Magnetic Reconnection in Solar and Space Physics: Consequences - A Personal Journey

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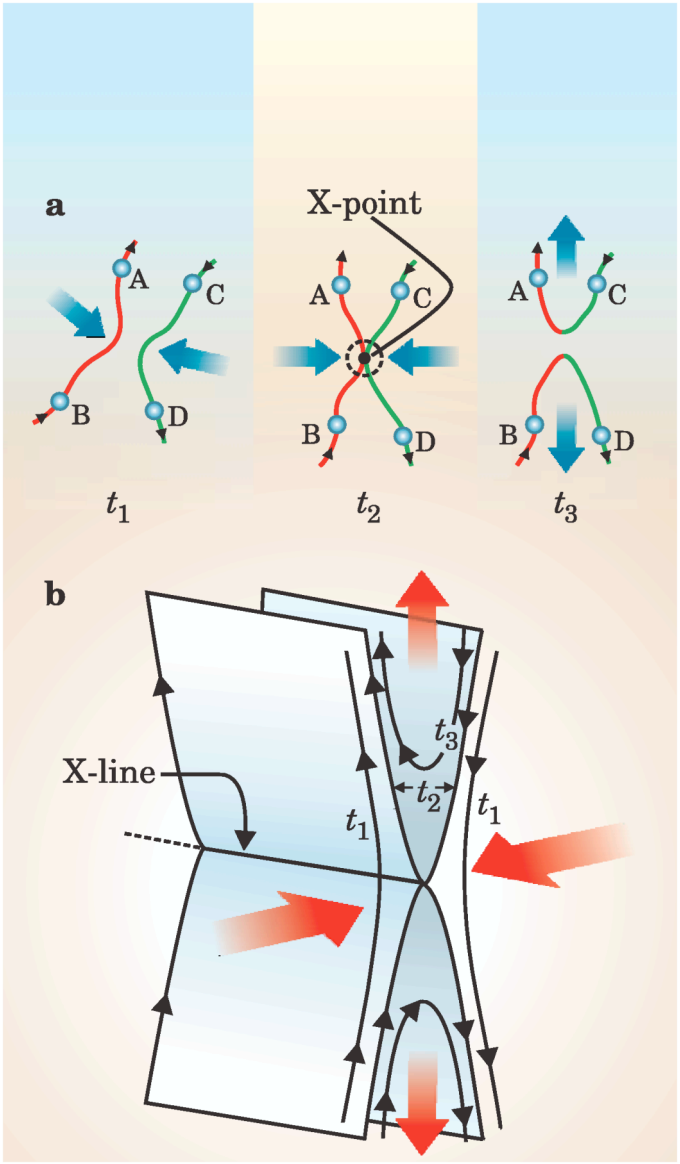
30 July 2006

Reconnection Pioneers



Paschmann

Giovanelli - *null points, sunspots, flares*

Hoyle - *null point particle acceleration*

Cowling - *thin current sheets, flares*

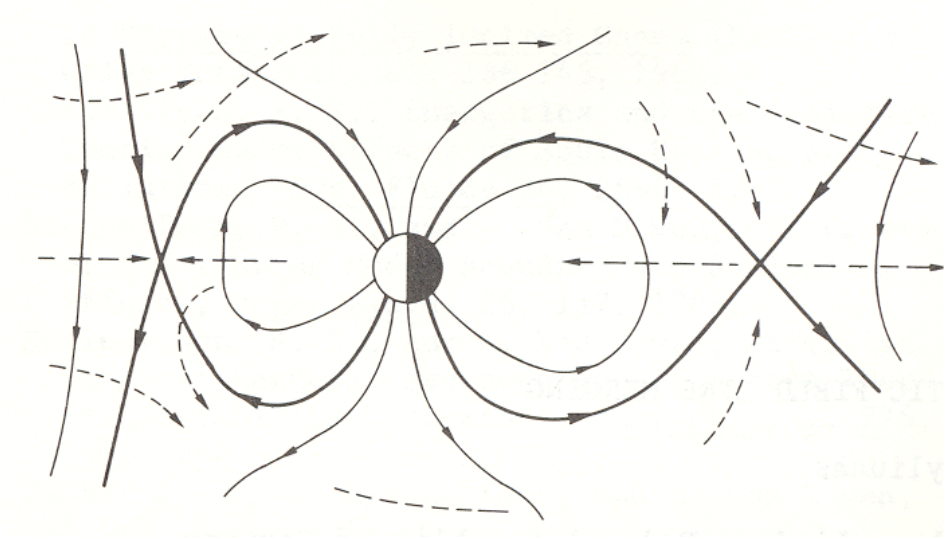
Dungey - *reconnection, magnetospheric convection*

Sweet, Parker - *slow reconnection, flares*

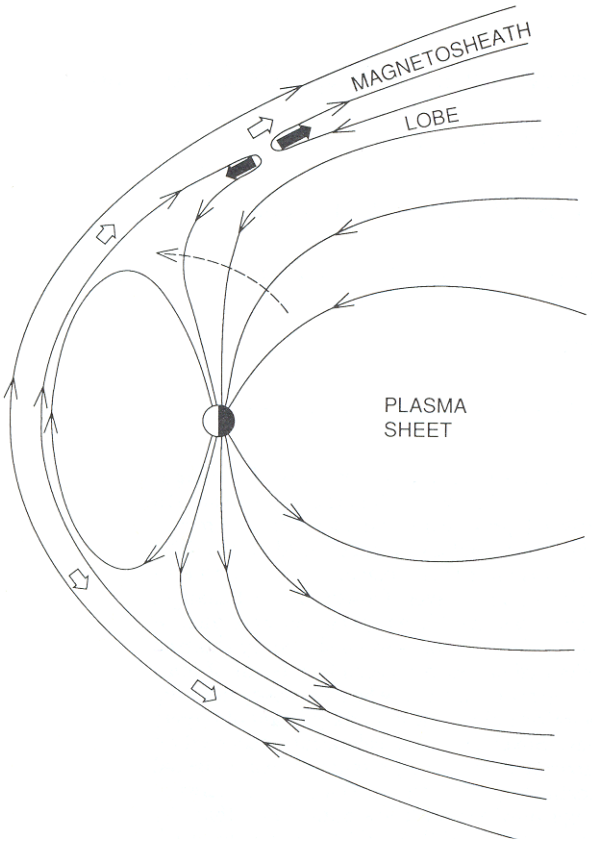
Petschek - *fast reconnection, slow shocks*

Furth et al. - *tearing mode - reconnection*

Reconnection - Earth's Magnetosphere



Southward HMF



Northward HMF

Reconnection Similarities - Solar and Magnetosphere

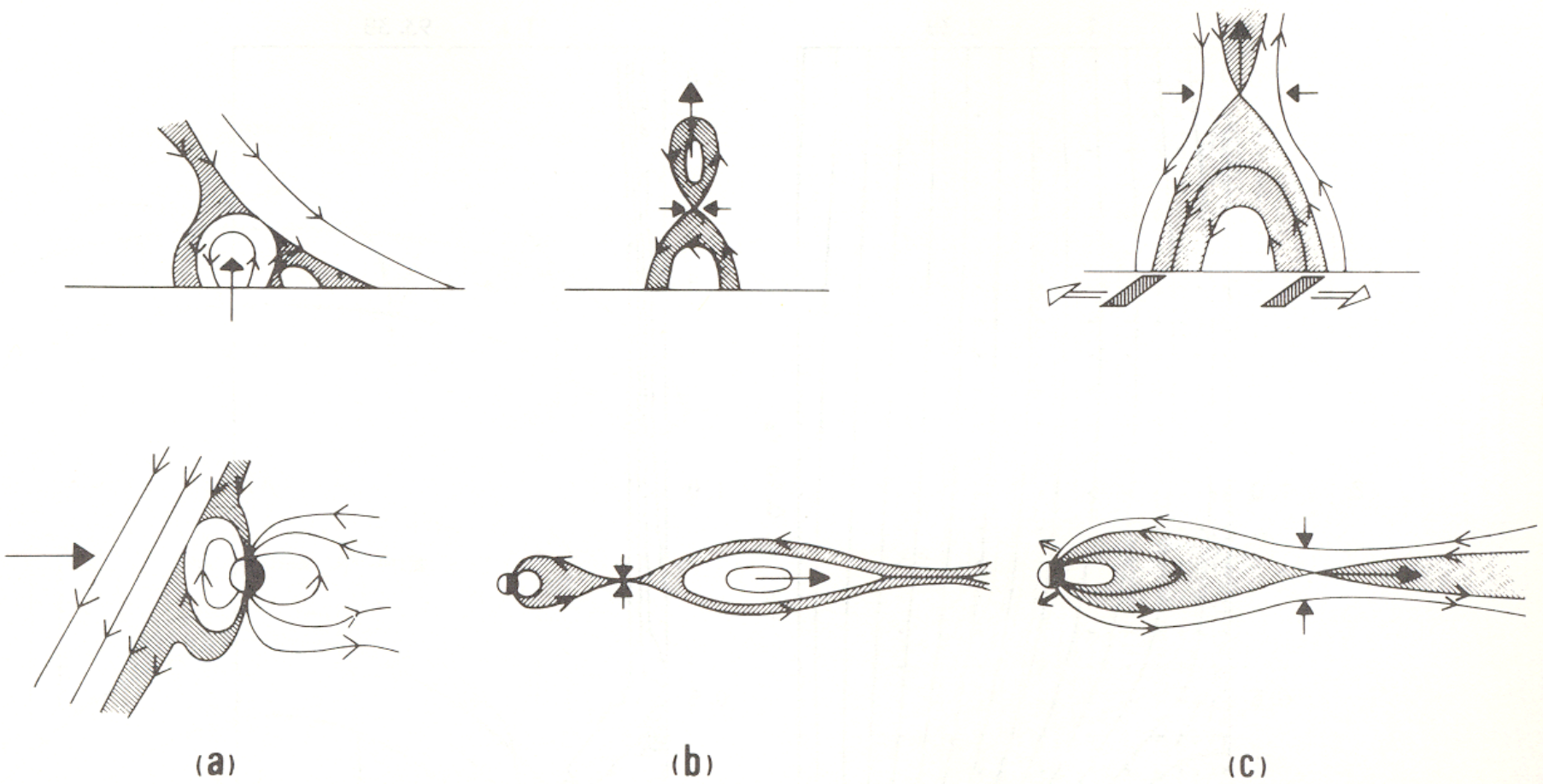
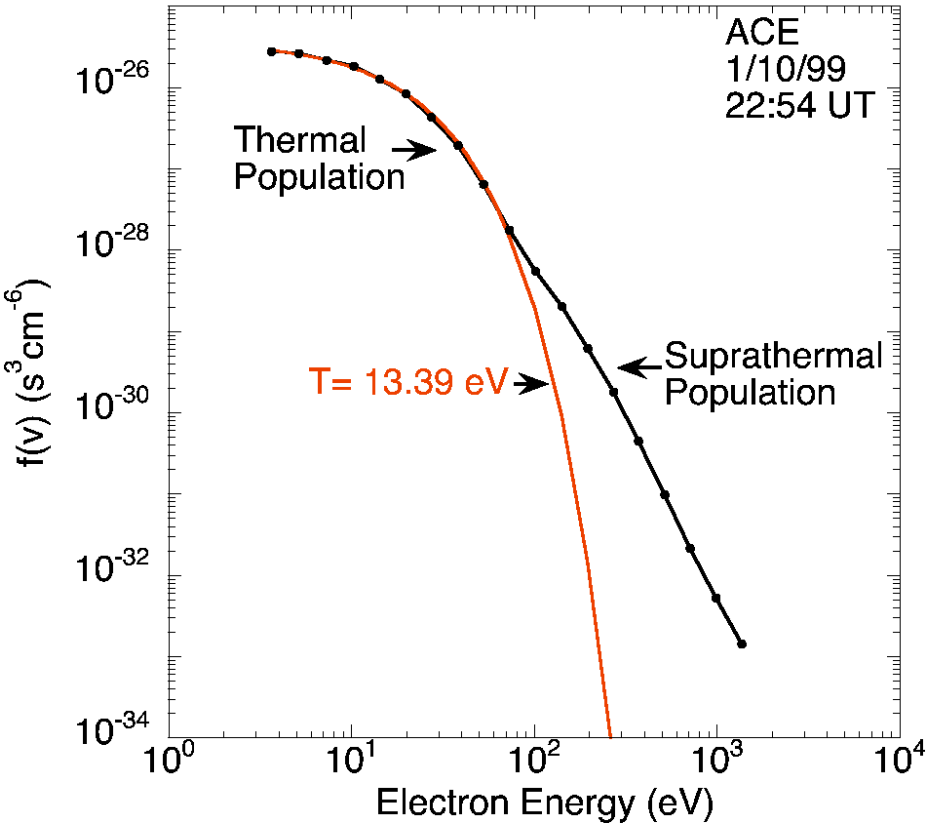


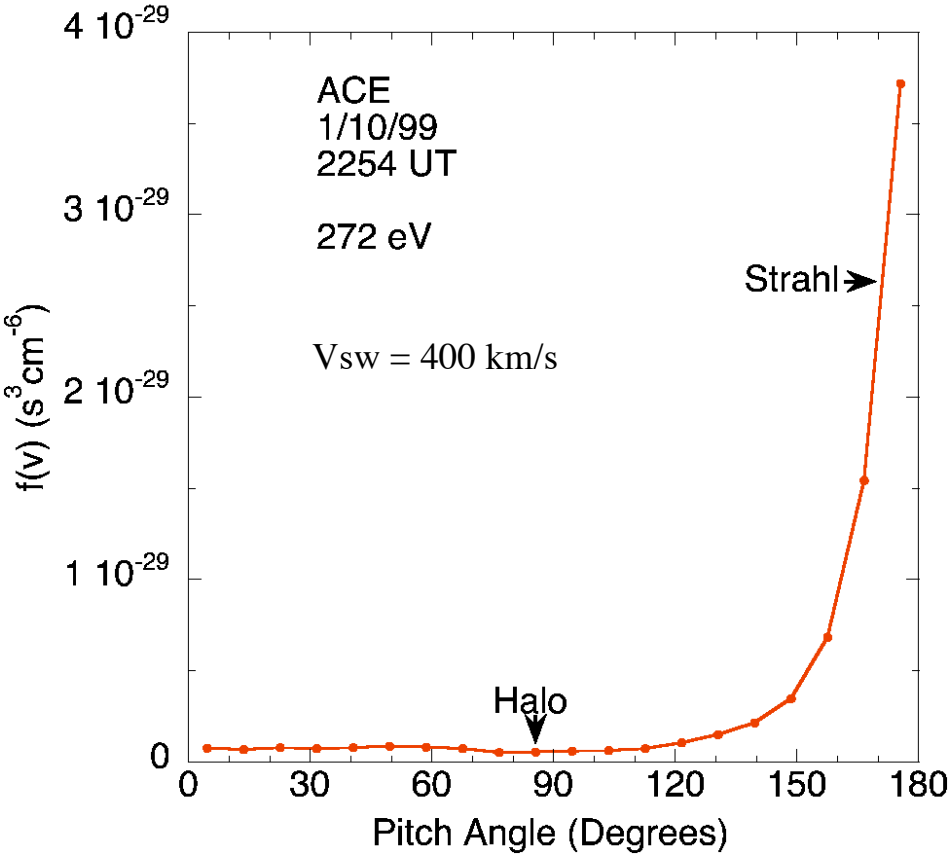
Fig. 15. Apparent similarities between solar flares (top) and the magnetosphere (bottom).

Priest

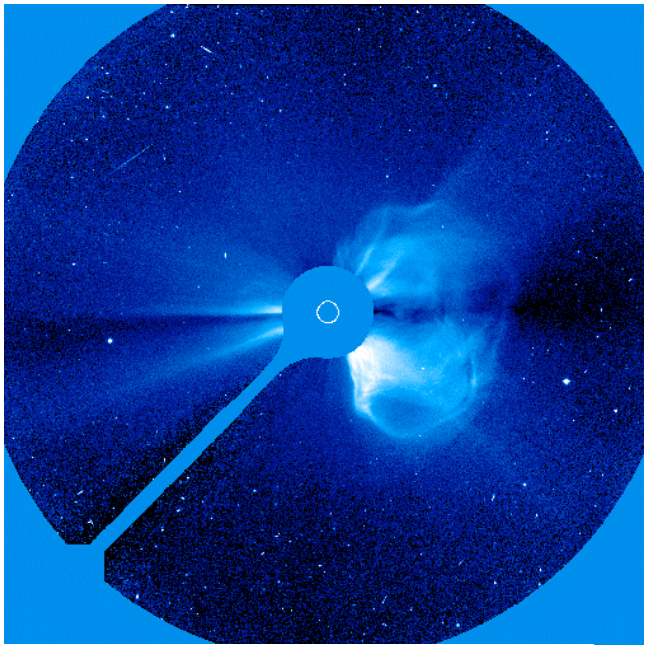
1-D Electron f(v)

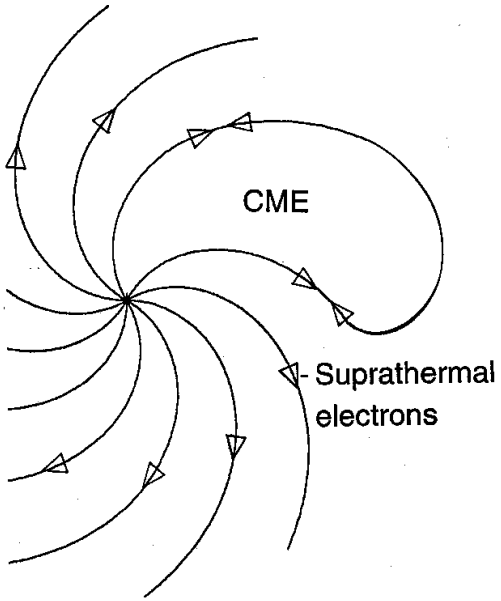


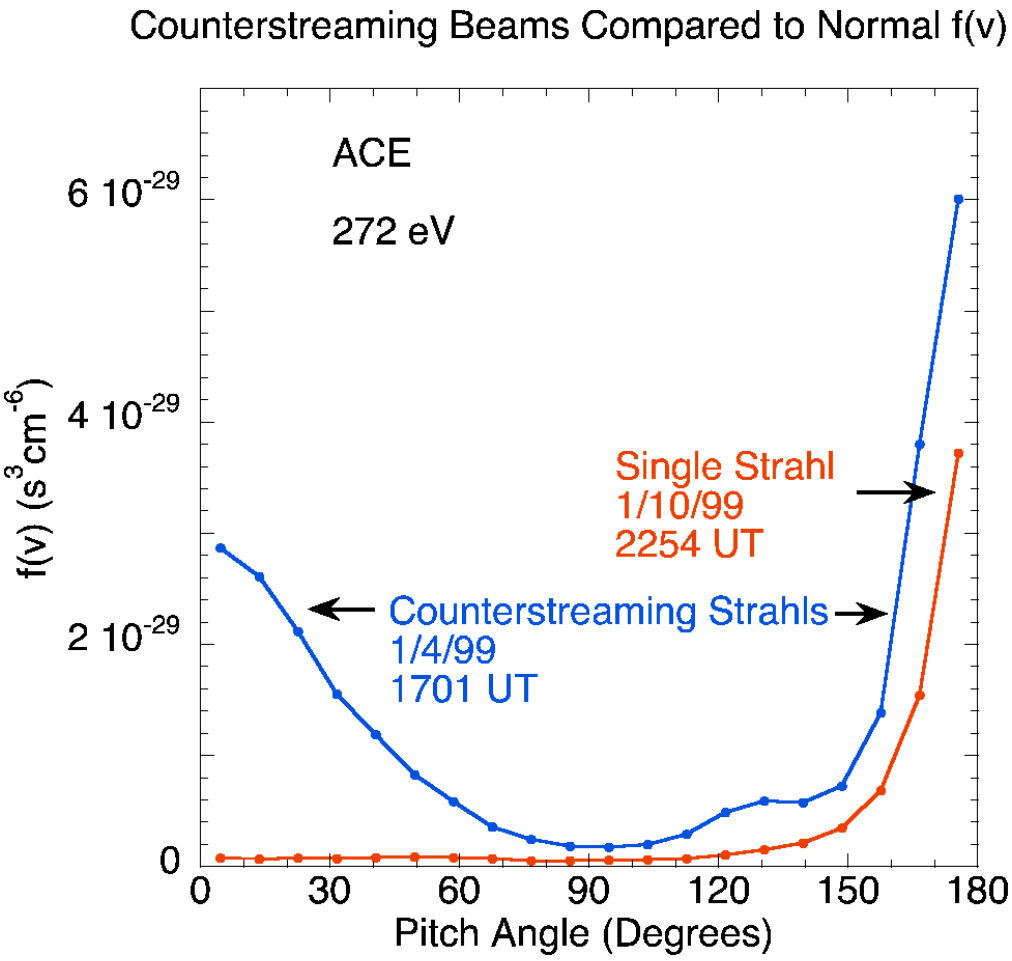
Suprathermal Electron Pitch Angle Distribution



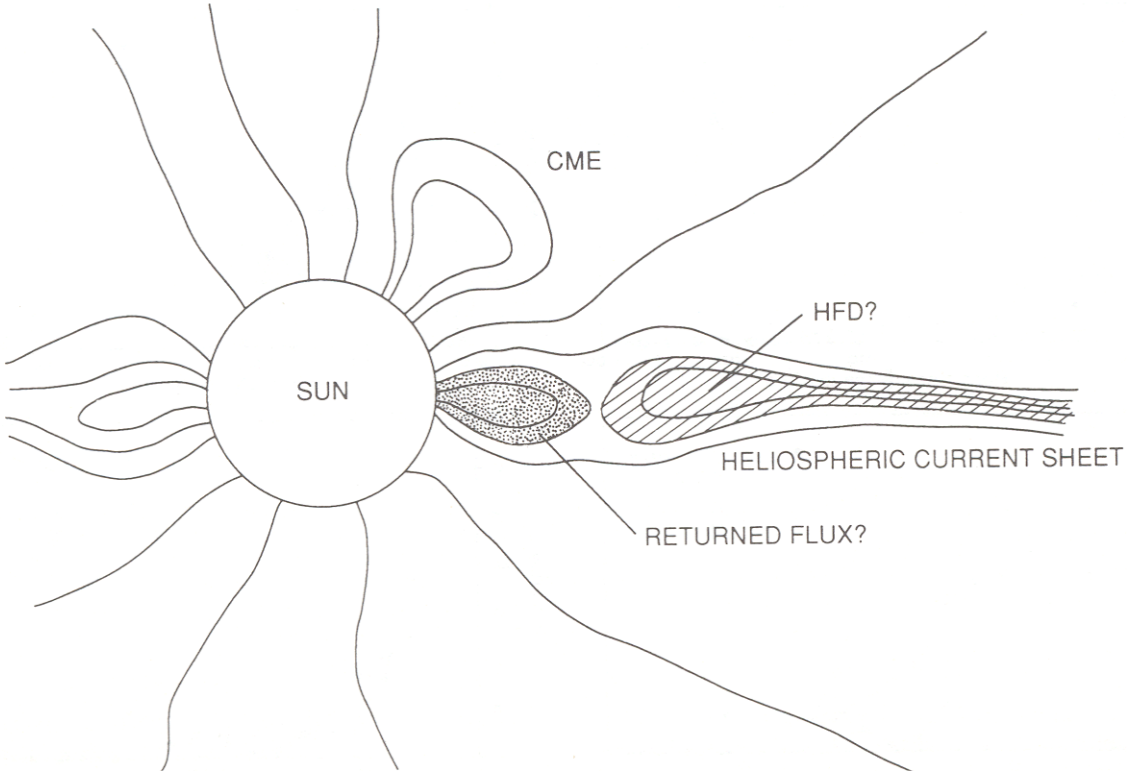
Counterstreaming Suprathermal Electrons and CMEs in the Solar Wind





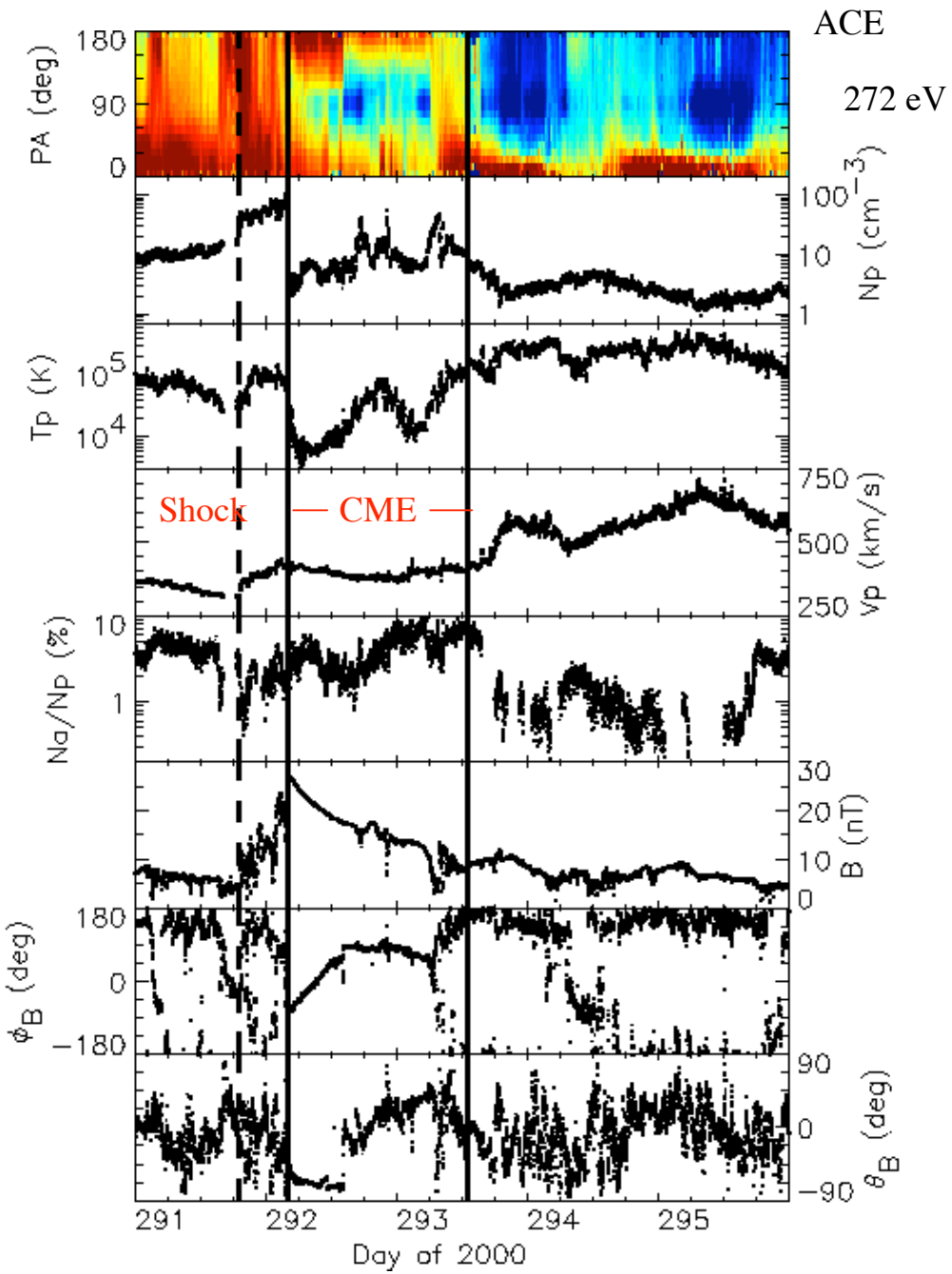


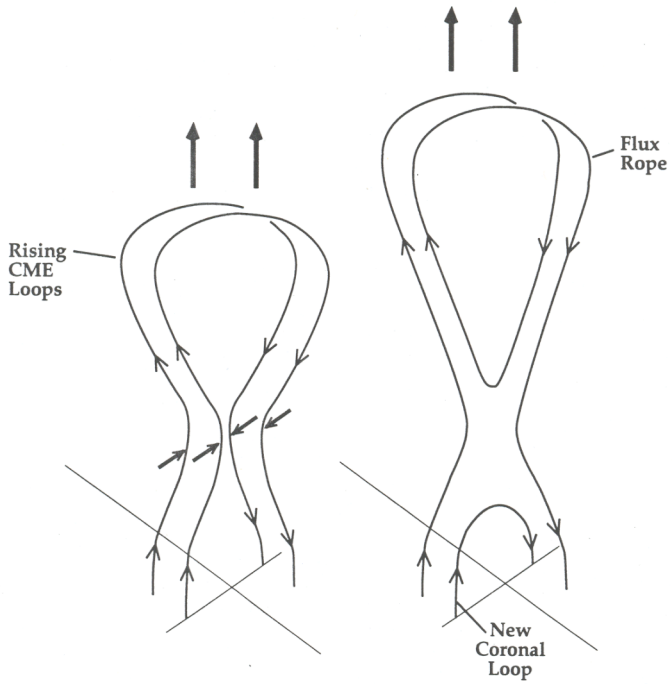
Reconnection at the HCS as a Means to Maintain Magnetic Flux Balance in Heliosphere



McComas et al.

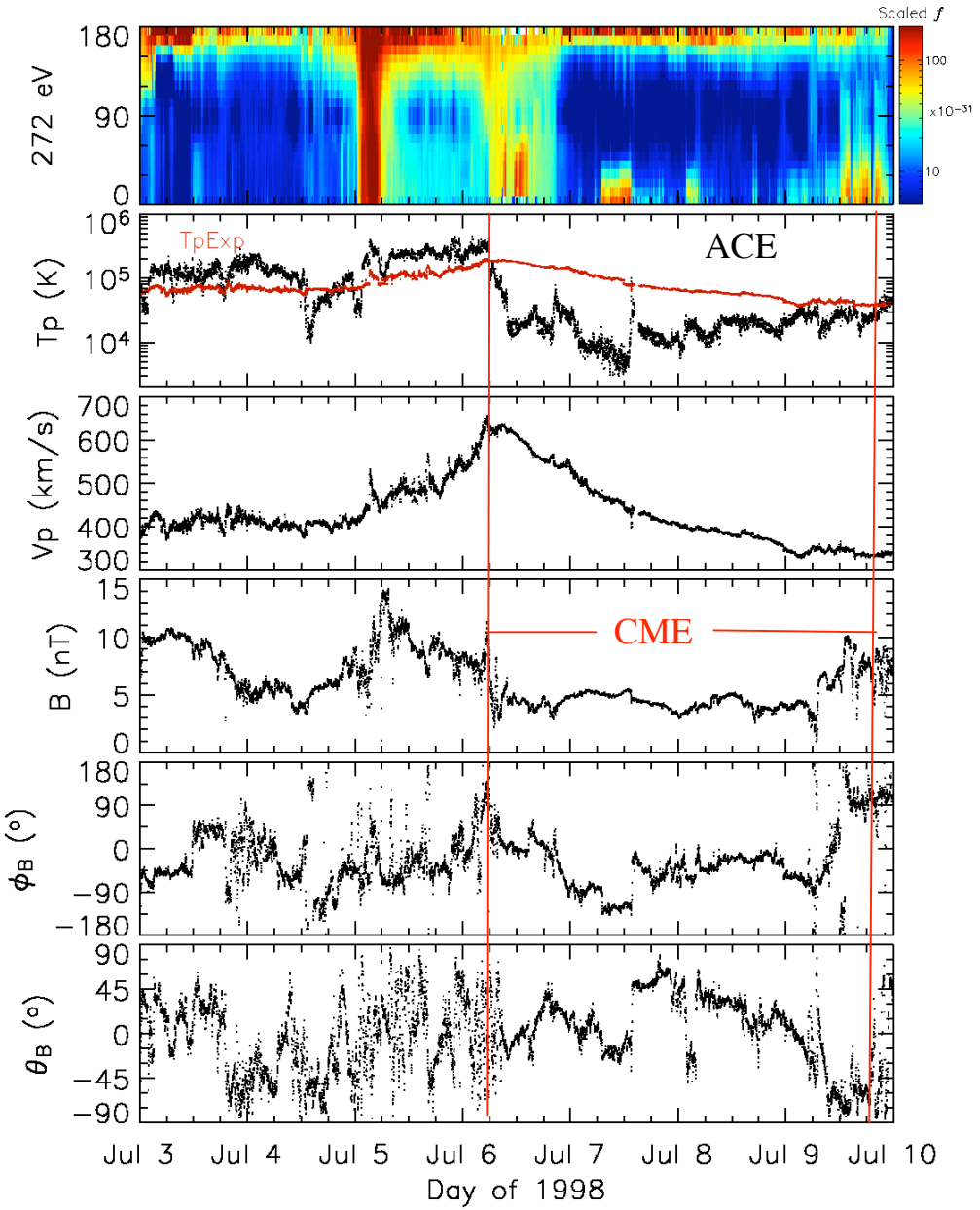
A Flux Rope CME in the Solar Wind at 1 AU



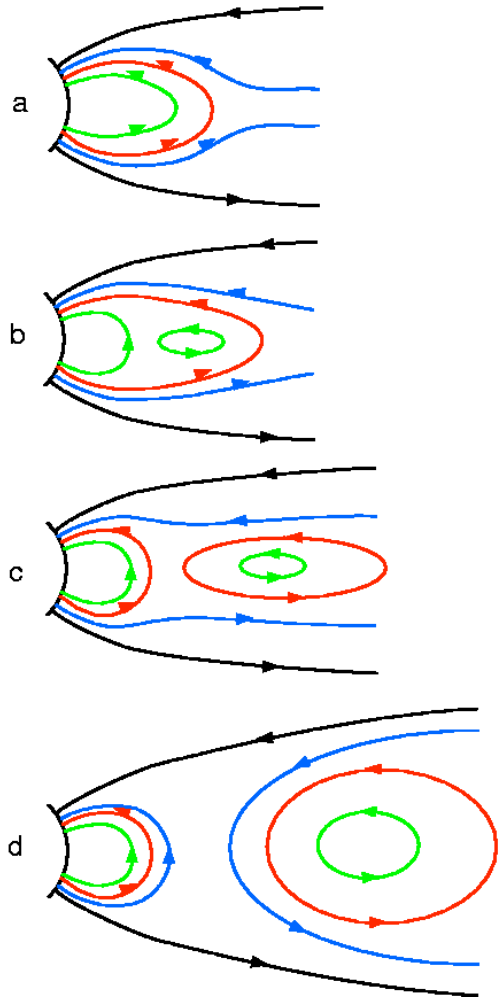


A suggested flux rope formation mechanism: Reconnection of rising, sheared, closed CME field lines.

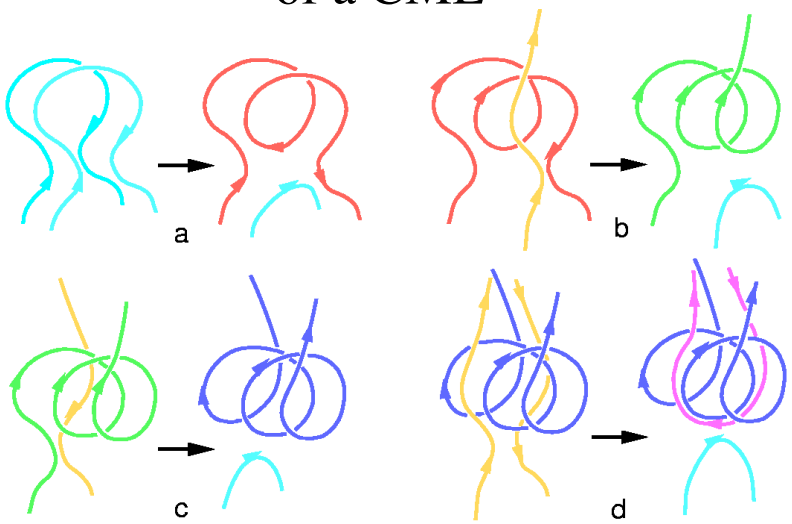
A CME With a Mixture of Open and Closed Field Lines



2D Reconnection in Rising CME Loops

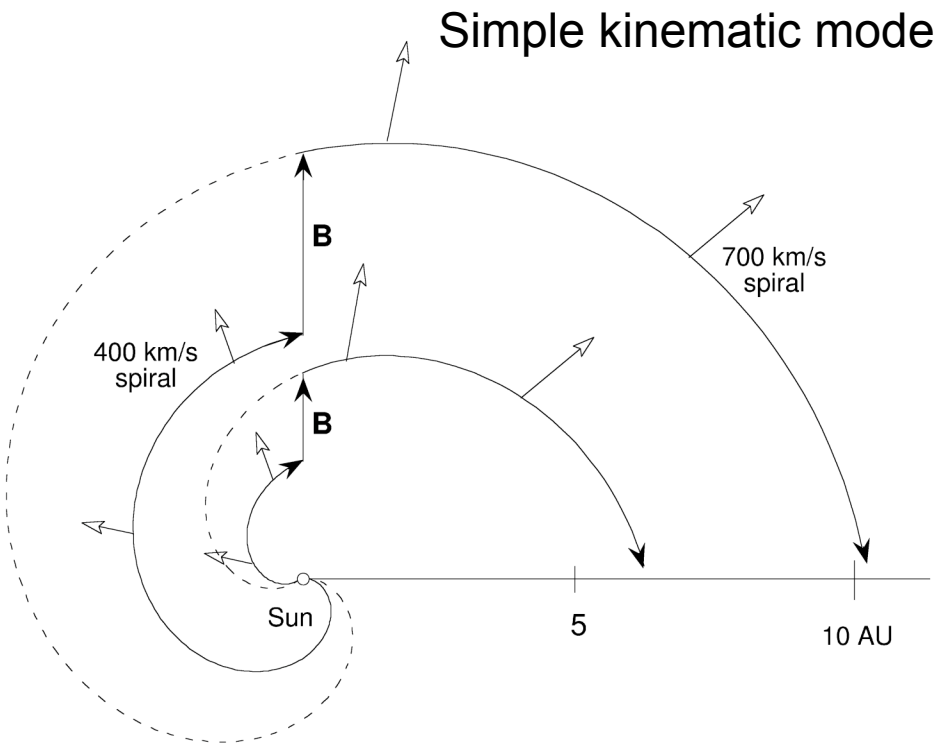


3D Reconnection Within the Magnetic Legs of a CME



Possible Mixture of Resulting Topologies

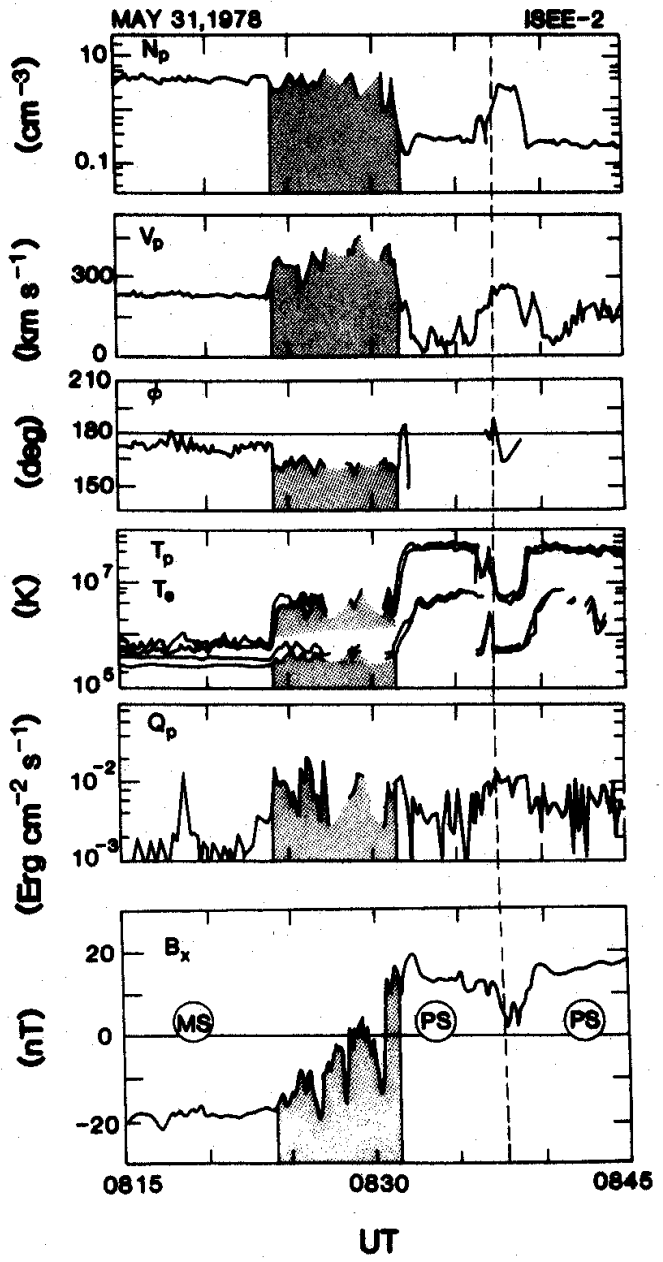
Idealized Magnetic Field Structure Produced by a Sudden, Localized Decrease in Solar Wind Speed at the Sun



The sudden speed decrease may be associated with interchange reconnection between open and closed field lines in solar atmosphere.

Sudden decrease in flow speed produces a radial field segment connecting pre and post-decrease spirals.
Radial segment propagates radially away from Sun and grows in size with increasing heliocentric distance.
Sharp speed decrease evolves into a gradual speed decline.

Accelerated Plasma Flow at Earth's Magnetopause



Accelerated plasma flow within the field reversal region at Earth's magnetopause is the smoking gun for reconnection there.

Some topics considered:

Quasi-stationary reconnection

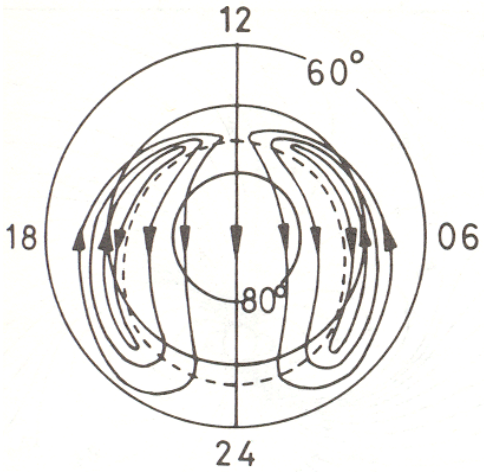
Reconnection at flank magnetopause

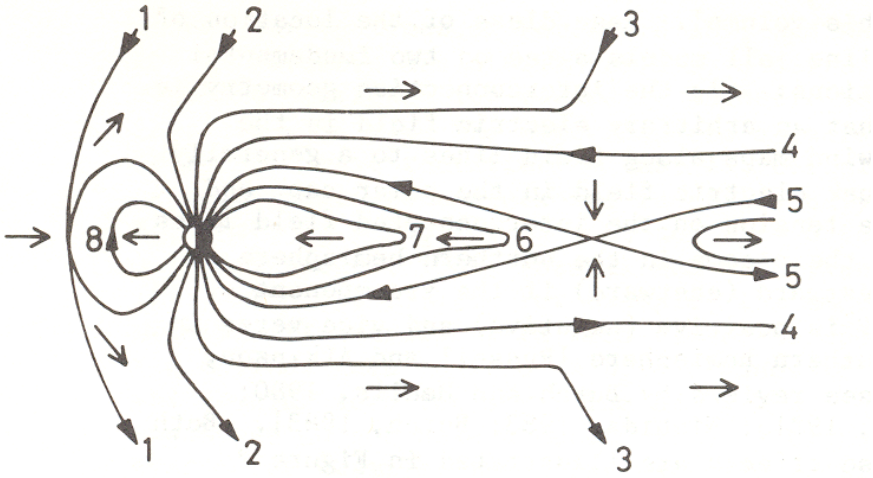
Flow reversals at dayside magnetopause and asymmetric polar cap convection

Reconnection at lobe magnetopause

Kinetic effects associated with reconnection at magnetopause

Magnetic Reconnection and Magnetospheric Convection

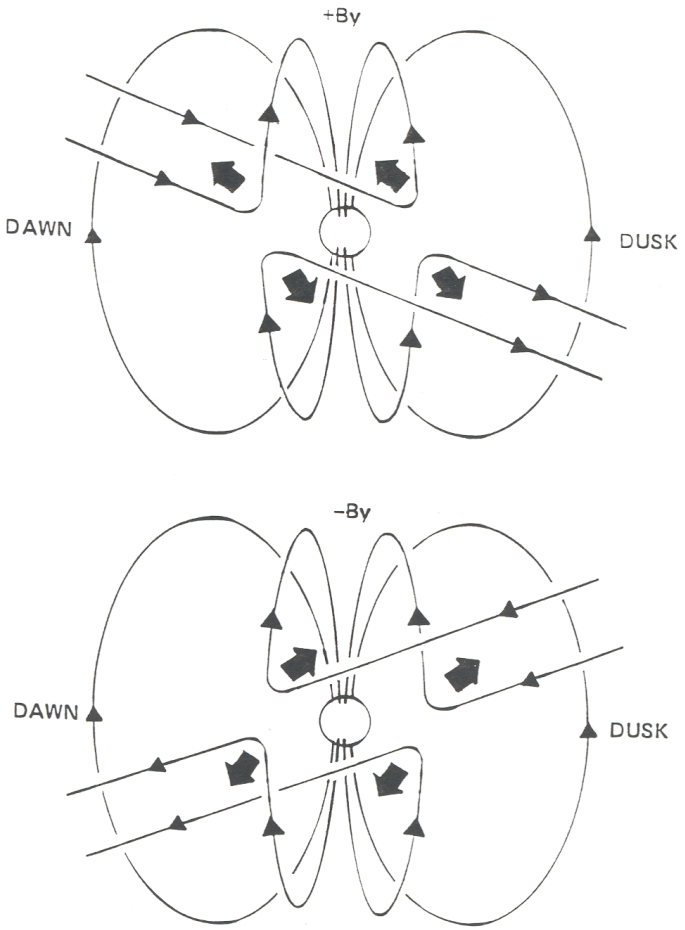




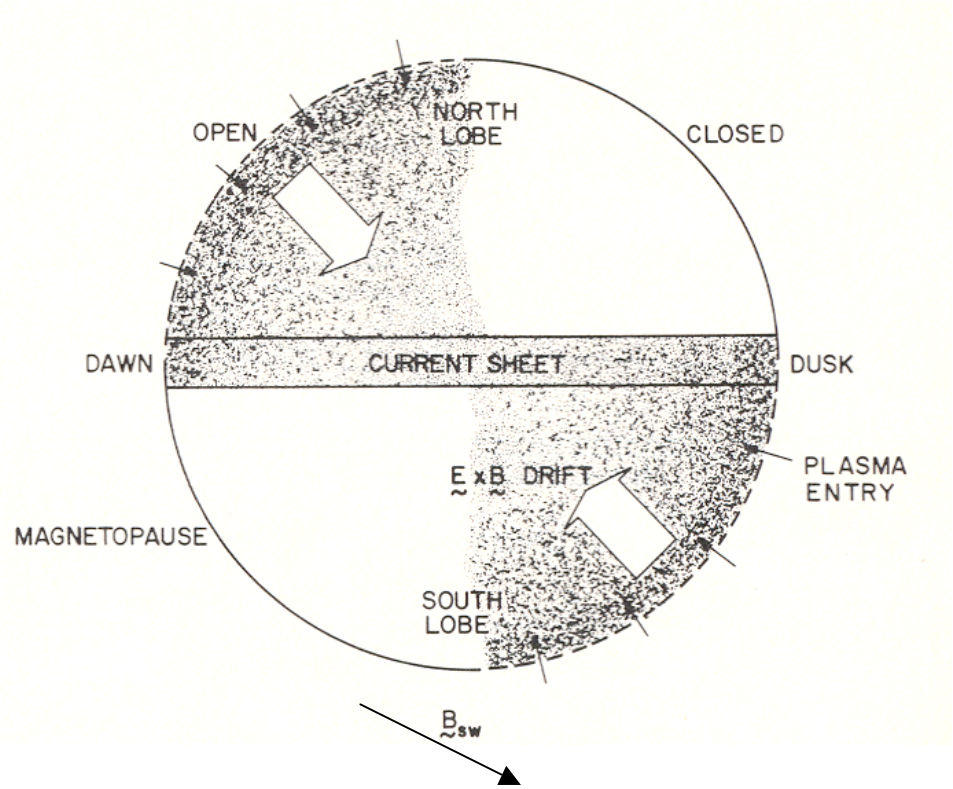
Reiff

B_y Effects of Magnetic Reconnection at Magnetopause

Flow Reversals at Magnetopause and Asymmetric Polar Cap Convection

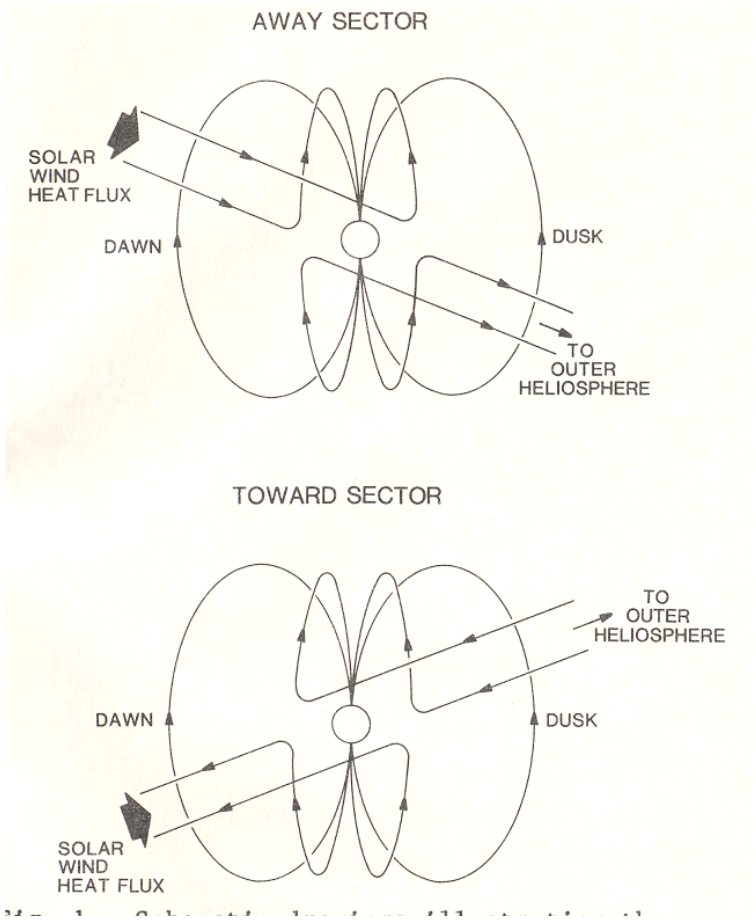


Asymmetric Plasma Entry into Tail Lobes

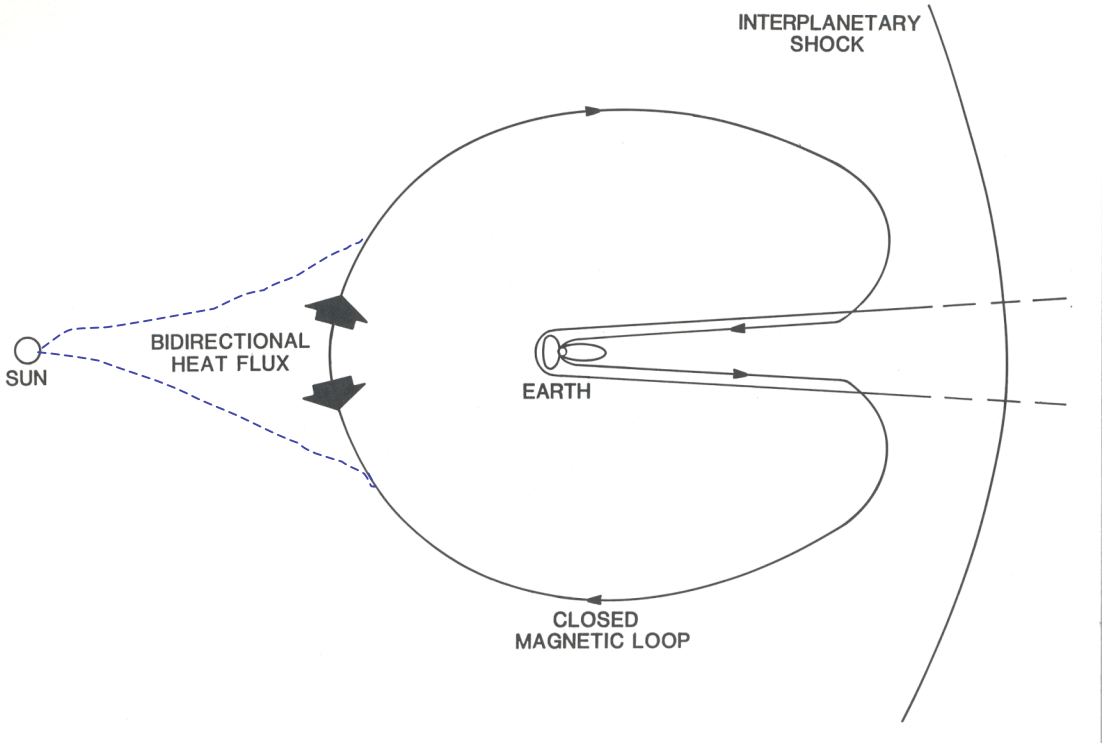


Reconnection and Polar Rain in Earth's Polar Caps

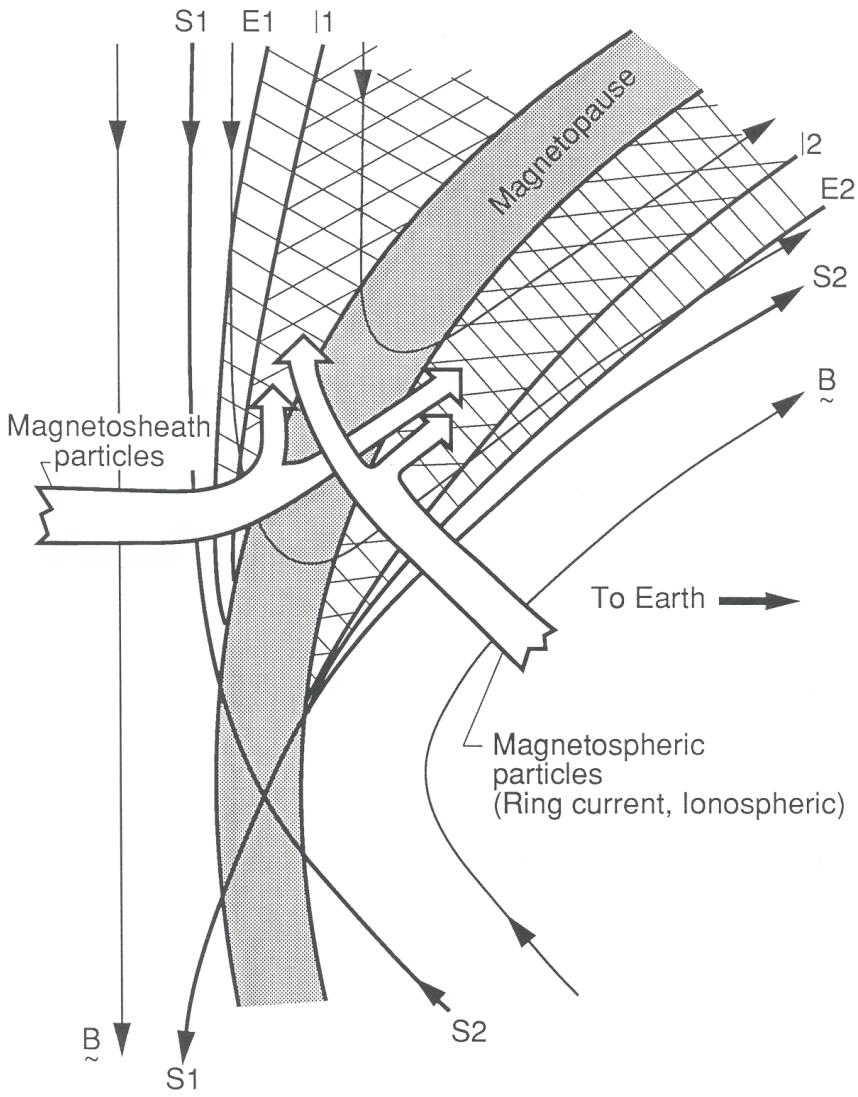
Polar Cap Experiencing Electron "Rain" Depends on HMF Polarity



CMEs and Hemispherically Symmetric Polar Rain



Kinetic Aspects of Reconnection at Magnetopause



Plasma interpenetration

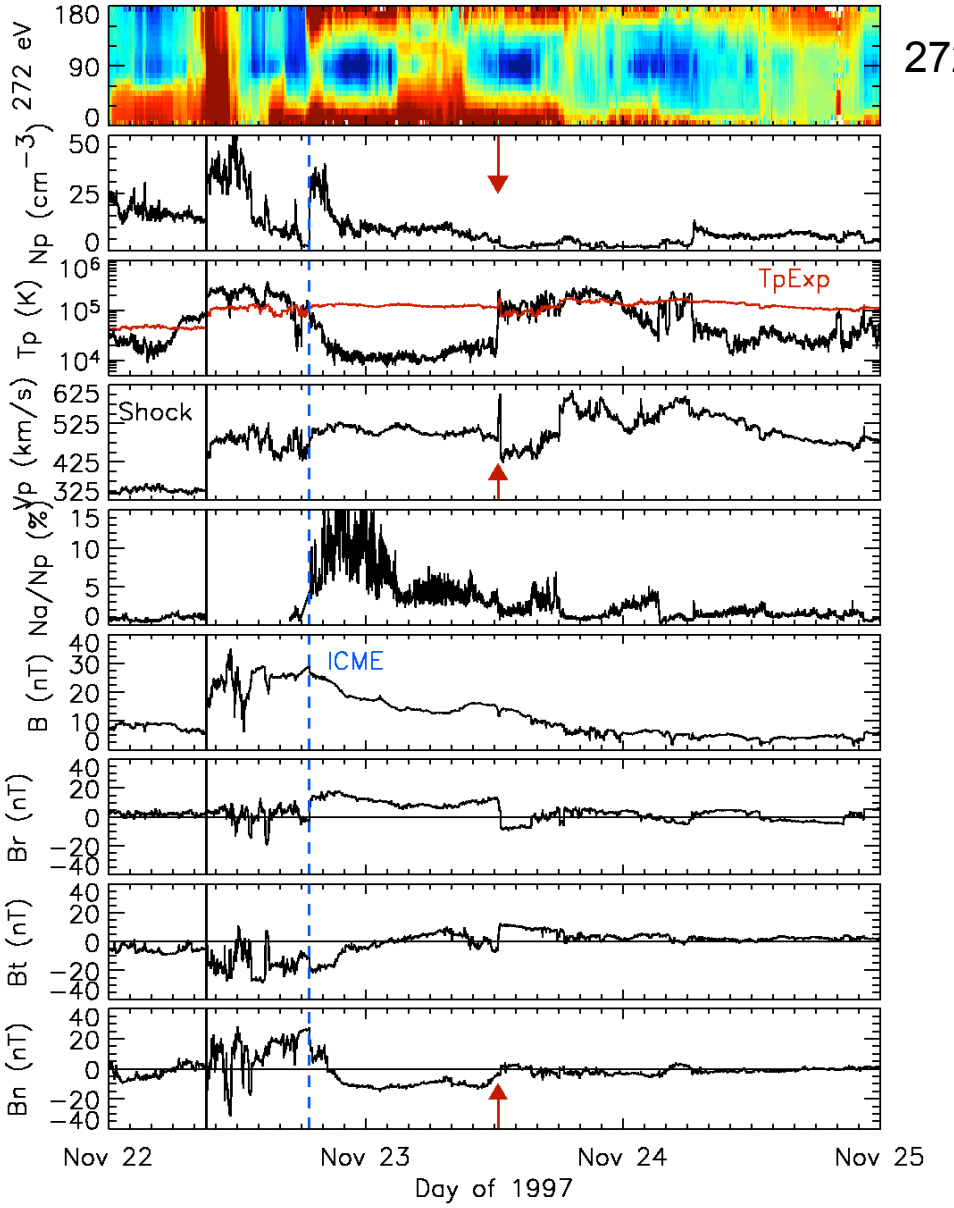
Particle reflection

Offsets of electron and ion edges to low latitude boundary layer associated with time-of-flight effects

Acceleration of cold ionospheric plasma in outer magnetosphere

Environment Surrounding a Brief Accelerated Flow Event in the Solar Wind

ACE

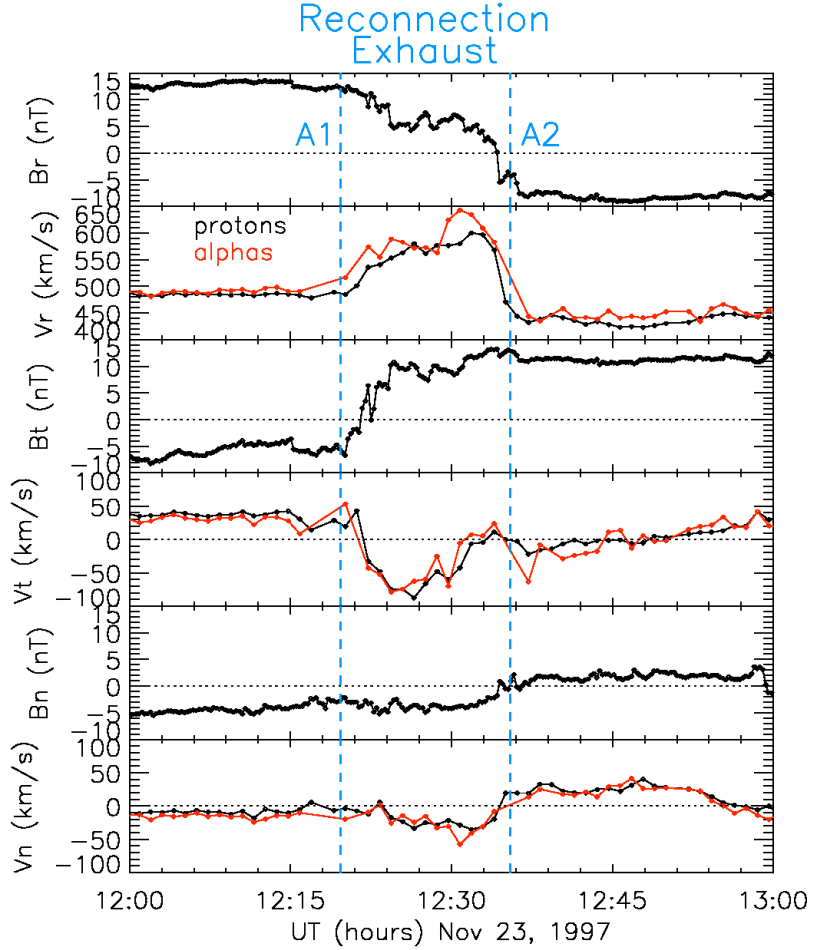


272 eV Pitch Angle Distribution

A brief interval of accelerated flow (red arrows) was associated with a large field shear separating distinctly different plasma regimes. It probably occurred at the interface between two ICMEs.

Many such accelerated flow events are associated with ICMEs.

Magnetic Field and Flow Velocity Changes Associated with the 23 November 1997 Event



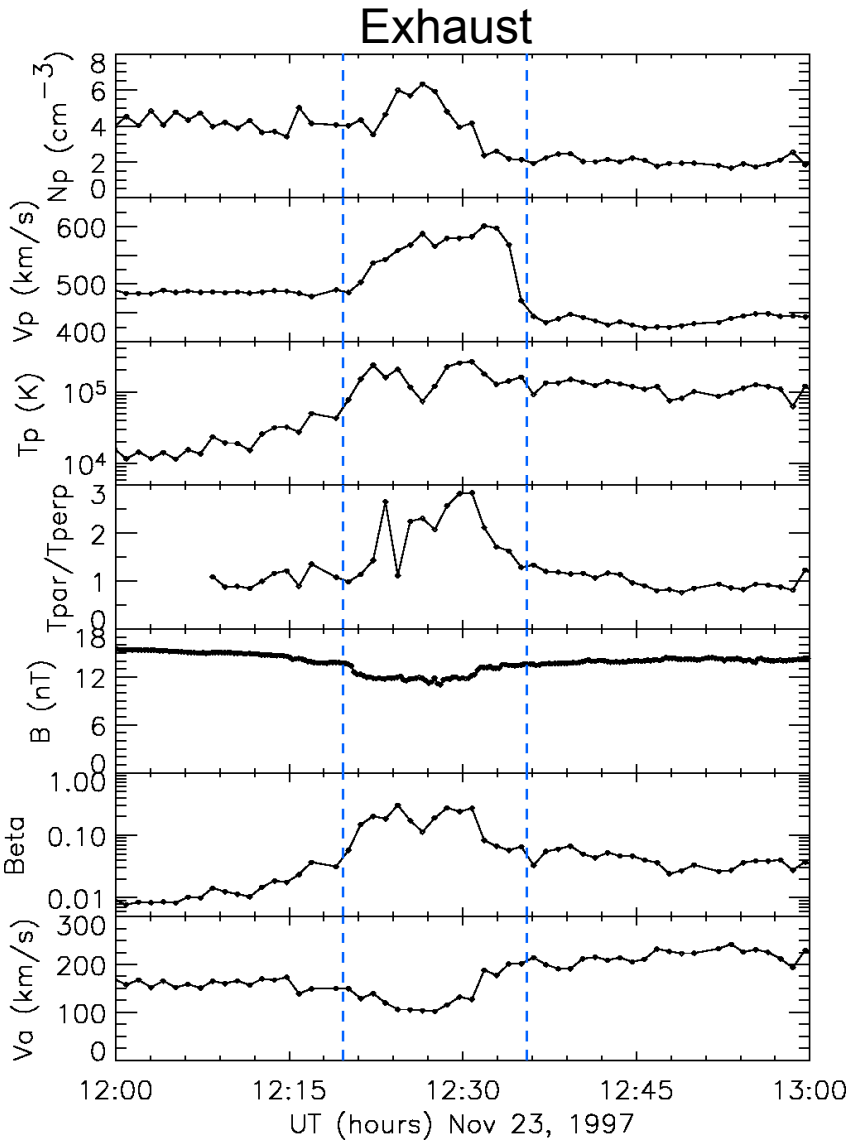
The event straddled a large (149˚) change in field orientation.

The current sheet was bifurcated with an intermediate field orientation in the center.

V,B changes were anticorrelated at leading edge and correlated at trailing edge of exhaust. Thus the exhaust was bounded by Alfven waves propagating antisunward along B.

Above is the characteristic signature by which we identify reconnection exhausts in the solar wind.

Other Aspects of the 23 November 1997 Event

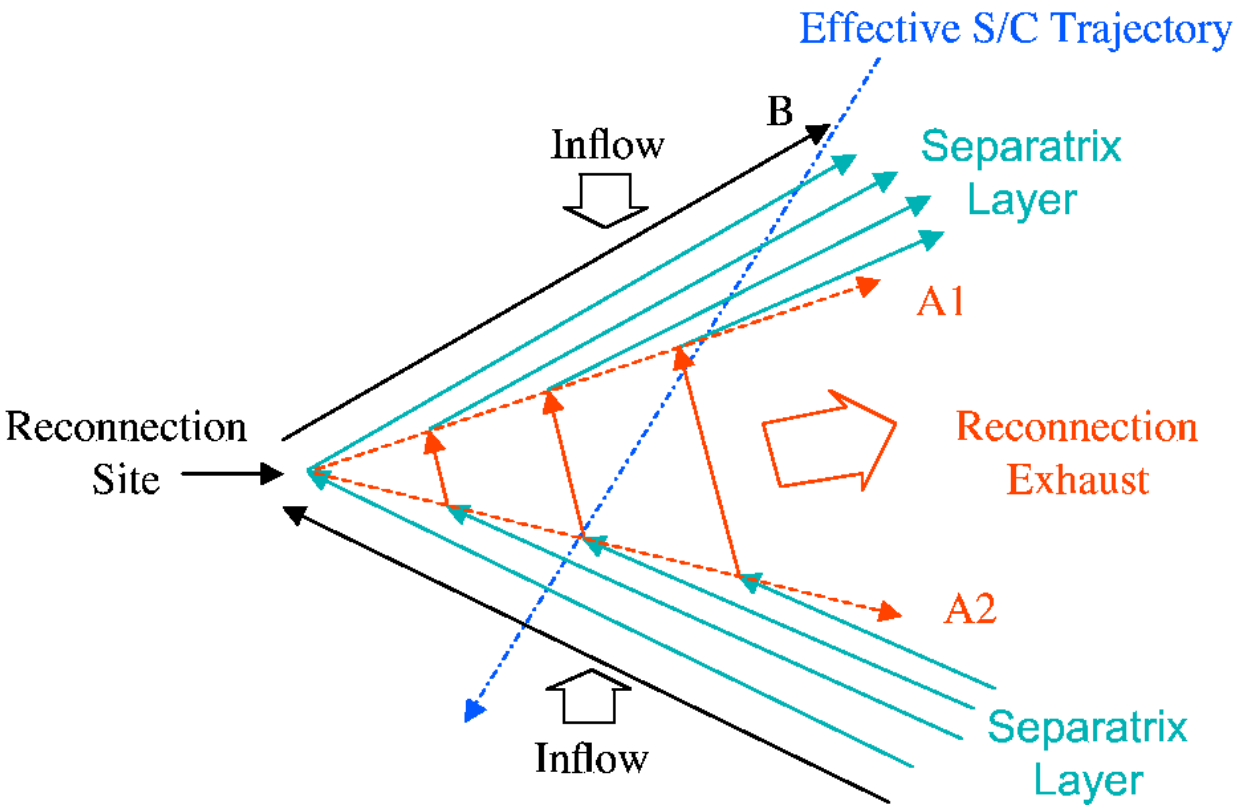


The plasma states on opposite sides of the event were distinctly different, but both were characterized by low proton beta.

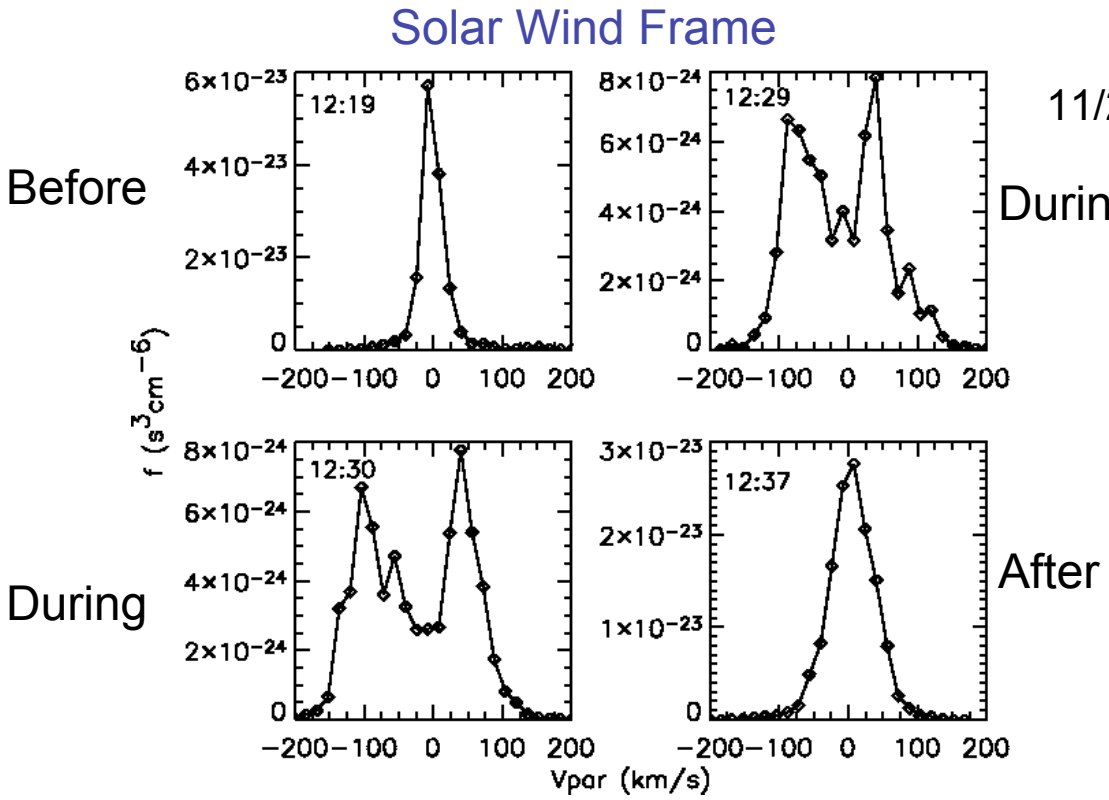
Overall transitions from outside to inside the exhaust were slow-mode-like on both sides.

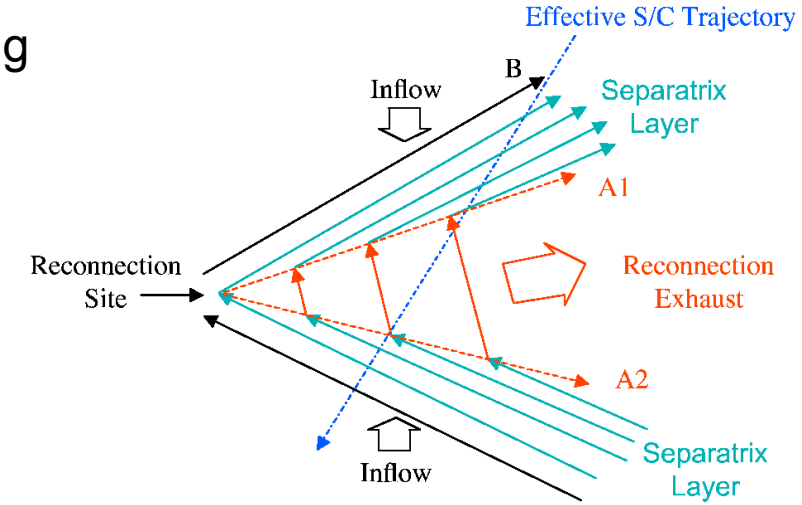
We have now identified more than 170 events of this nature in ACE, Ulysses and Helios solar wind data. For the most part, these results are general for all exhausts observed.

Interpretation of the Observations



Interpenetrating Proton Beams Within a Reconnection Exhaust



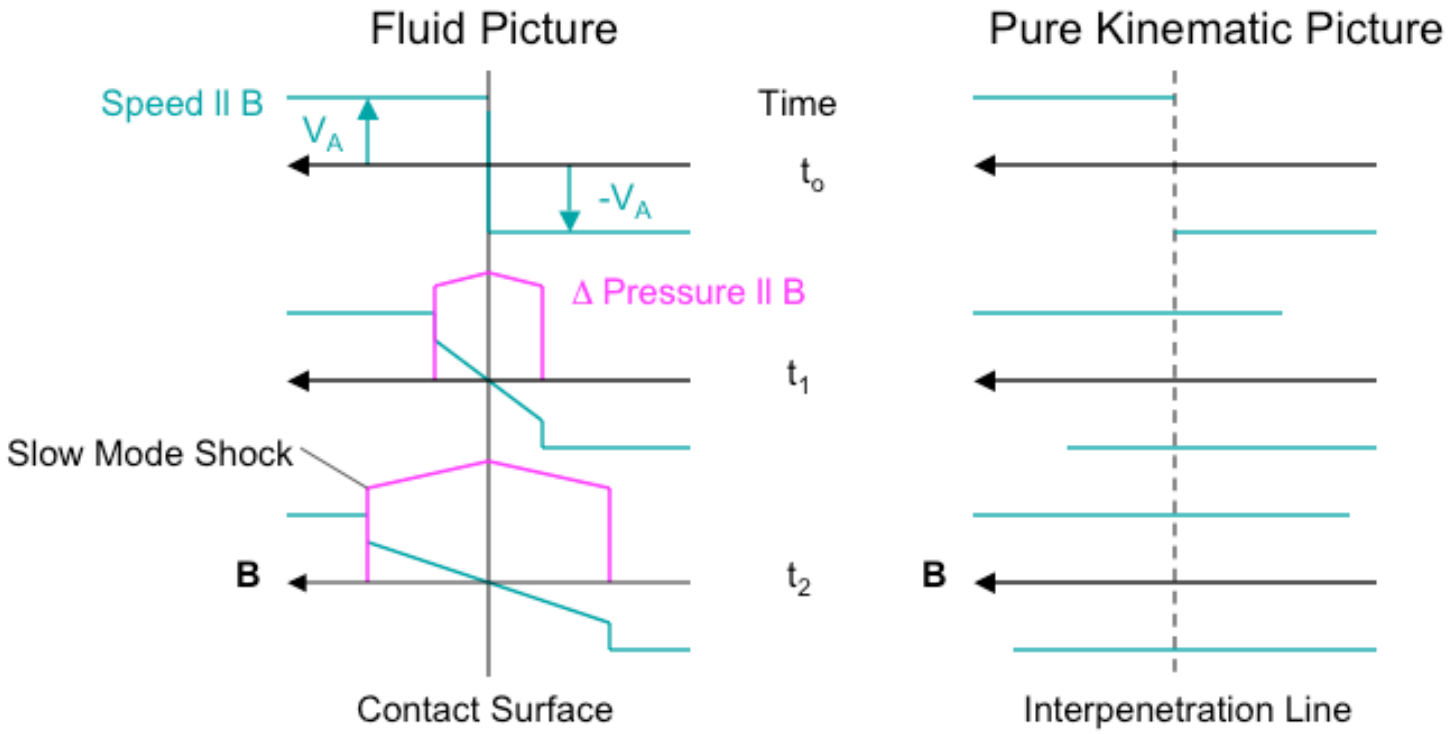


The apparent large proton temperatures and temperature anisotropies within reconnection exhausts typically are associated with cold interpenetrating proton beams.

Interpenetrating beams demonstrate magnetic connection across an event and are characteristic of solar wind reconnection exhausts.

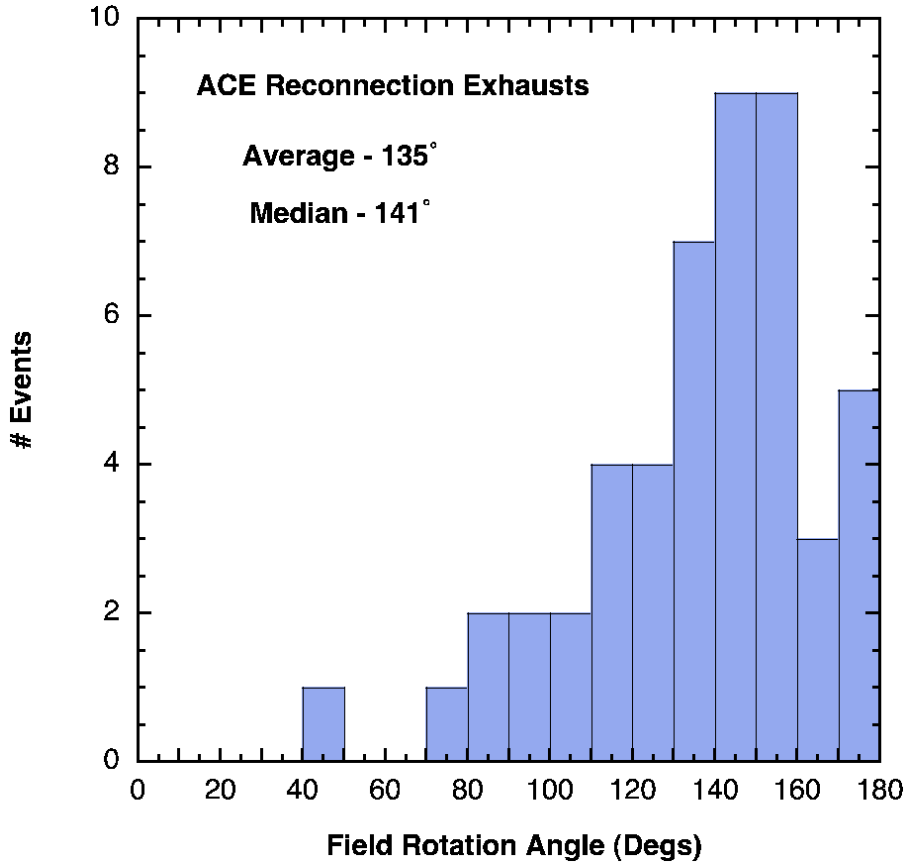
Do the reconnection exhausts contain slow mode shocks?

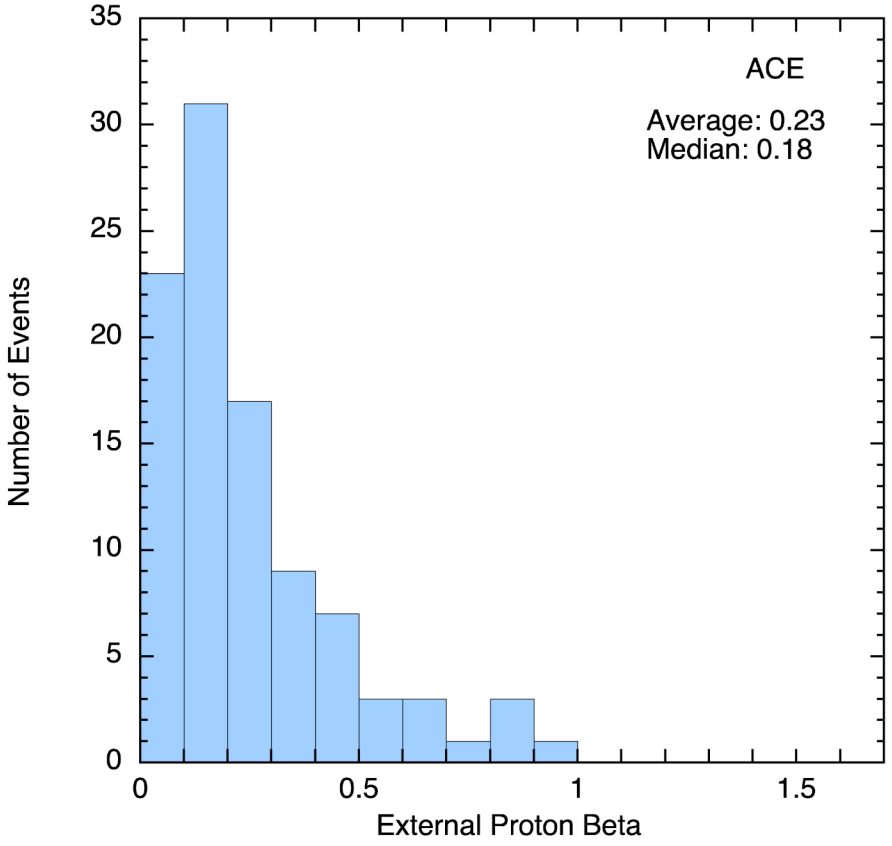
Solar Wind Frame



The real solar wind case, which includes some coupling between the interpenetrating beams, is something in between these pictures.

Reconnection Exhausts and the Local Magnetic Shear and External Proton Beta

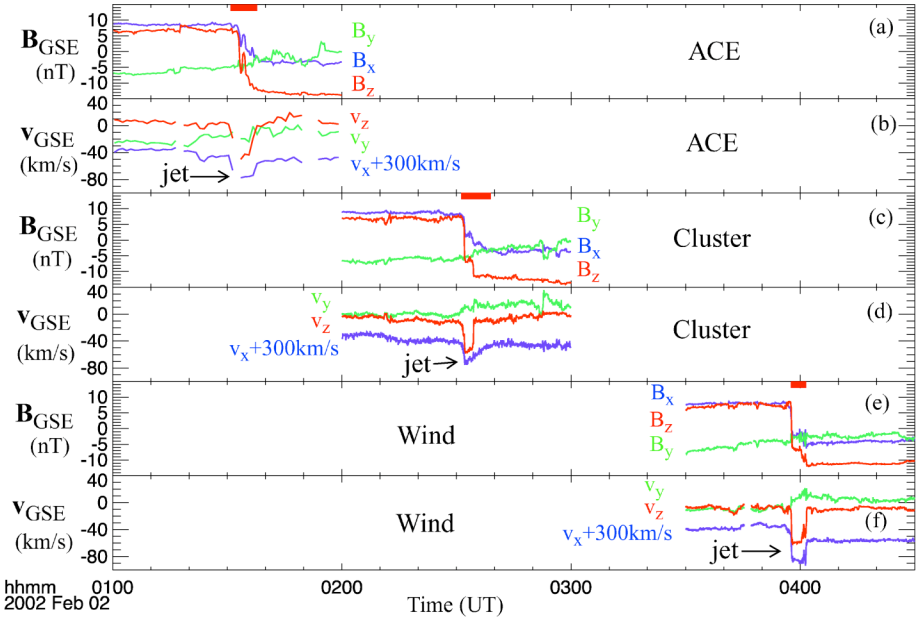




Implies guide field reconnection

Implies tearing mode?

3 S/C Observations of the 2 Feb. 2002 Exhaust

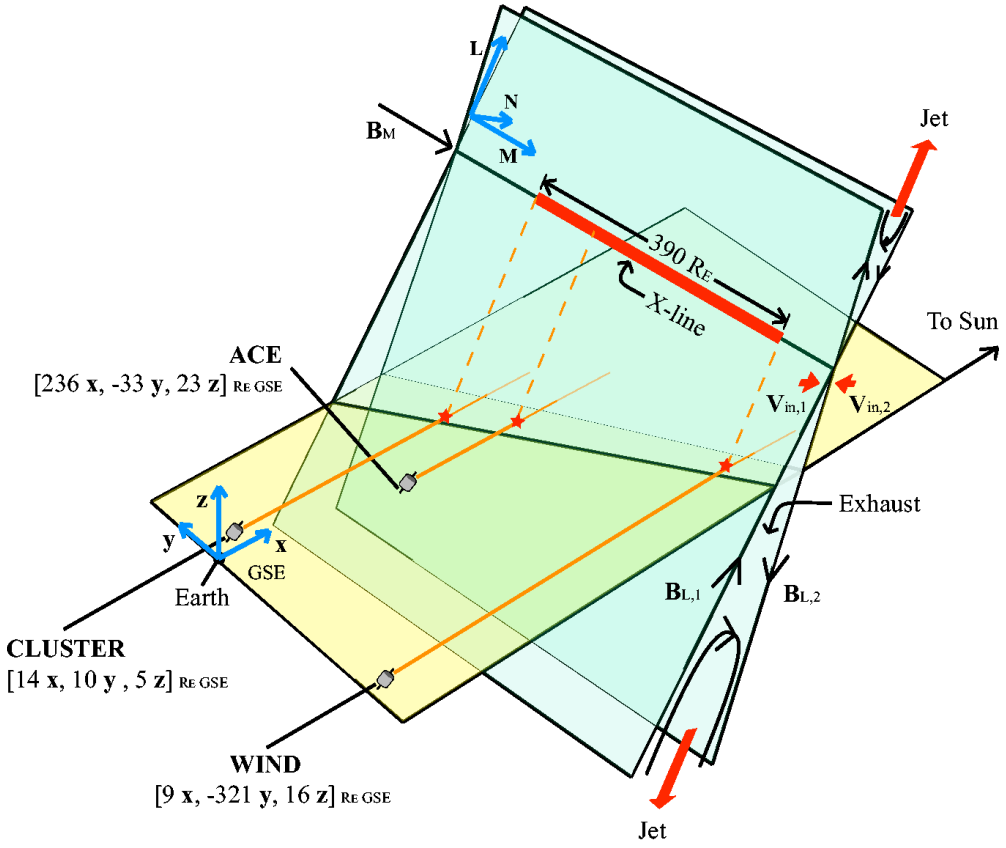


Reconnection X-line extended at least 390 Re.

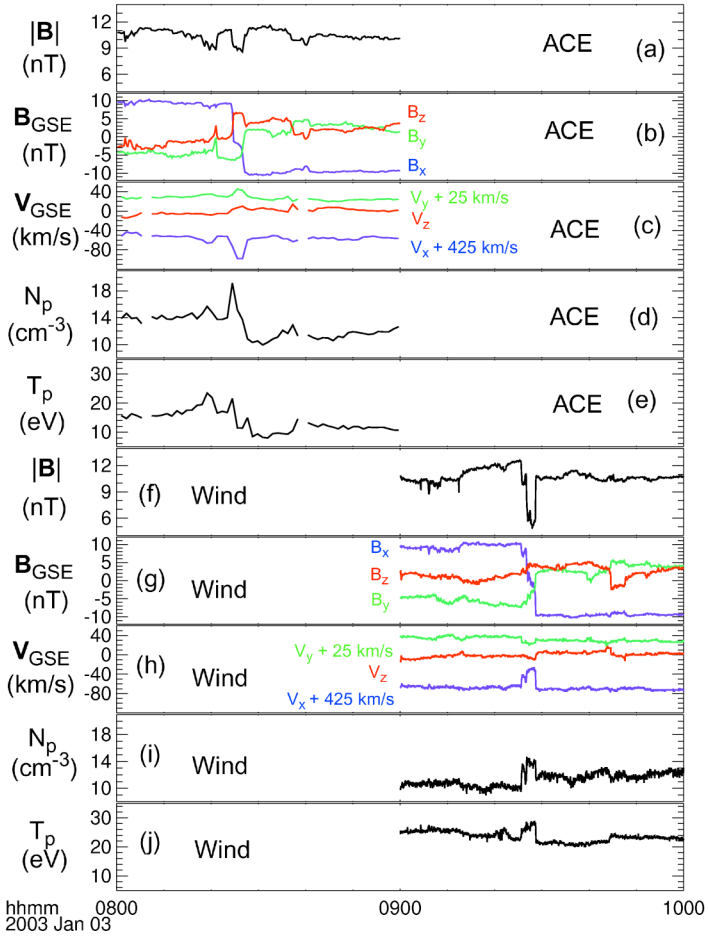
Reconnection persisted for at least 2.5 hours.

Geometry of the Observations

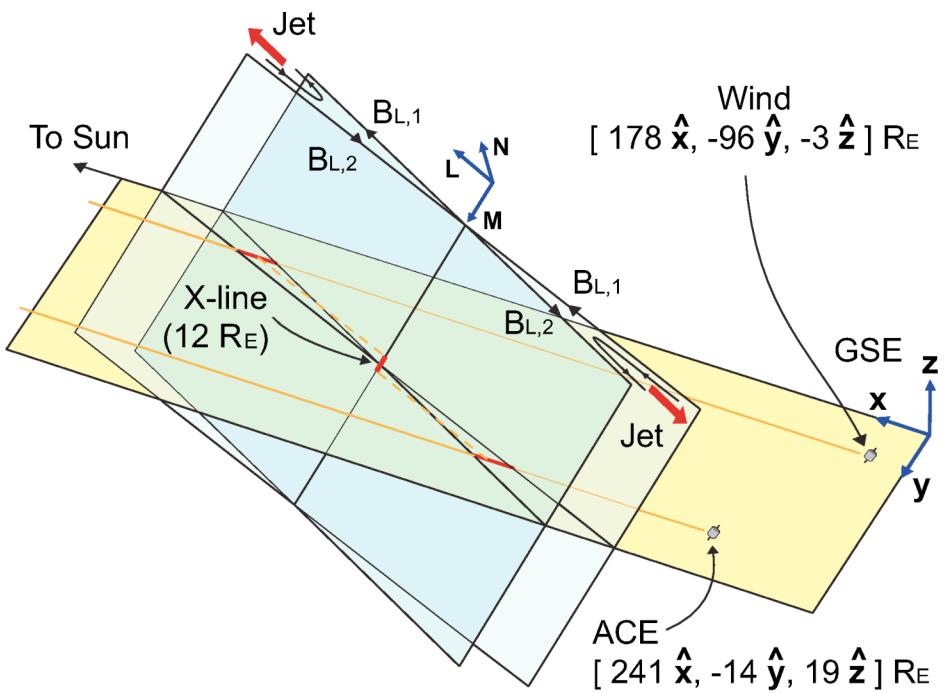
Phan et al.



Oppositely Directed Jets From a Reconnection Site



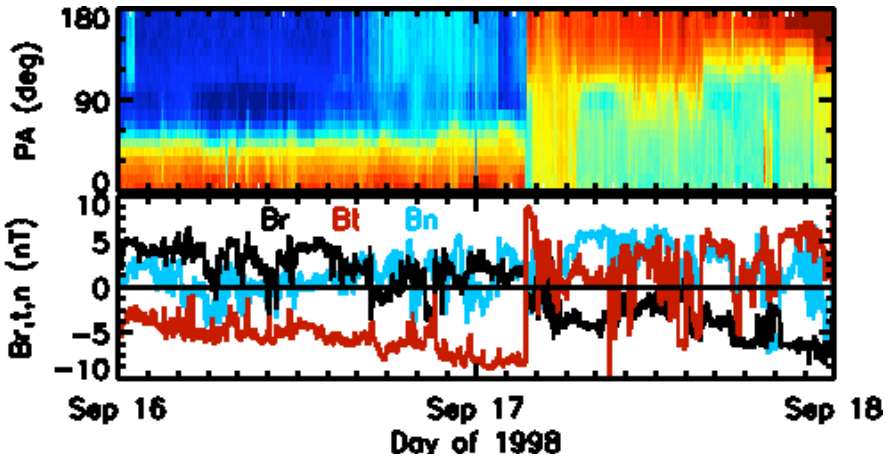
Davis et al.

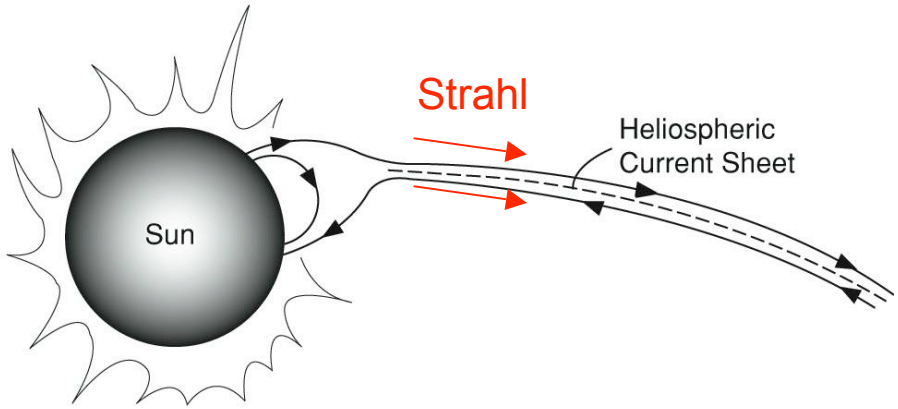


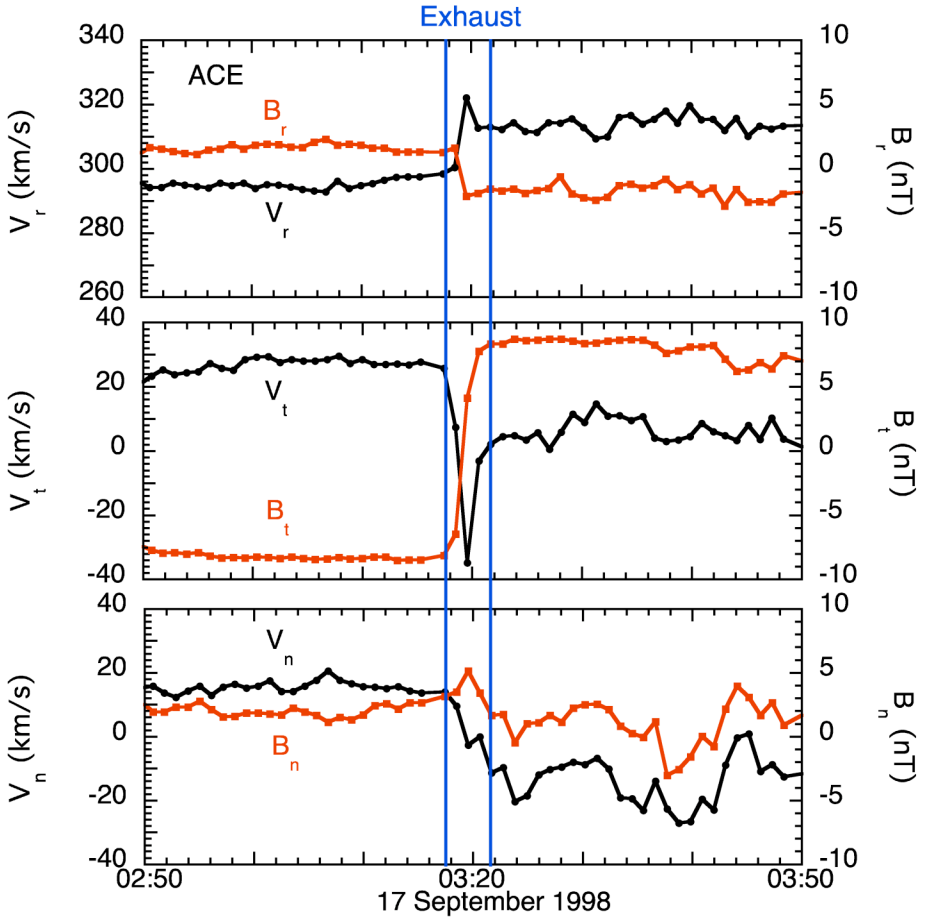
Provides strong confirmation that these events are product of local, quasi-stationary reconnection in solar wind.

Confirms presence of strong guide field at reconnection site.

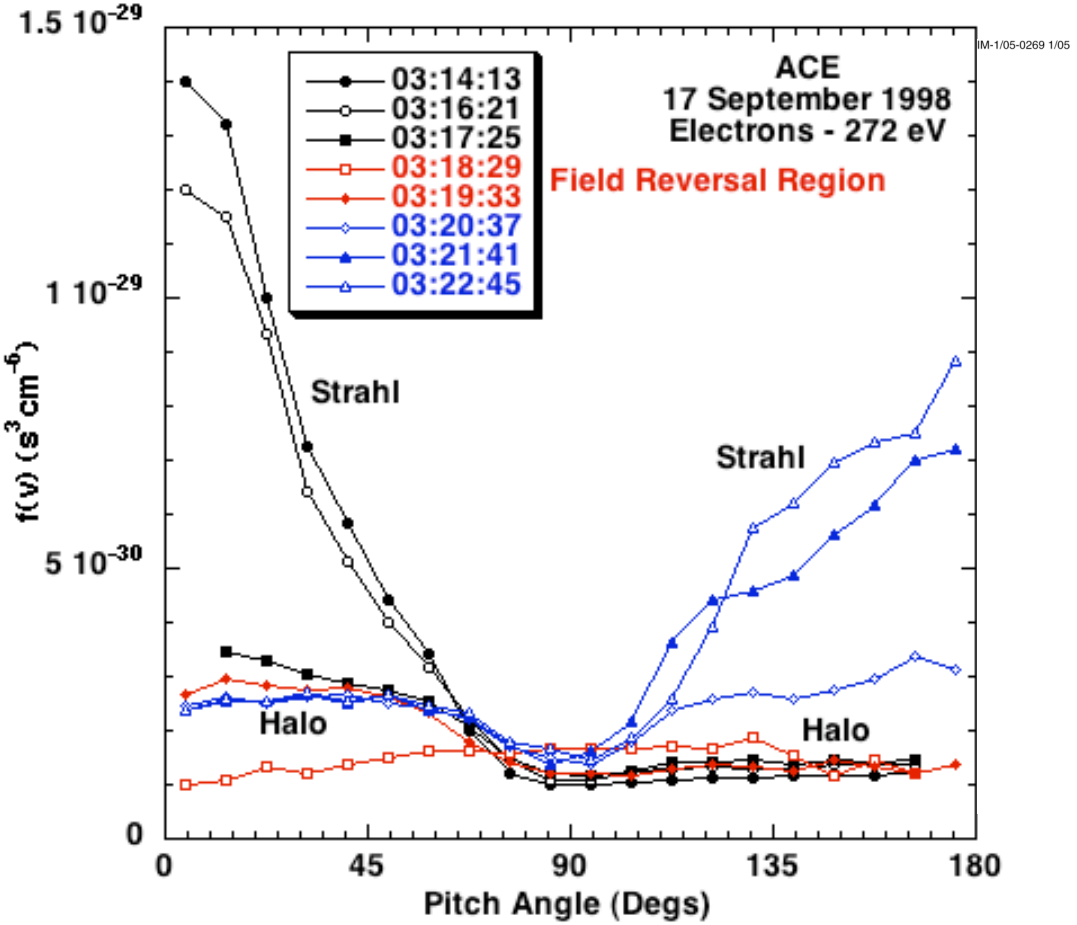
Reconnection at the Heliospheric Current Sheet

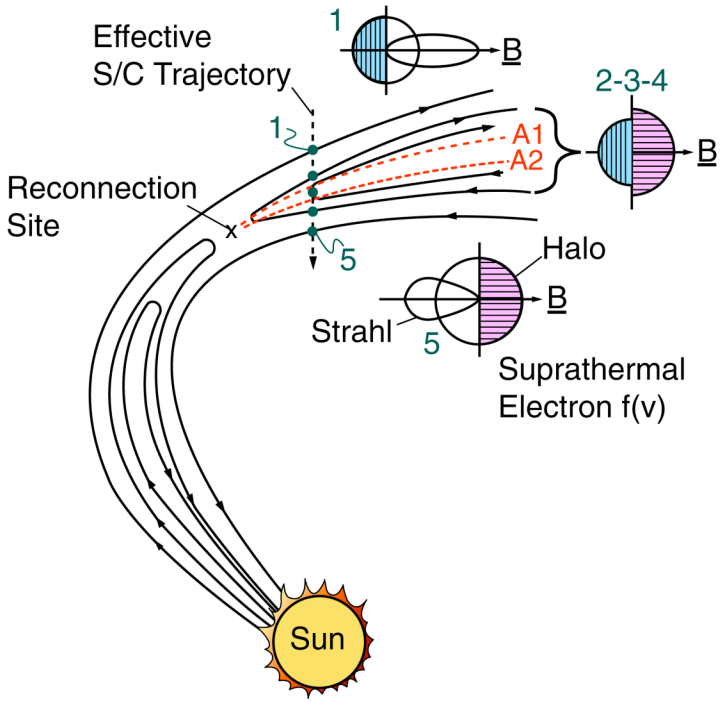






Strahl Disappearance and An Asymmetric Halo: Evidence for Magnetic Disconnection From the Sun

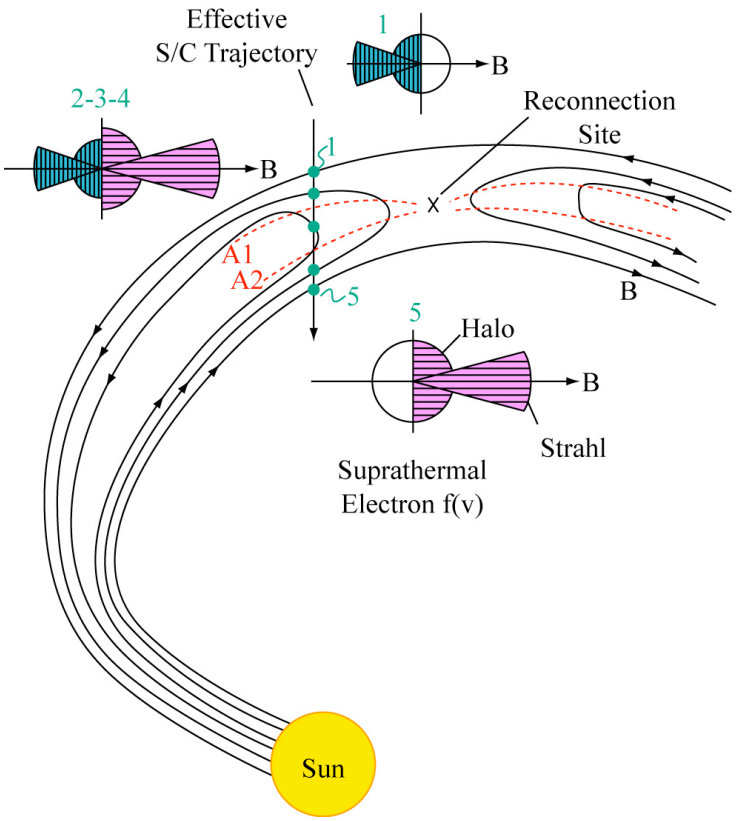




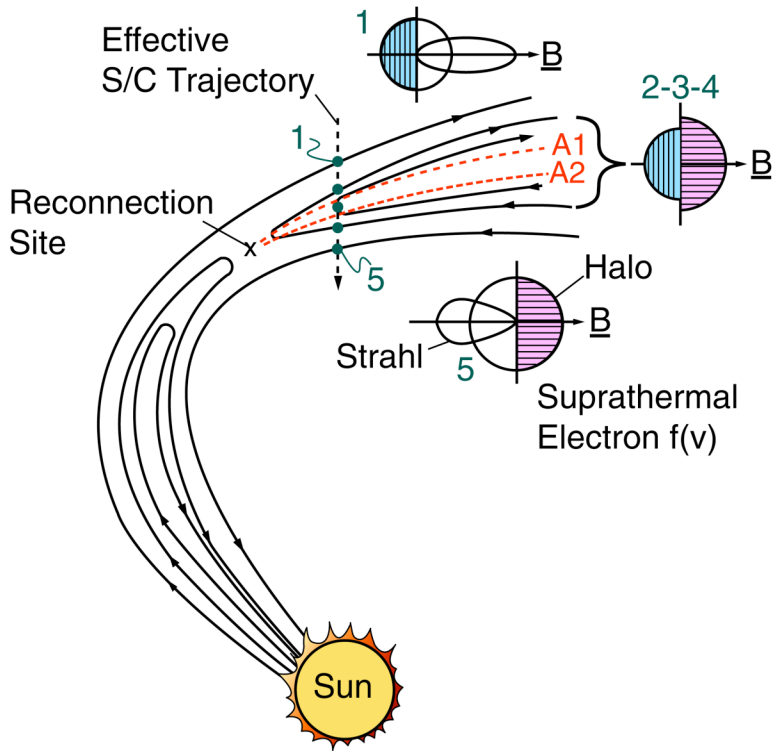
Schematics Illustrating Evolution of Suprathermal Electron f(v) for Reconnection at the Heliospheric Current Sheet*

* Note: B-orientations reversed in left and right plots

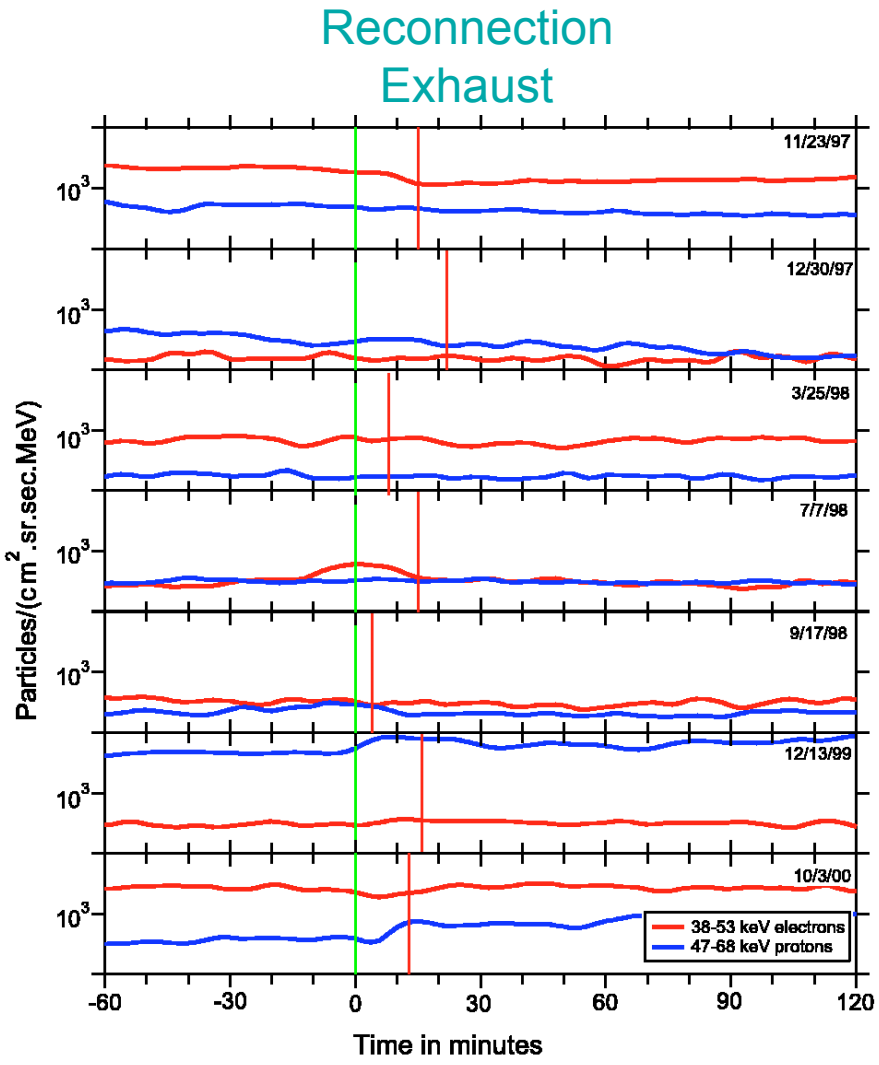
Sunward Side



Anti-sunward Side



Energetic Electron and Proton Measurements in 3-Hr Intervals Encompassing 7 Solar Wind Reconnection Exhausts

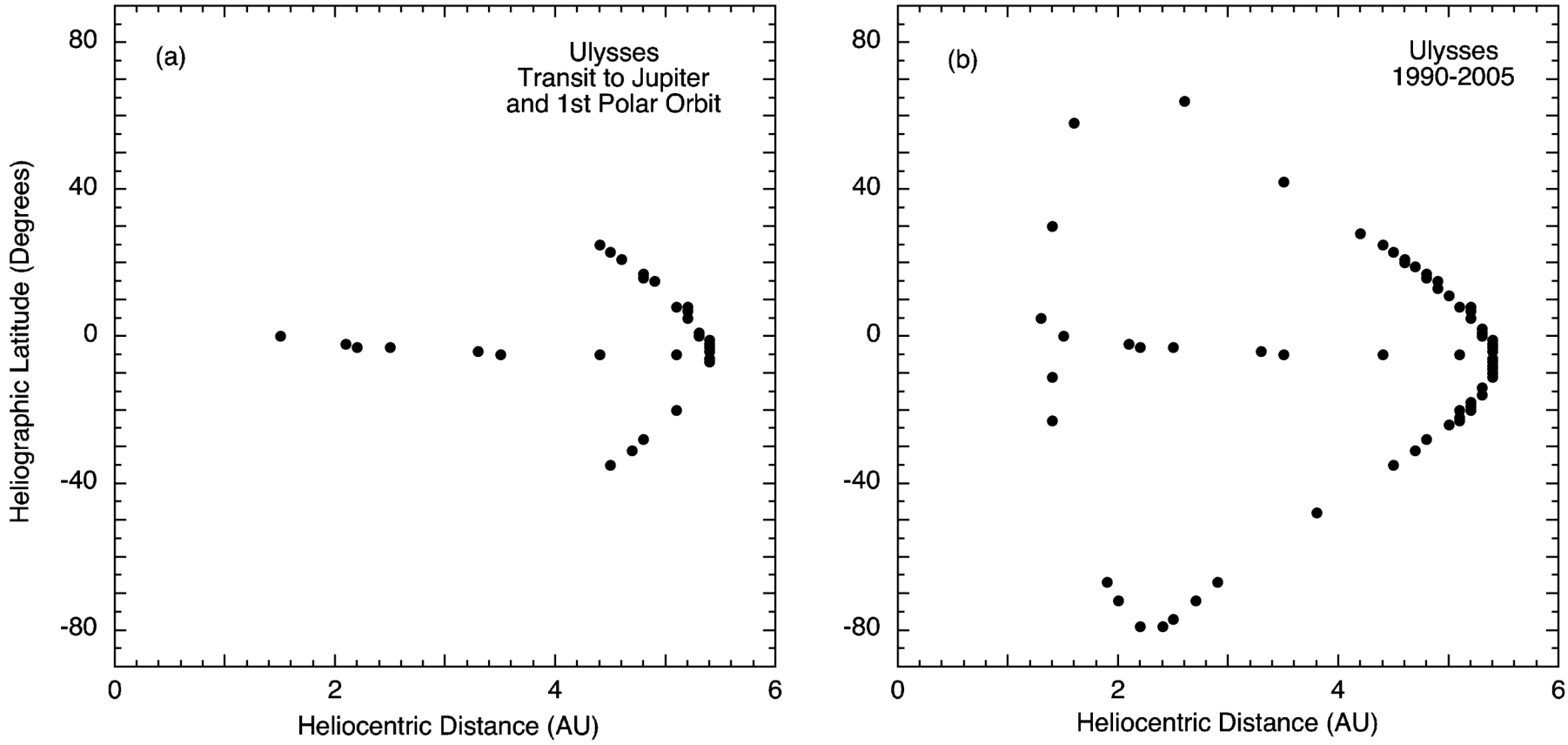


Various energetic particle background events prevailed during the 3-hr intervals.

There were no substantial energetic electron or proton enhancements one would associate with the reconnection exhausts in any of these intervals.

Does reconnection necessarily produce high-energy particles?

Exhaust Encounters Along Ulysses' Orbit



Reconnection exhausts have been encountered at all heliocentric distances and latitudes sampled by Ulysses (and Helios), but not within high-speed streams from coronal holes.

Why haven't we detected Petschek-like exhausts in the high-speed wind from coronal holes?

1. *High-speed wind from coronal holes typically has high proton beta.*
2. *Almost all current sheets in high-speed wind appear to be associated with steepened Alfven waves rather than with tangential discontinuities.*
3. *Stable and well-ordered magnetic fields seldom are present in the Alfven wave and turbulence-dominated high-speed wind.*

If turbulence drives reconnection in the high-speed wind it probably does not form well-organized Petschek-type exhausts.

Reconnection: Questions, Problems, Topics for Future Work

Role of reconnection in CMEs and flares

Resolution of heliospheric magnetic flux balance problem

Role of interchange reconnection in:

- *magnetic flux transfer on solar surface*
- *producing nearly radial HMF and underwound spirals*
- *producing folded HMF intervals*

Particle acceleration associated with reconnection

Origin(s) of solar wind heat flux dropouts

Heliospheric counterpart of Sheeley-Wang coronal inflows

Sweet-Parker vs Petschek-type reconnection in corona and solar wind

X-line extents in solar atmosphere and solar wind: How long? How formed?

How long does/can reconnection persist in solar wind? What turns it off?

Signatures of patchy (in space and time) reconnection in corona and solar wind

Questions, Problems, Topics for Future Work (continued)

Signatures of turbulence-driven reconnection in heliosphere

Reconnection exhaust evolution and interaction with ambient wind

Reconnection with significant guide fields

Role of slow mode shocks in fast reconnection in solar wind

Slow mode shock physics

What initiates reconnection in corona and solar wind?

Is reconnection driven or spontaneous or both?

Why is low beta preferred in solar wind reconnection? Tearing mode?

Reconnection rates and exhaust wedge angles

Physics of coupling of interpenetrating ion beams and electrons in reconnection exhausts

Comparison of observations and fluid and kinetic simulations of reconnection exhausts

Reconnection inflow physics

Questions, Problems, Topics for Future Work (continued)

Diffusion region physics

Hall physics

Comparative reconnection: corona, solar wind, magnetopause, geotail, lab

Reconnection-oriented NASA missions in near future:

- *STEREO*
- *Themis*
- *MMS*
- *RAM?*