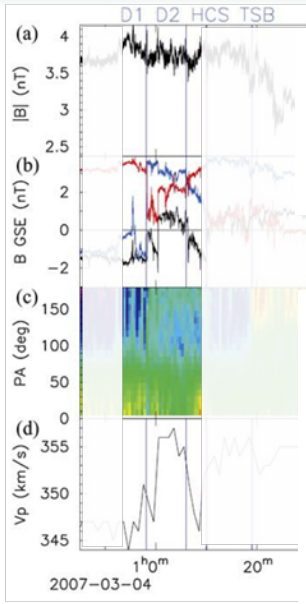


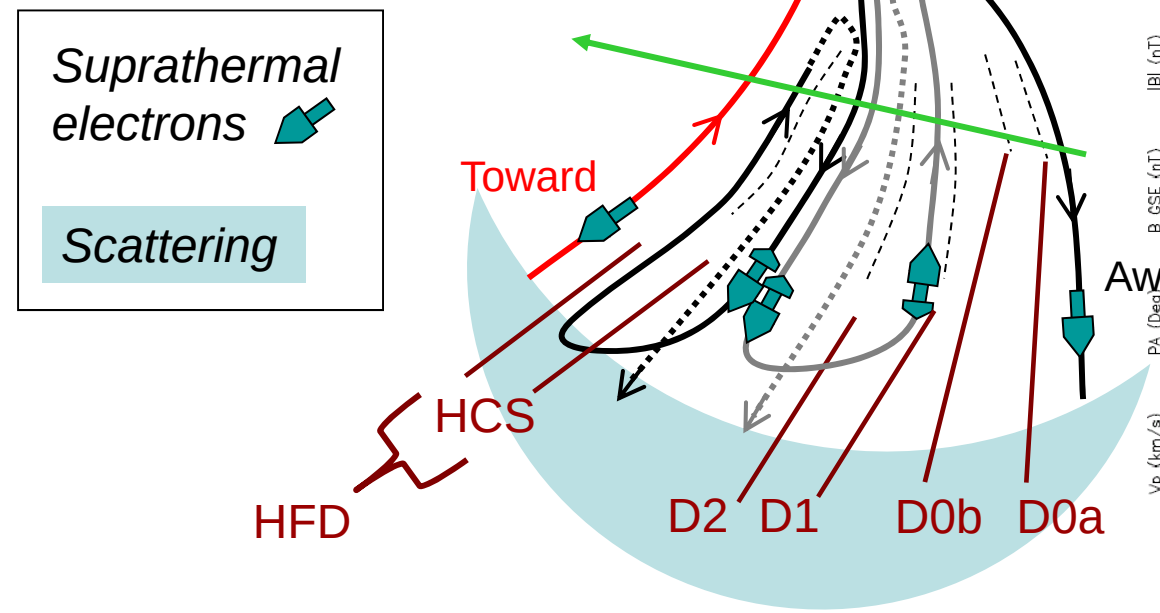


Another pattern of IR [Crooker et al, 2004b].

-Dominant 0˚ PA on both legs

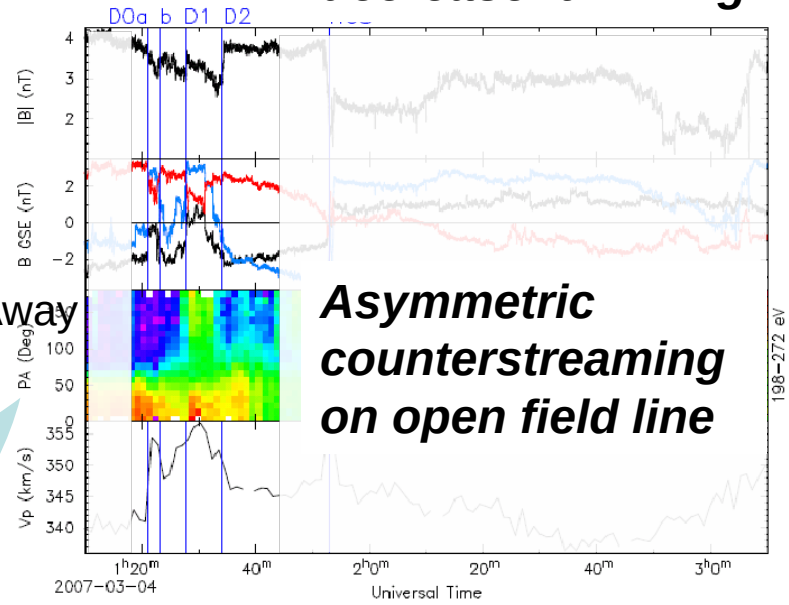
-Stronger Vz

-D1/D2 distance decrease: thinning



Suprathermal electrons

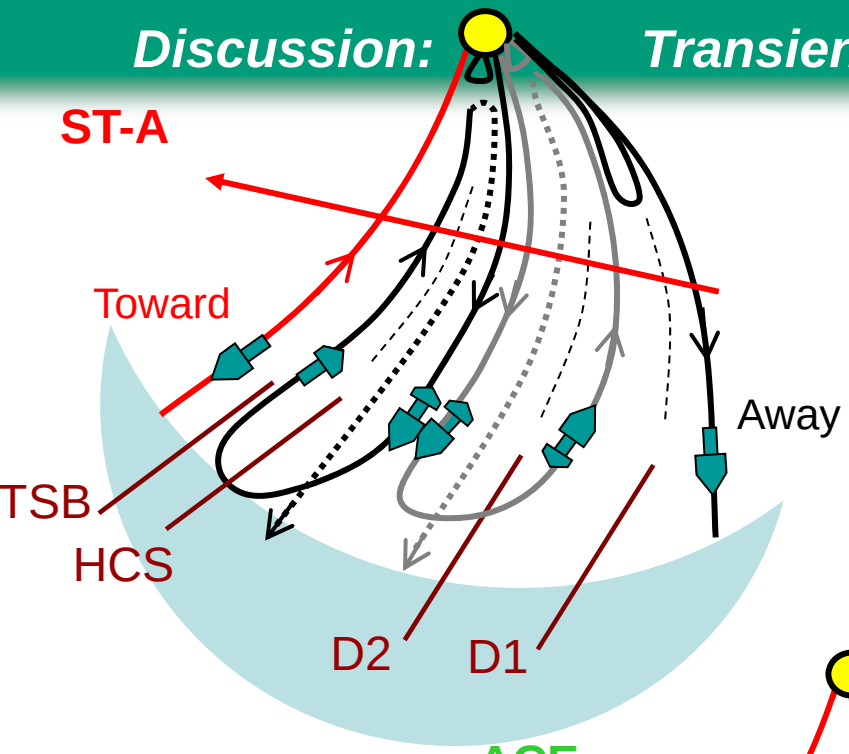
Scattering

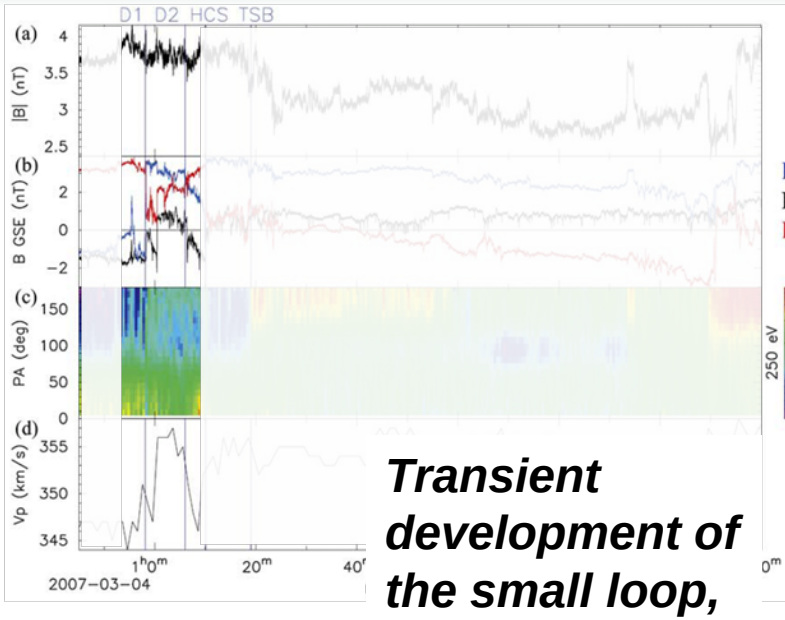


Asymmetric counterstreaming on open field line

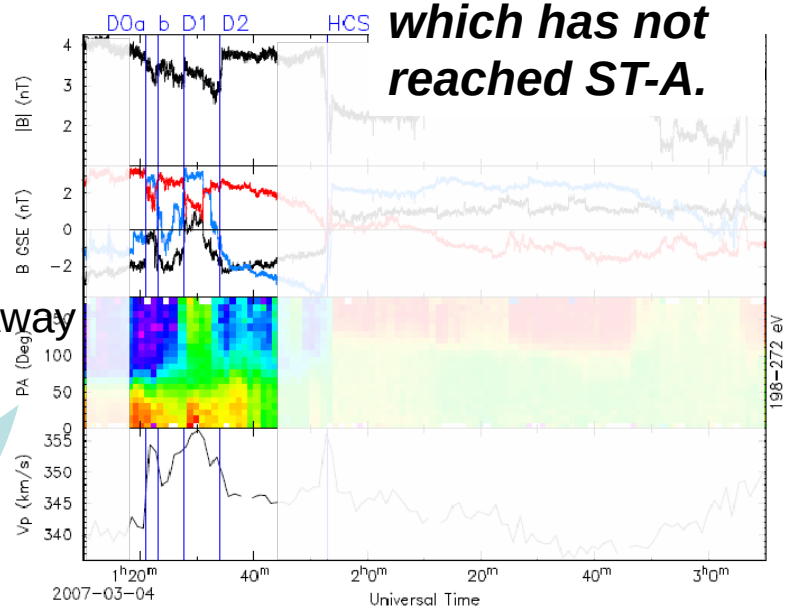
Discussion: Transient Outflowing Loops

WARWICK





Transient development of the small loop, which has not reached ST-A.



ACE

Toward

Away

HCS

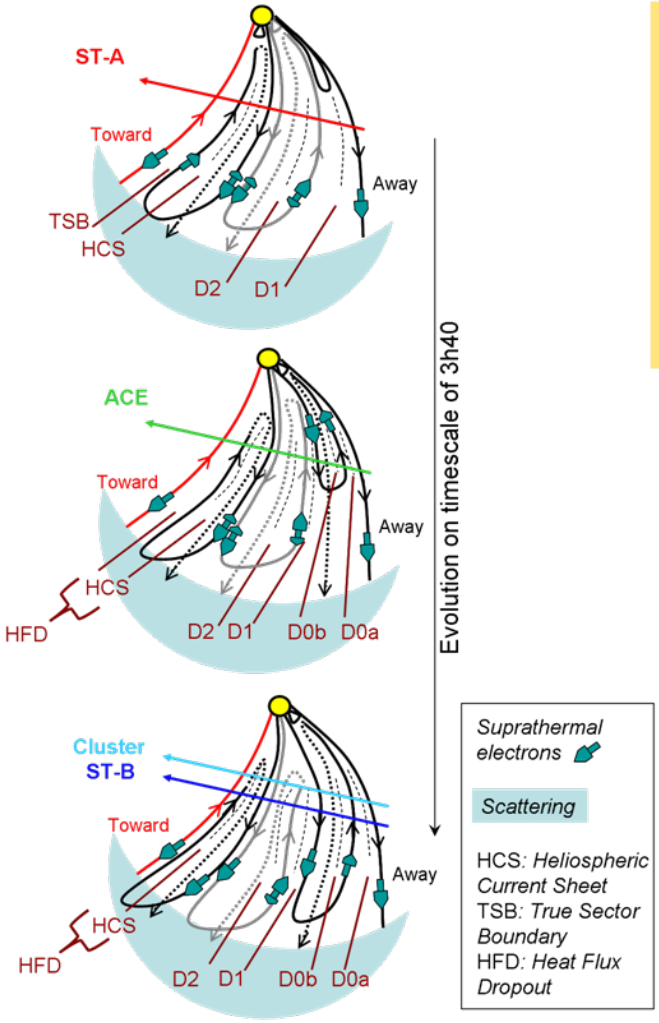
HFD

D2 D1 D0b D0a

Suprathermal electrons

Scattering

Part I Summary



Foullon et al. 2009,
Solar Physics 259 (1), p. 389

Thanks to the HCS, we can

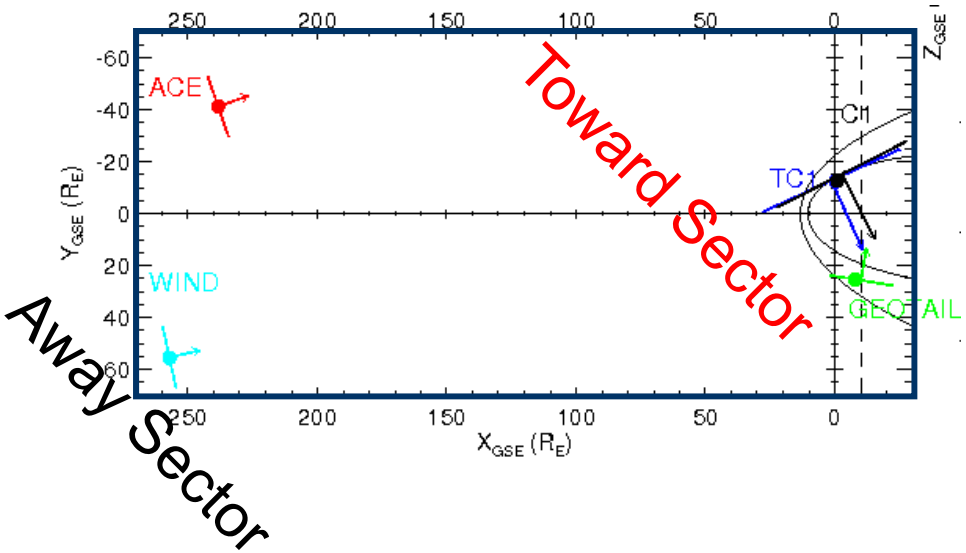
(1) relate in-situ multi-spacecraft observations

(2) demonstrate the link between the apparent layered structure of the sector boundary and slow solar wind transients.

- Overall a **steady** multi-layered structure;
- **Evolution** between stages of transient outflowing loops formed by interchange reconnection;
- **Circumstantial evidence** that a HFD can arise from interchange reconnection and scattering;
- **Inter-spacecraft comparison** of shear flows/Alfvénic fluctuations & asymmetric electron counterstreaming;
- **Fine substructures**: occasional non-planar structures on the Cluster spatial scale suggest a bunch of loops with variable properties.

Part II

June 27, 2005 HCS



Foullon et al. 2010, AIP Proc. Solar Wind 12, 1216, p. 367

Overview: Sector Crossing

The sector boundary (lower B) appears layered.

Three to four major magnetic field reversals are detected, depending on the observing spacecraft.

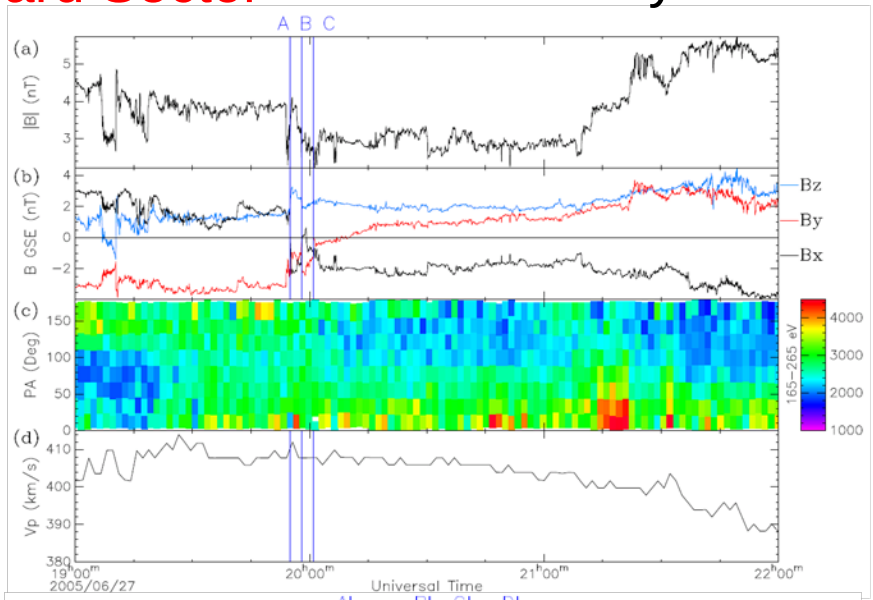
No substantial acceleration within the field reversal regions

Toward Sector

Away Sector

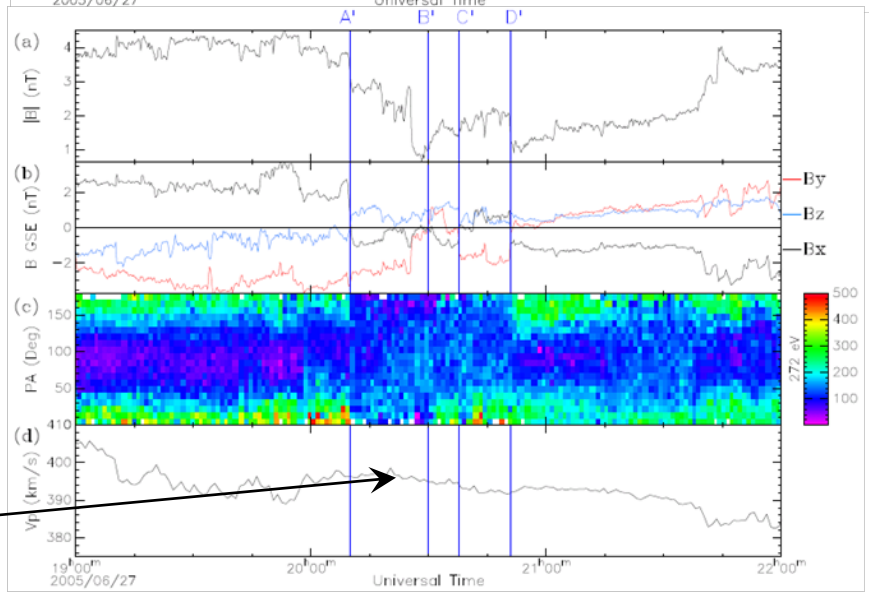
Wind

Before crossing: Northward IMF



ACE

Before crossing: Southward IMF, turning Northward after A' (same sign change at Geotail)



Overview: Sector Crossing

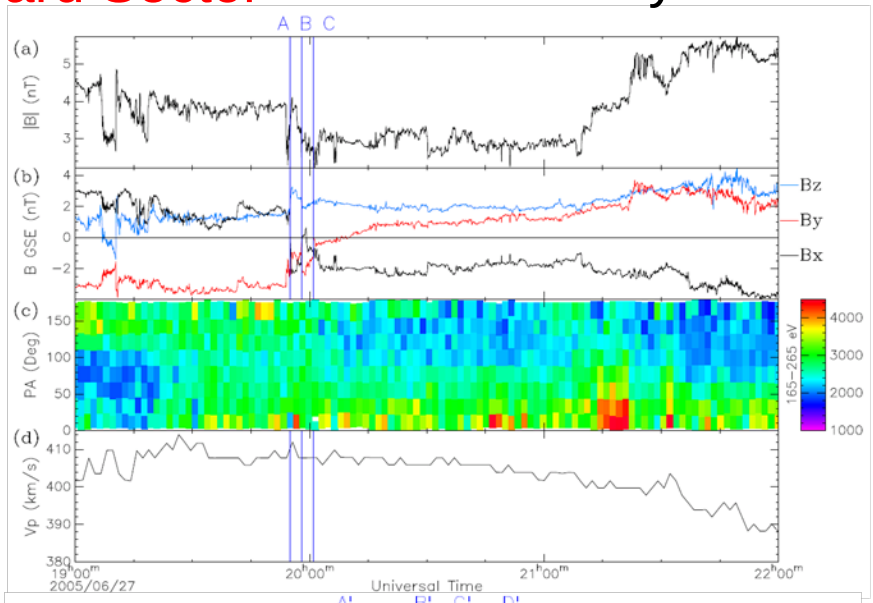
The sector crossing occurs within a HFD

No clear detection of the TSB

Wind

Toward Sector

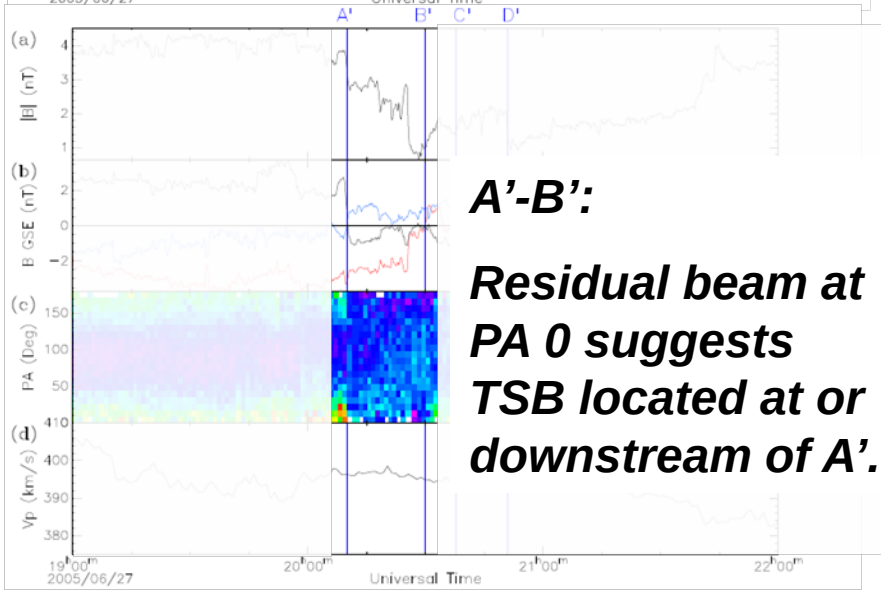
Away Sector



CS predominant downstream of A

ACE

Apparent CS due to depletions of plasma at 90° PA [Gosling et al, 2001], possibly over unequal halo populations [Crooker and Pagel, 2008]



A'-B':

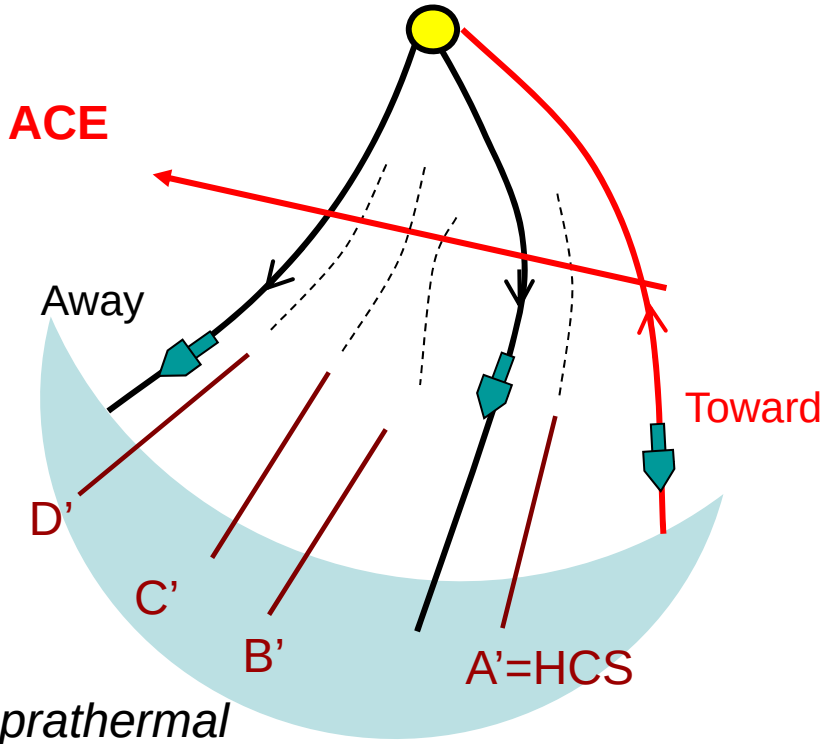
Residual beam at PA 0 suggests TSB located at or downstream of A'.

Overview: Sector Crossing

WARWICK

The sector crossing occurs within a HFD

No clear detection of the TSB

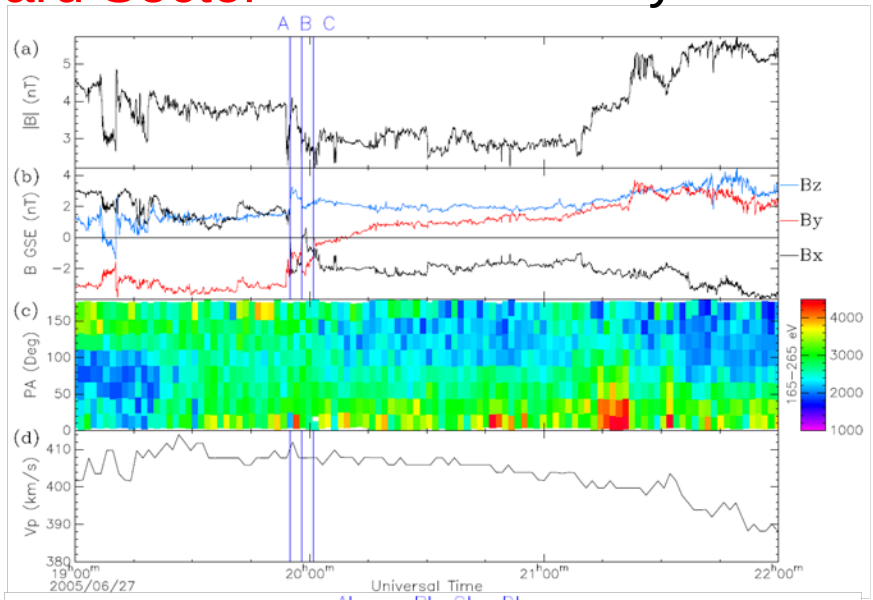


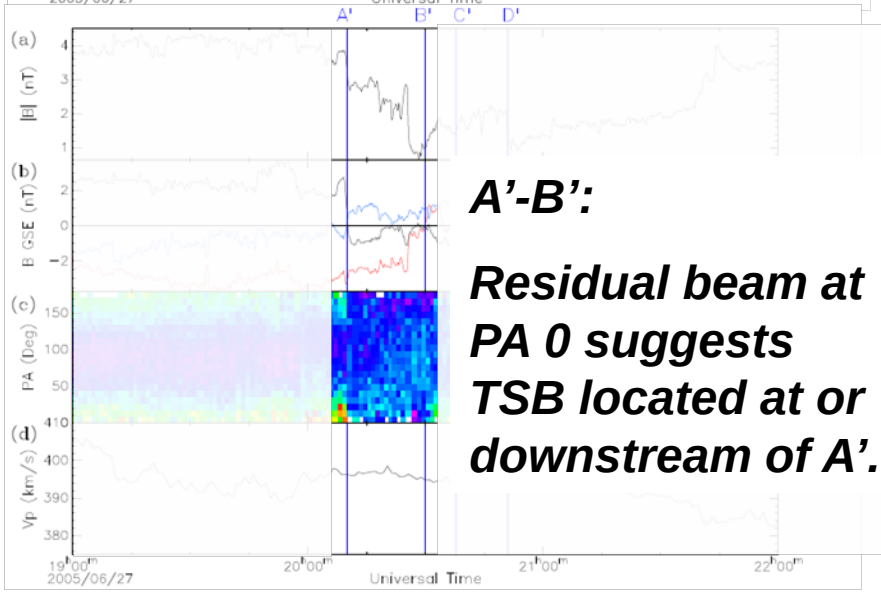
Suprathermal electrons

- *Simplified geometry: SBL cross-section*
- *Connection to the Sun as default*

Toward Sector

Away Sector





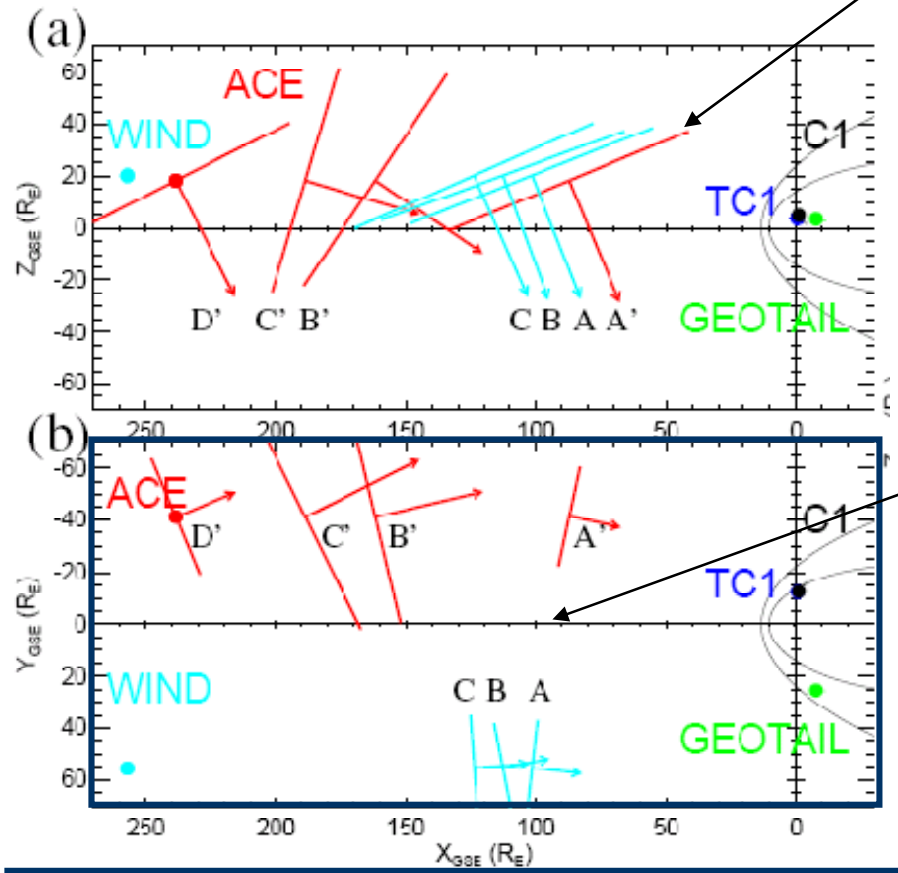
A'-B':

Residual beam at PA 0 suggests TSB located at or downstream of A'.

Analysis: Evolution across the Sun-Earth line

Orientation estimates of all current sheets using single s/c methods

MVA (Cross-product)



SBL: evolution across the Sun-Earth line, i.e. No planar structure can be assumed

Southward directed HCS normal (pointing downstream) indicates a toward sector below an away sector, in apparent contradiction with the global heliospheric magnetic configuration.

Alignment across the S-E line:

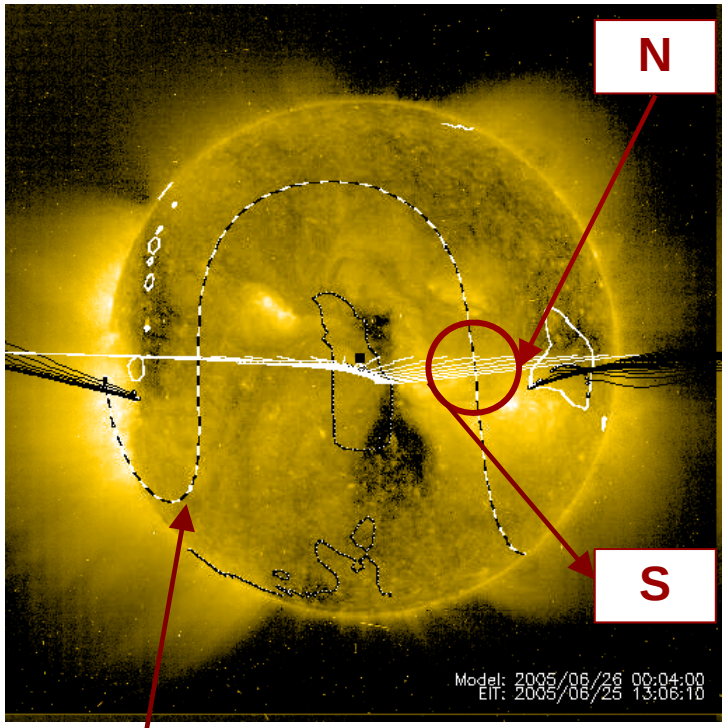
- A-A' good: steady structure identified as the **main HCS**;
- Following discontinuities not so good: **evolution from West to East** (Bz similar at ACE and Geotail), with ACE transients possibly following the track of Wind transients along the sector boundary.

Analysis: Evolution across the Sun-Earth line

Orientation estimates of all current sheets using single s/c methods

MVA (Cross-product)

The HCS is highly inclined at the Sun, making an angle of ~90° with the HCS near 1 AU, in the plane across the Sun-Earth line.



HCS

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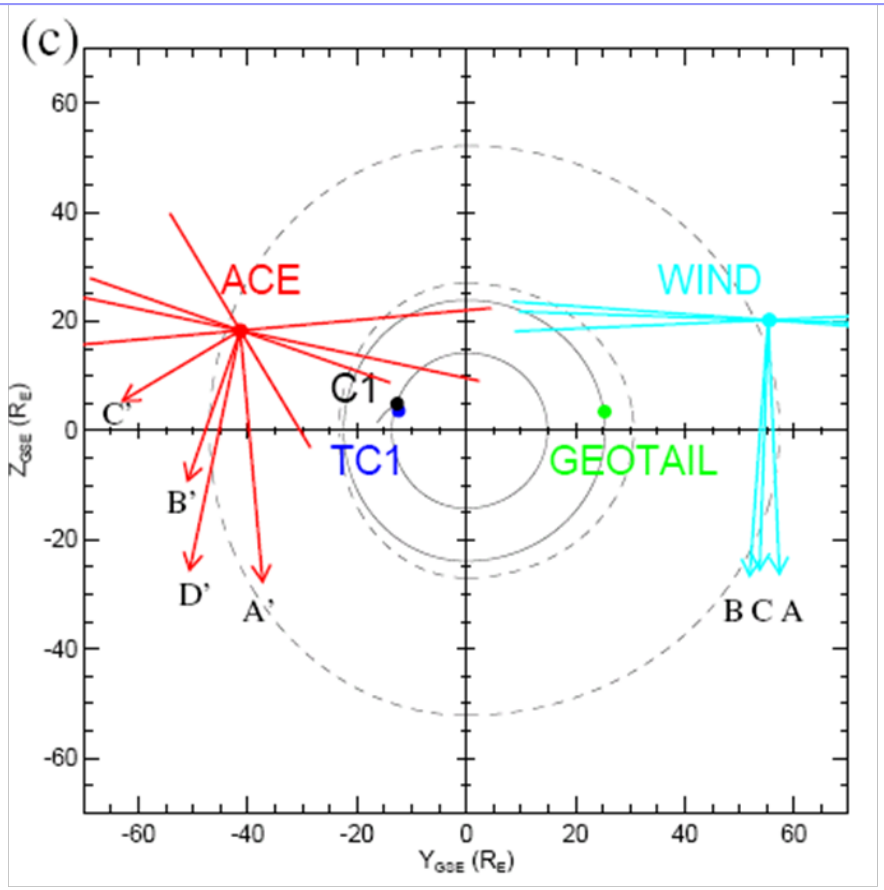
VSL Solar and Heliospheric Weather model

W



Indicative of distortion effect in the solar wind.

WARWICK

Two complementary sector crossings during the recent solar minimum

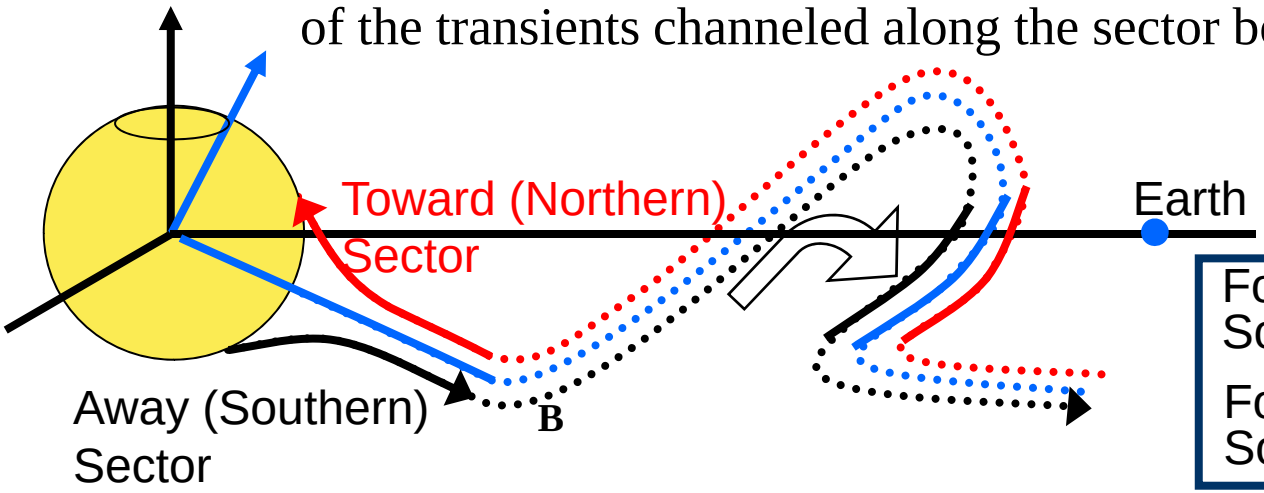
[Borovsky, 2008]

without dynamics

- **Apparent simplicity** of the structures (relatively small number and scale-sizes) facilitate the multi-s/c analysis;
- **Association between transients and large angular changes** (usually attributed to spaghetti-like flux tubes, but their **evolution** may not be so easily deduced);
- **No planar structure** can be assumed in one case on the scale of the magnetospheric cross-section.

both having an Away sector (with transients) above Toward sector.

- Linked to HCS **southward displacement** via outflowing loops?
- **Flow accelerations & extent of HFD** may reflect the number and age of the transients channeled along the sector boundary.



Foullon et al. 2009,
Solar Physics 259 (1), p. 389

Foullon et al. 2010, AIP Proc.
Solar Wind 12, 1216, p. 367