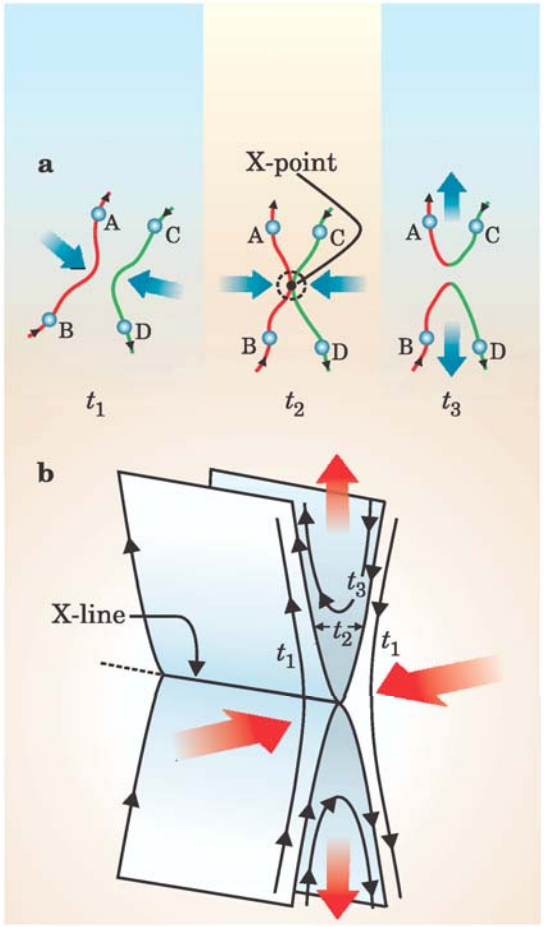
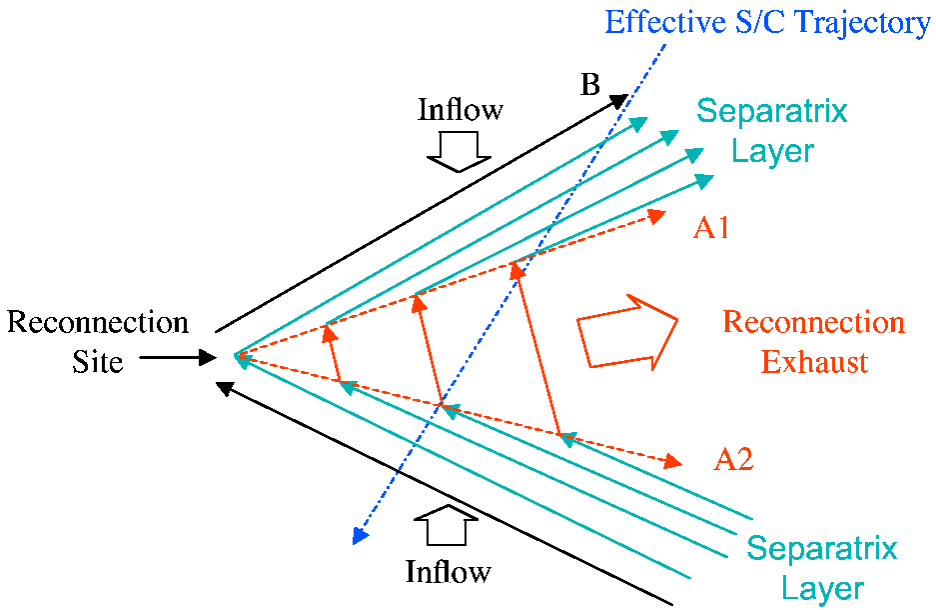
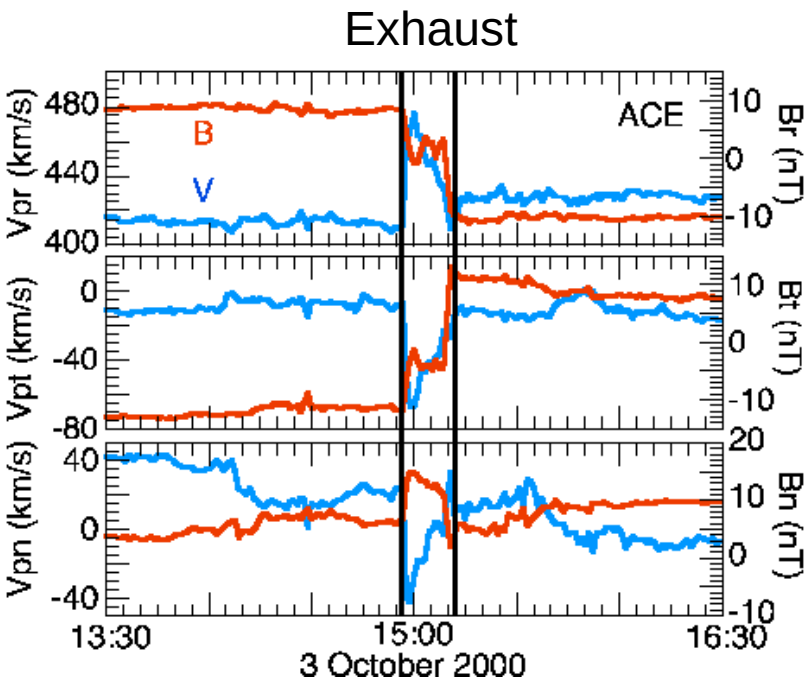
Five Spacecraft Observations of Oppositely Directed Exhaust Jets from a Magnetic Reconnection X-line Extending > 4.3 x 10^6 km in the Solar Wind

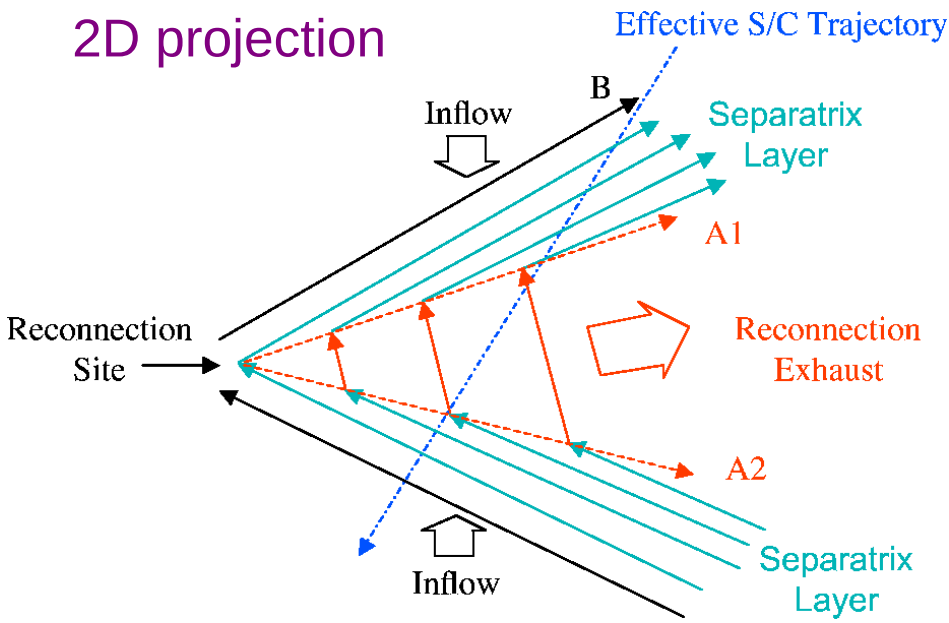




Gosling et al., GRL, 34, L20108, doi:10.1029/GL031492, 2007

Reconnection Exhausts in the Solar Wind





A reconnection jet or exhaust is identified as roughly Alfvenic accelerated plasma confined to a field reversal region.

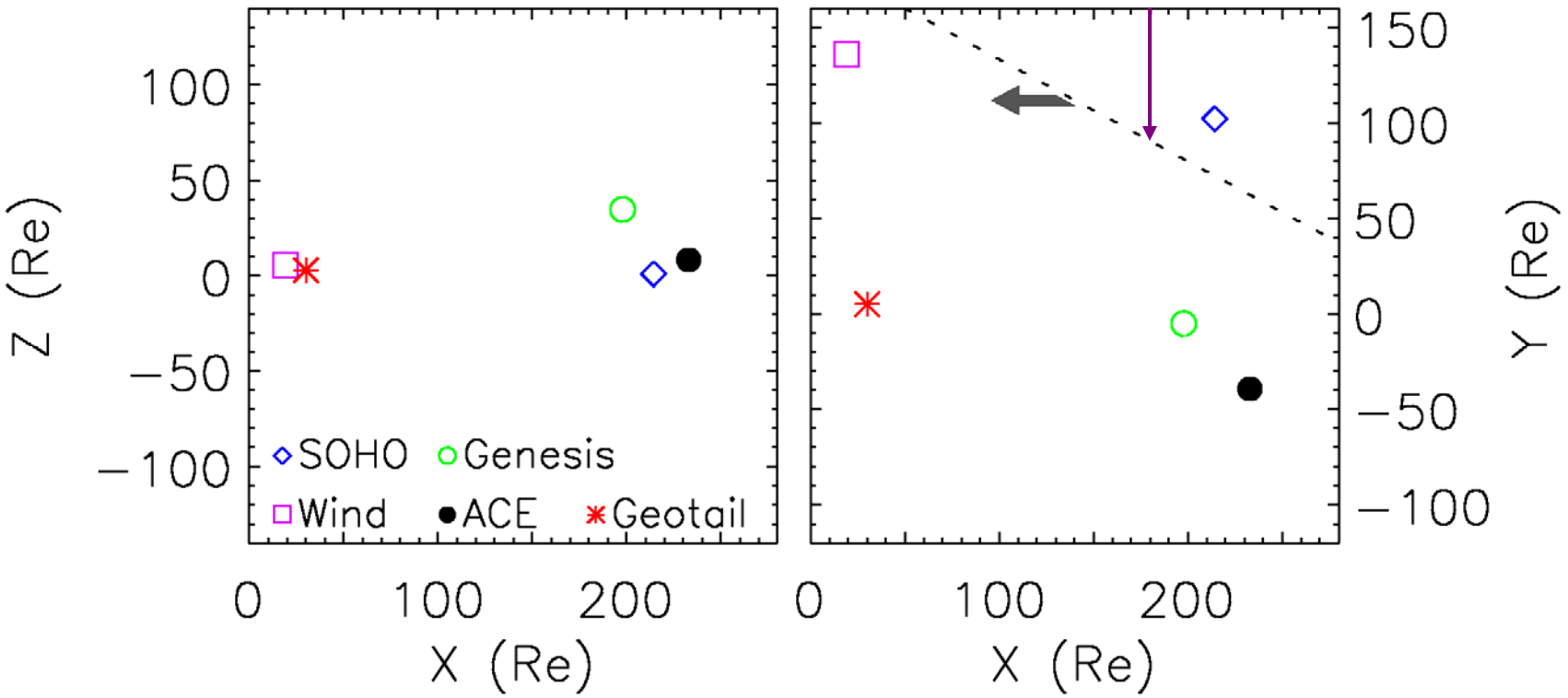
Current sheet is typically bifurcated (double step).

Changes in ***V*** and ***B*** are anti-correlated at one edge and correlated at other edge, consistent with Alfven waves propagating in opposite directions along reconnected field lines.

A very large number (40 - 70 events/month at solar minimum) of such exhausts have now been identified in solar wind data.

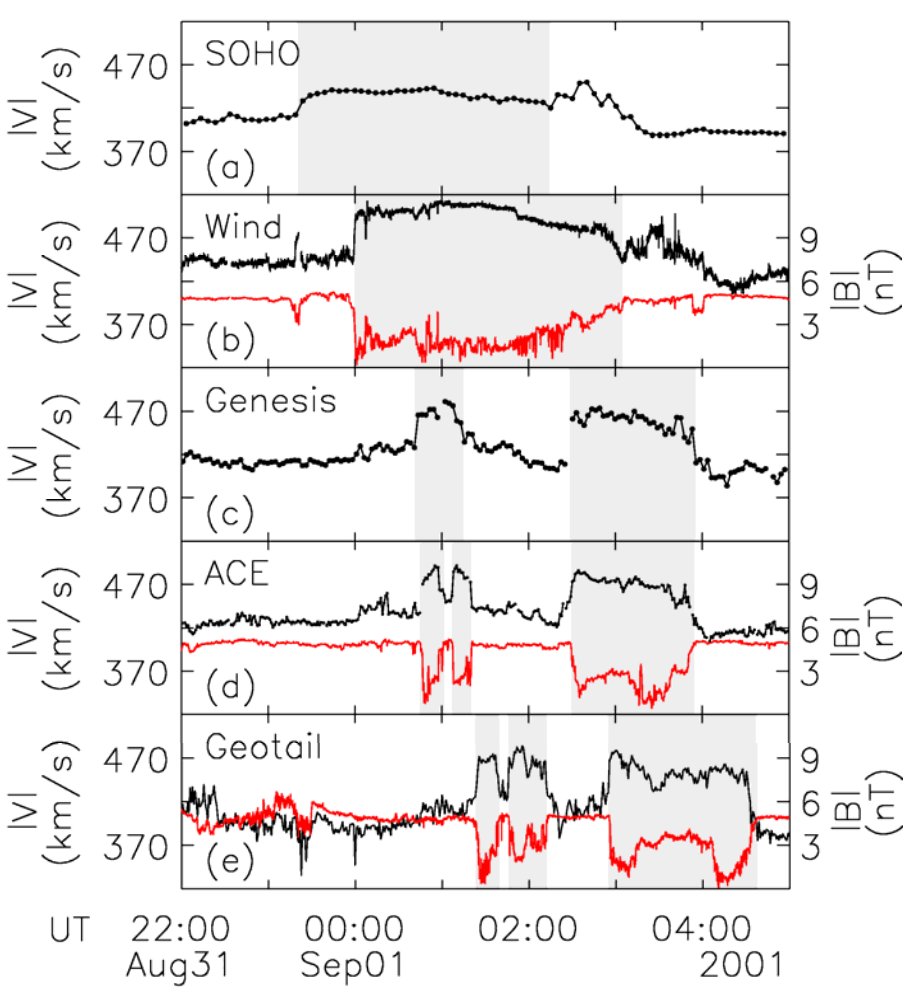
Observational Geometry for a Grazing Encounter with an Extended Reconnection Exhaust by 5 Spacecraft on 31 August and 1 September 2001

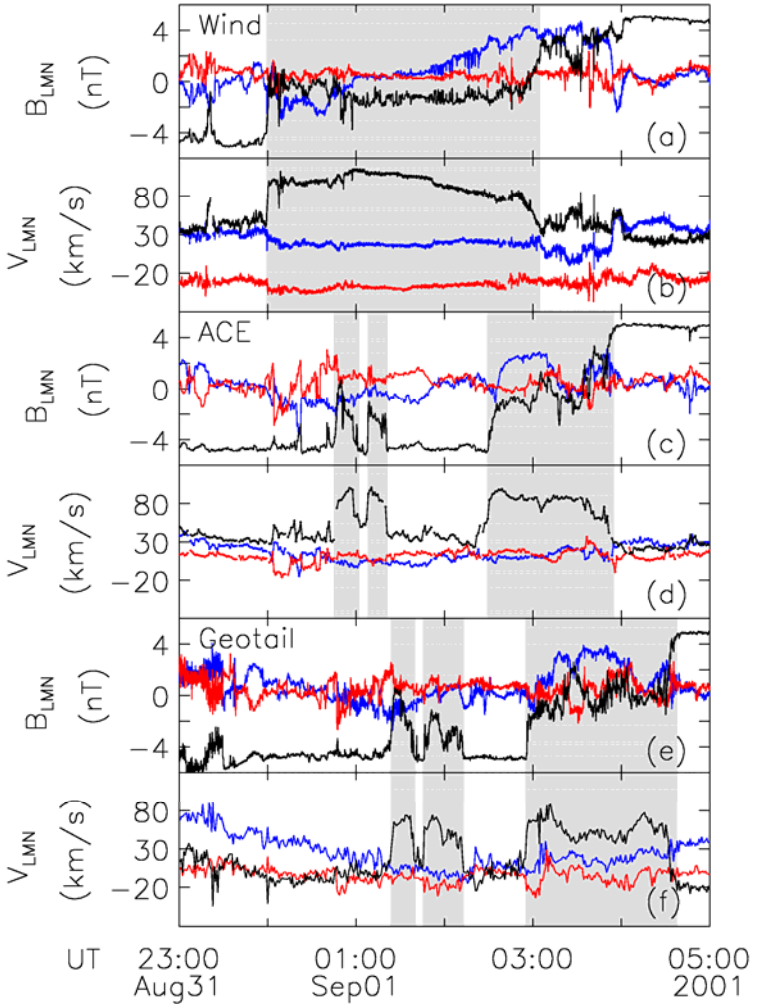
Exhaust intersection with xy-plane



Prolonged Reconnection at an Extended and Continuous X-line:

L,M,N (minimum variance coordinates)





Energy extracted from the current sheet was ~1.2 x 10^{24} ergs - comparable to energy released in a large geomagnetic storm, but small compared to energy released in a large flare or CME (10^{32} ergs).

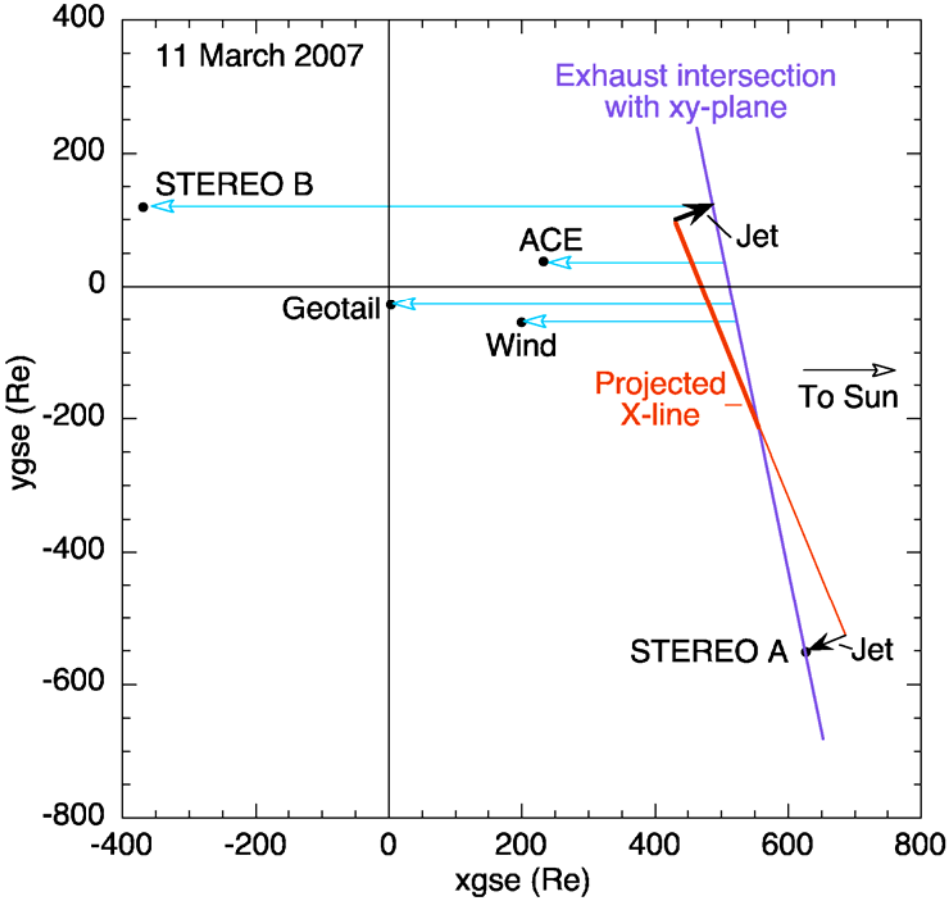
Measurements of X-line lengths and reconnection durations are important because:

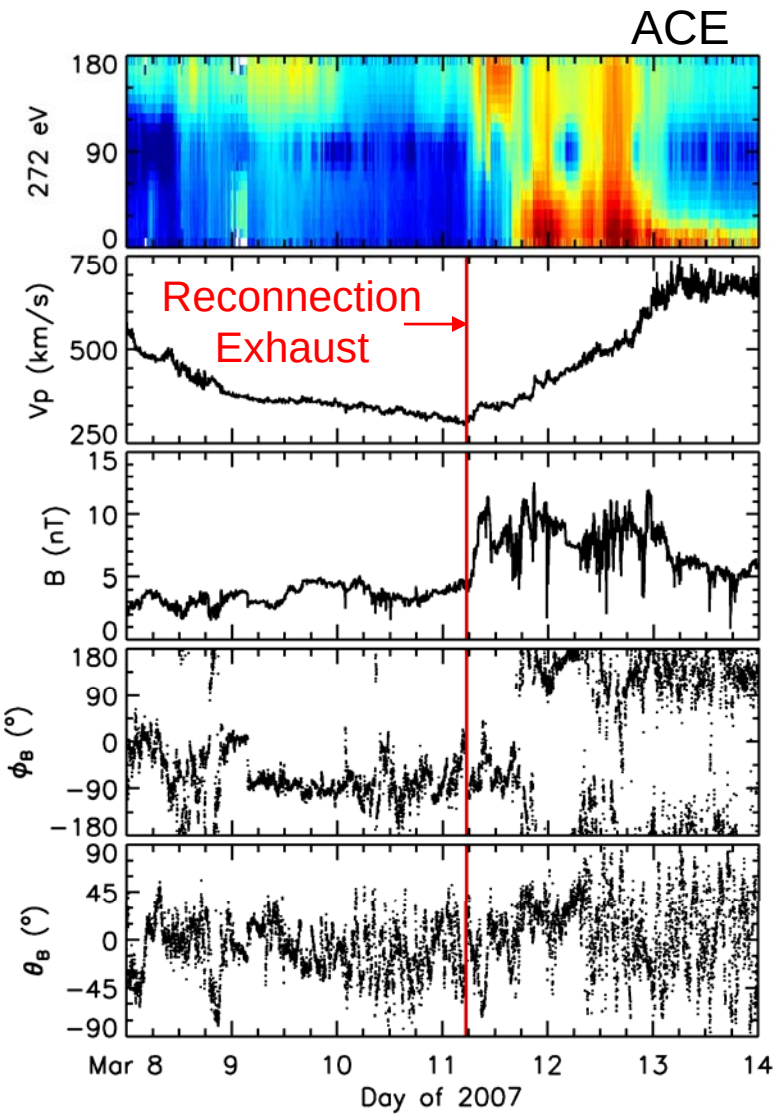
1) They inform us of the overall spatial and temporal scale size of the reconnection process,

2) They contrast with the view that reconnection is fundamentally highly localized in space and time, and

3) Along with reconnection rates, they determine how much magnetic flux is reconnected in an event.

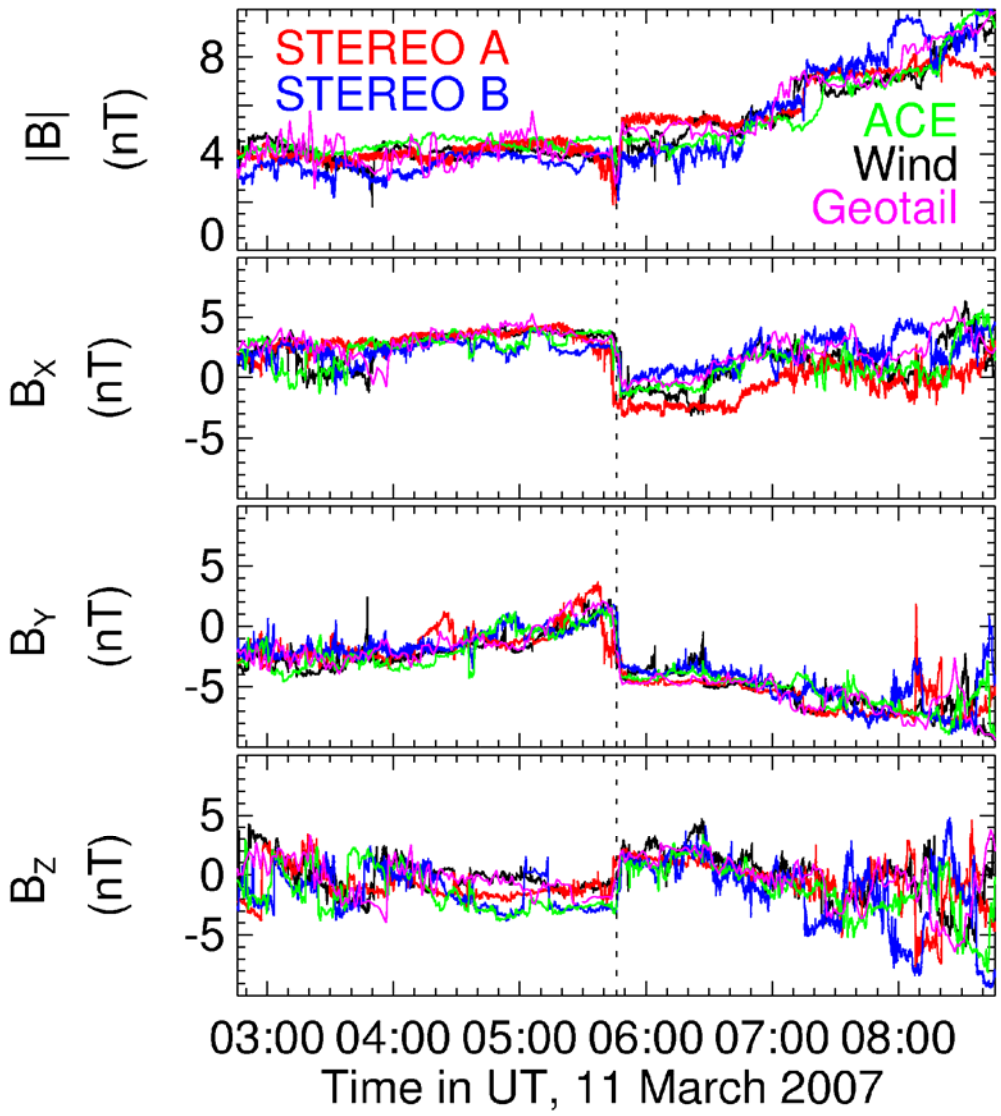
S/C Geometry and Heliospheric Environment of the 11 March 2007 Event





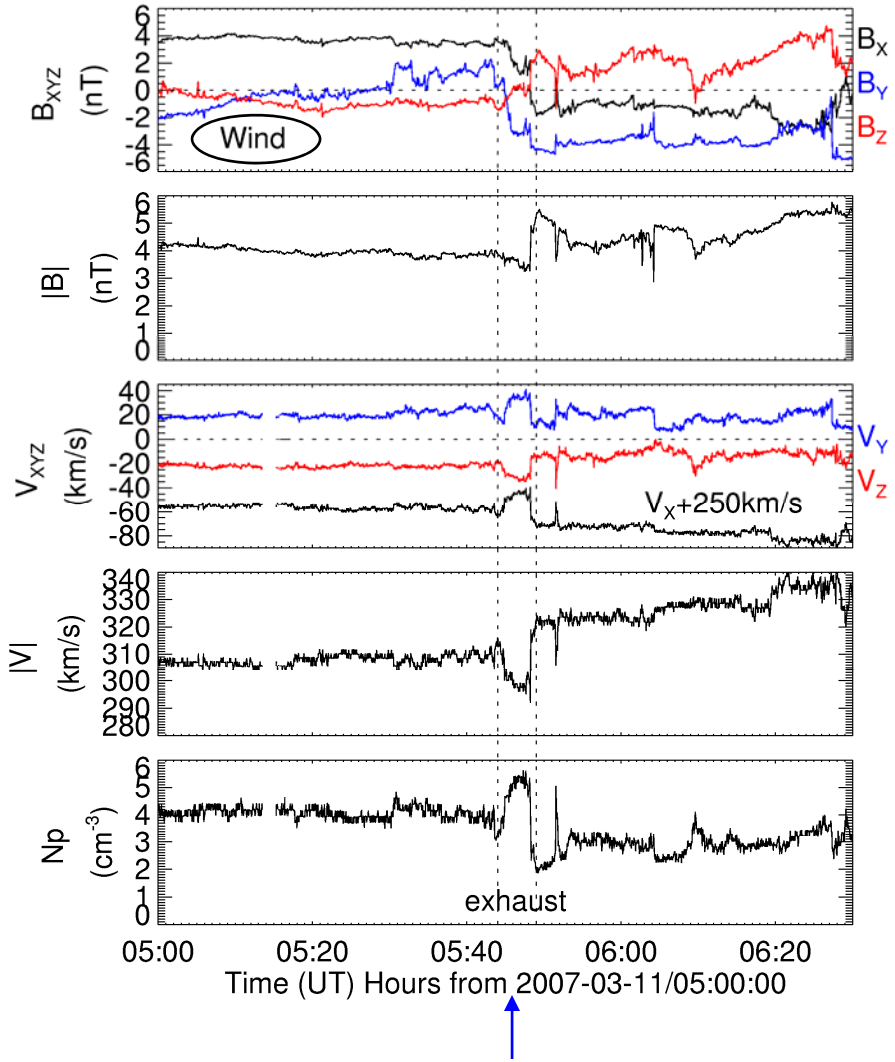
STEREO A and B were separated by 1215 Re.

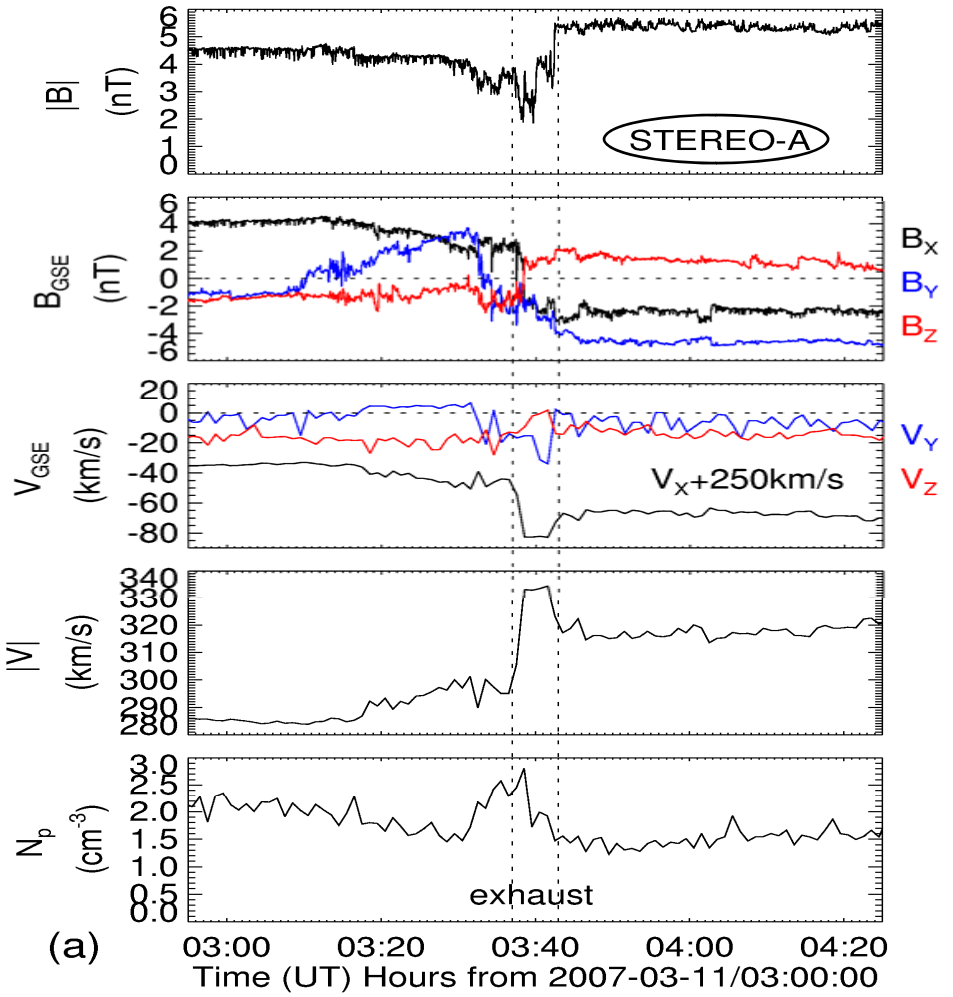
A Reconnecting Current Sheet Observed by all 5 Spacecraft



Time shifts: Stereo A +126 min; ACE +20 min; Wind 0 min; Geotail -58 min; Stereo B -193 min Field shears: 95˚ 127˚ 133˚ 138˚ 146˚

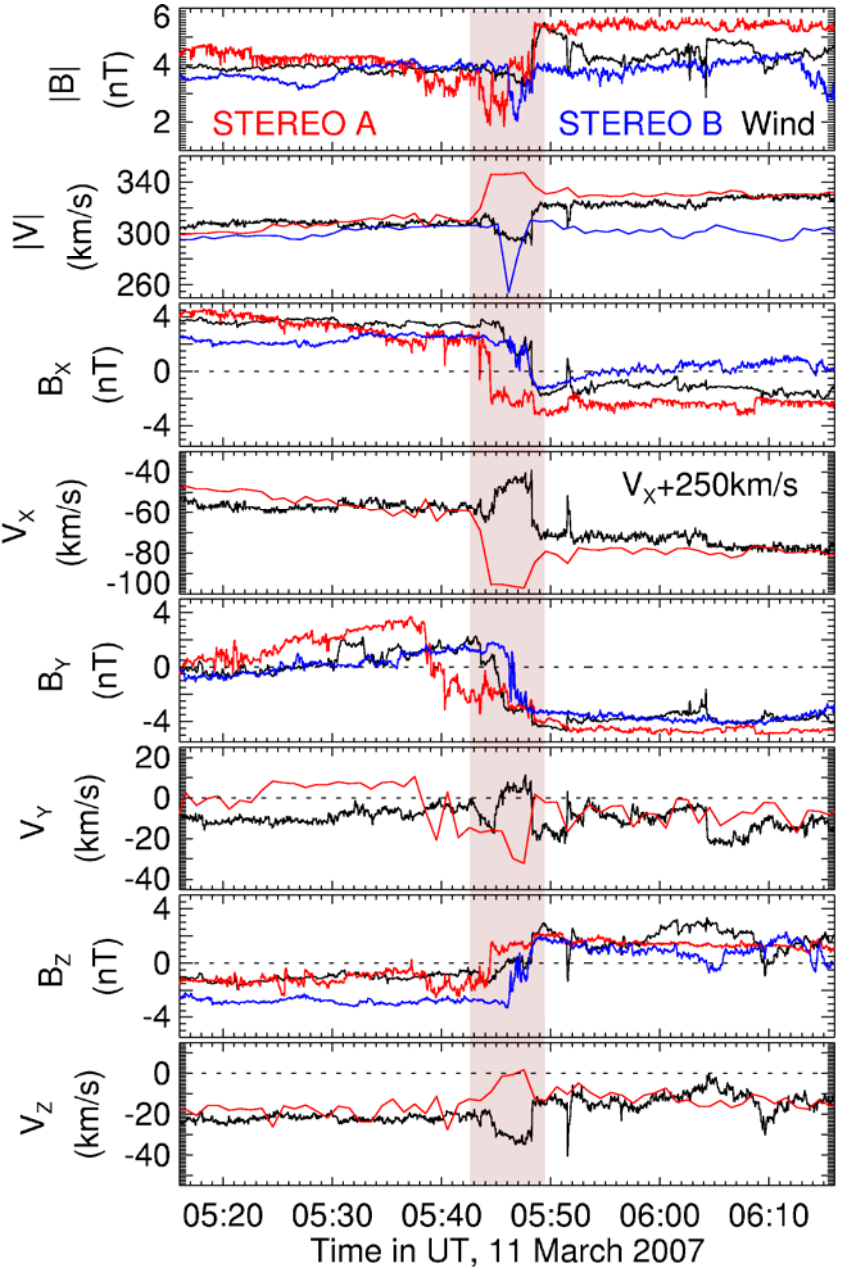
Oppositely Directed Exhausts From a Common Reconnection X-Line





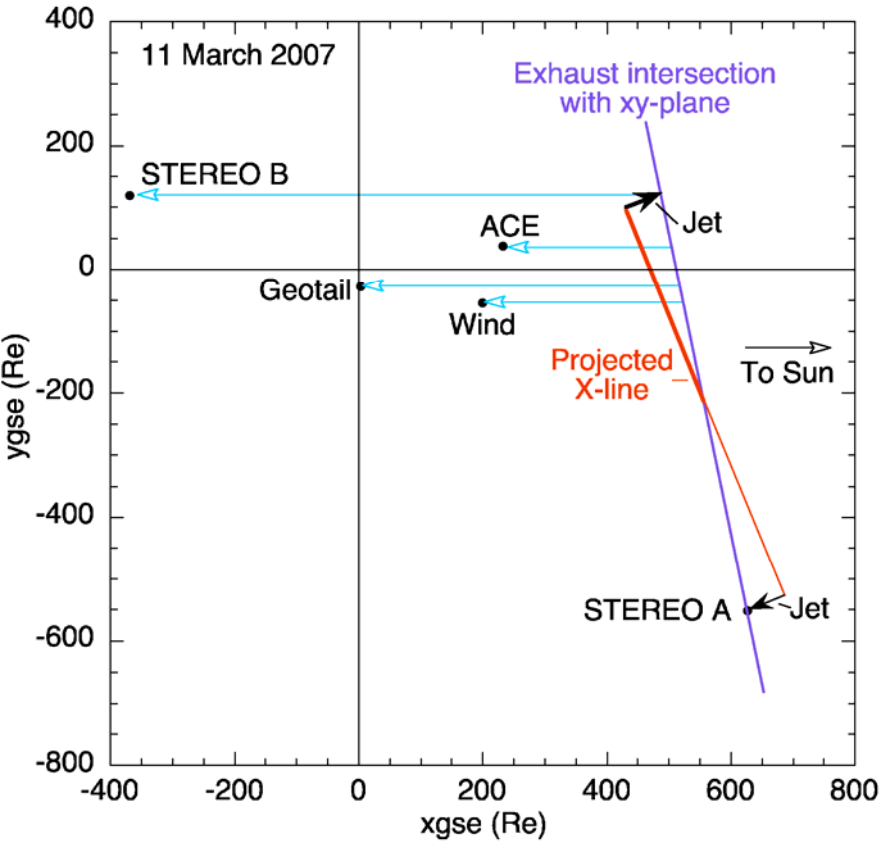
Similar signatures observed at ACE, Geotail and STEREO B.

A Time-Shifted Overlay of STEREO A, Wind and STEREO B Plasma and Field Data



Note: 3D velocity data are not yet available for STEREO B.

Observational Summary



Exhaust intersection and X-line orientation were determined from MVAB of STEREO A field data.

X-line tilt: 6.7˚ to xy plane.

Delays relative to STEREO A:

Observed: (105, 126, 184, 320) minutes

Calculated: (96, 115, 182, 309) minutes

X-line length: At least 668 Re = 4.26 x 10^6 km = 0.0284 AU = 6.12 solar radii.

Reconnection duration: At least 320 minutes.

Discussion

Why is reconnection quasi-stationary?

Pressure gradients associated with rarefaction produced by the outflow of plasma from diffusion region sustain reconnection by continually accelerating new plasma and magnetic field into the diffusion region.

Why are some reconnection X-lines so long?

In 2D (no guide field) short initial X-line expands at significant fraction of Alfven speed (Shay et al,; Lapenta et al.). - Owing to pressure gradient in X-line direction?

In presence of strong guide field X-line expansion might proceed at electron thermal speed (Drake, Lapenta: private communication). Not clear why.

The End

We are in the process of extending this type of analysis to other current sheets / reconnection exhausts observed as STEREO A and B drift ever further apart.

What we would really like to have for current sheet and reconnection exhaust analyses

Readily available, reliable, 3D data at 1 minute temporal resolution (at least) from both the A and B spacecraft.

Common coordinate system for field and plasma data, preferably r,t,n.

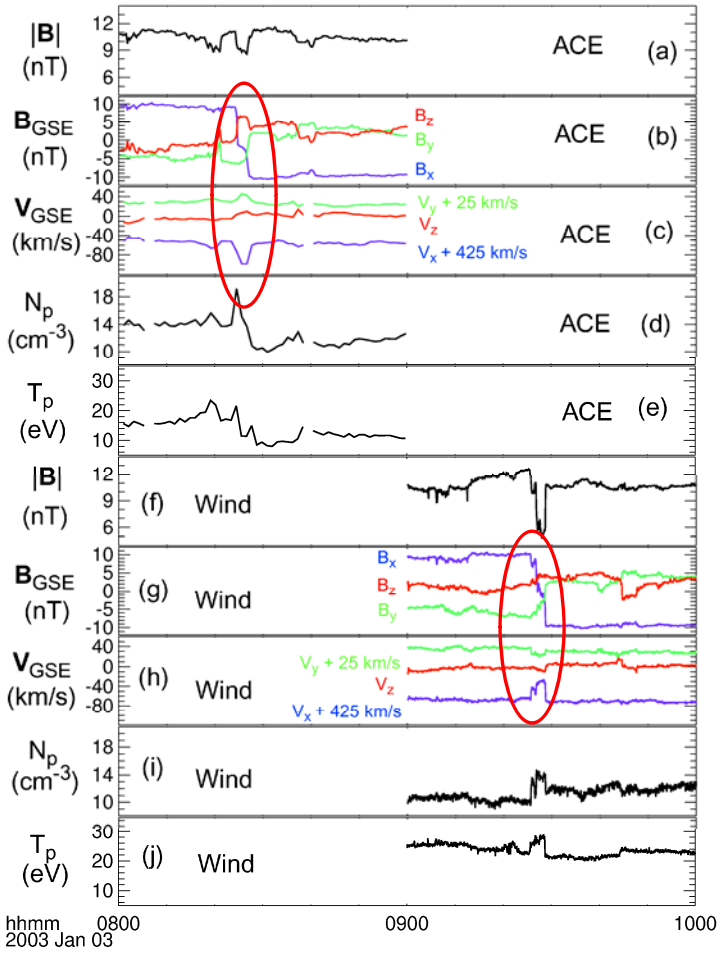
Common timing labeling, preferably hh:mm:ss.

Suprathermal electron pitch angle plots.

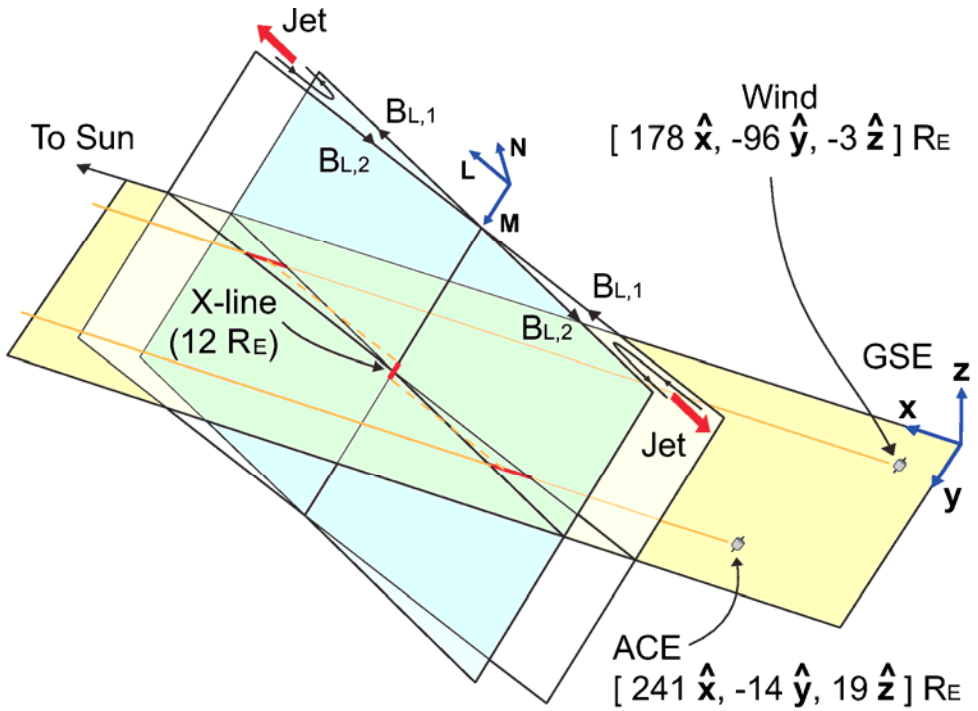
Combined 3D ion moment, magnetic field, and suprathermal electron pitch angle plots.

Magnetic field plots should include components, magnitude, and azimuth and polar angles.

Oppositely Directed Jets From a Reconnection Site



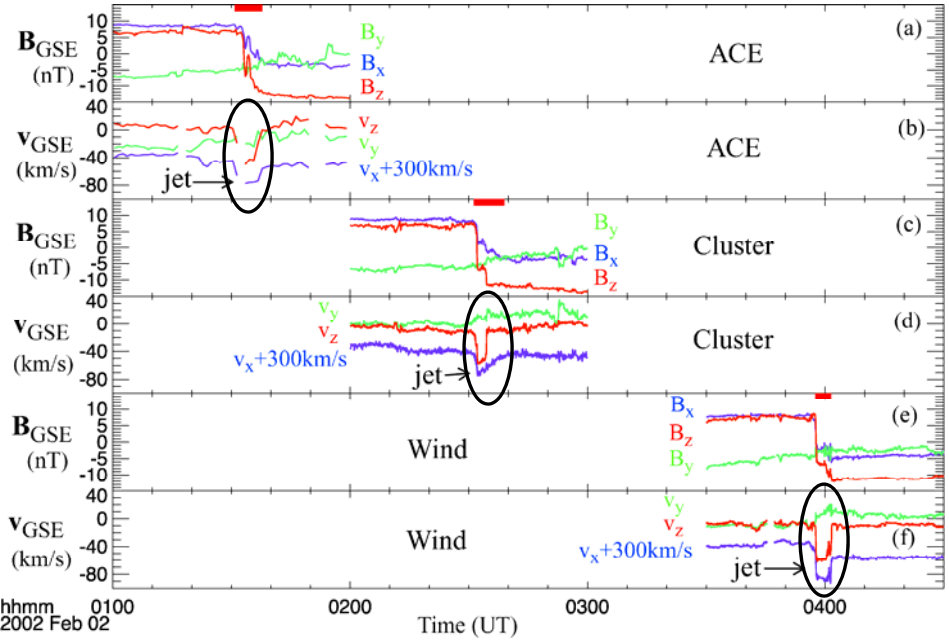
Davis et al.



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

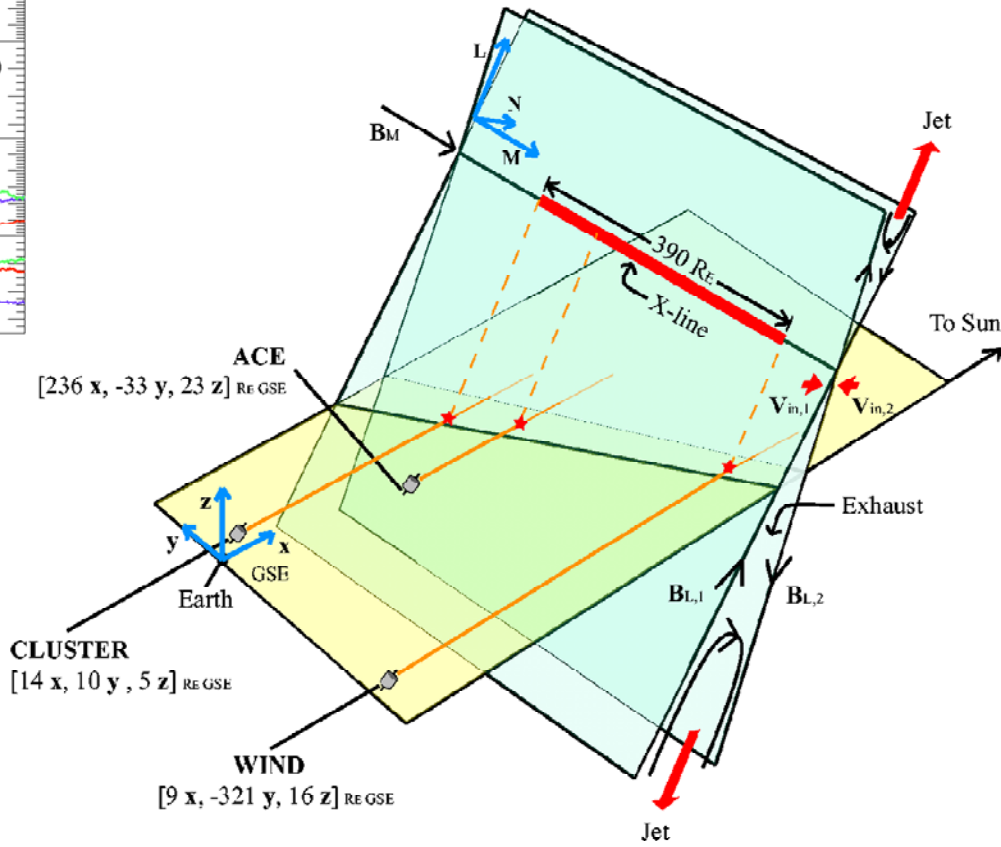
Confirms presence of strong guide field in many of these events.

An Extended X-line in the Solar Wind



Phan et al.

Geometry of the Observations

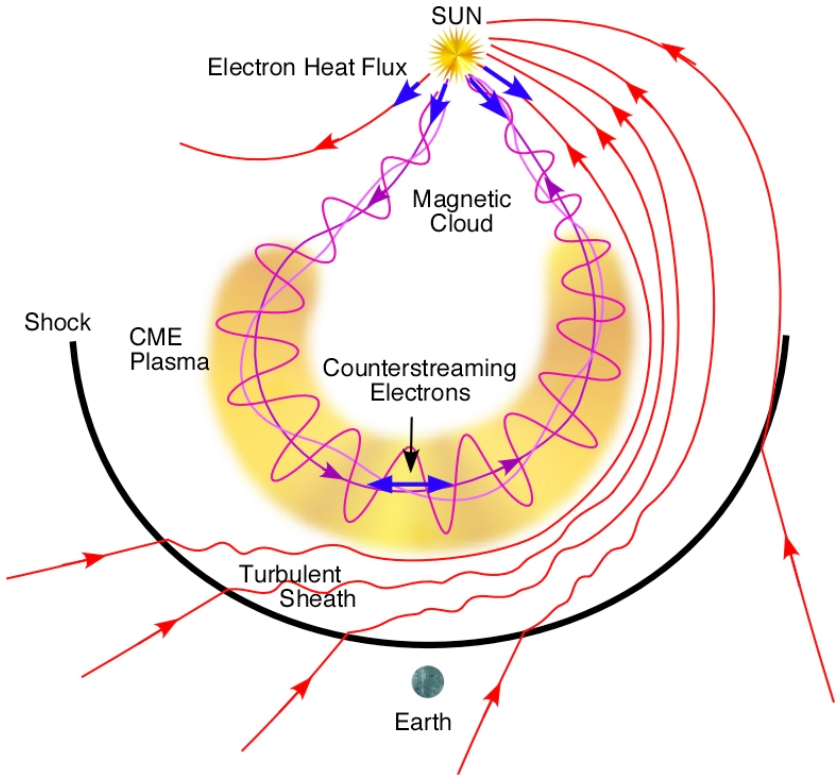


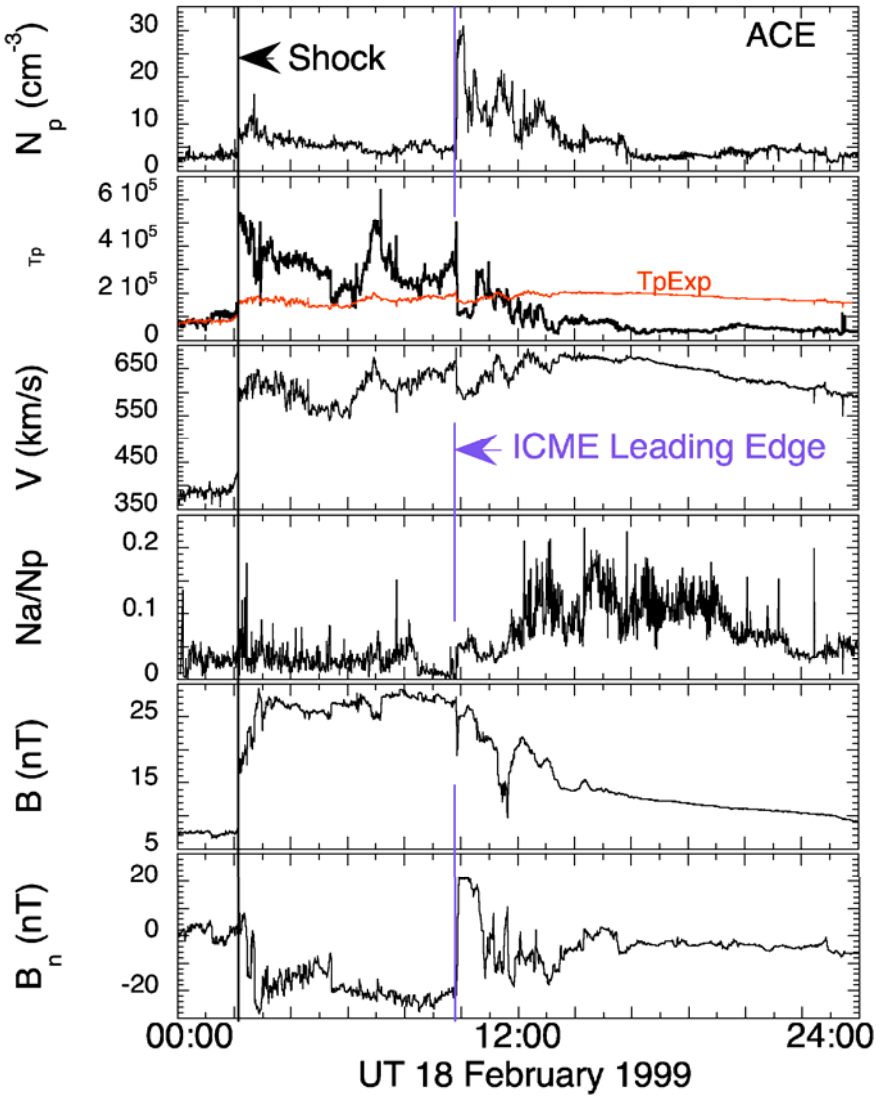
Reconnection X-line extended at least 390 Re (~2.45 x 10^6 km).

Reconnection persisted for at least 2.5 hours.

Numerous similar ACE/WIND events.

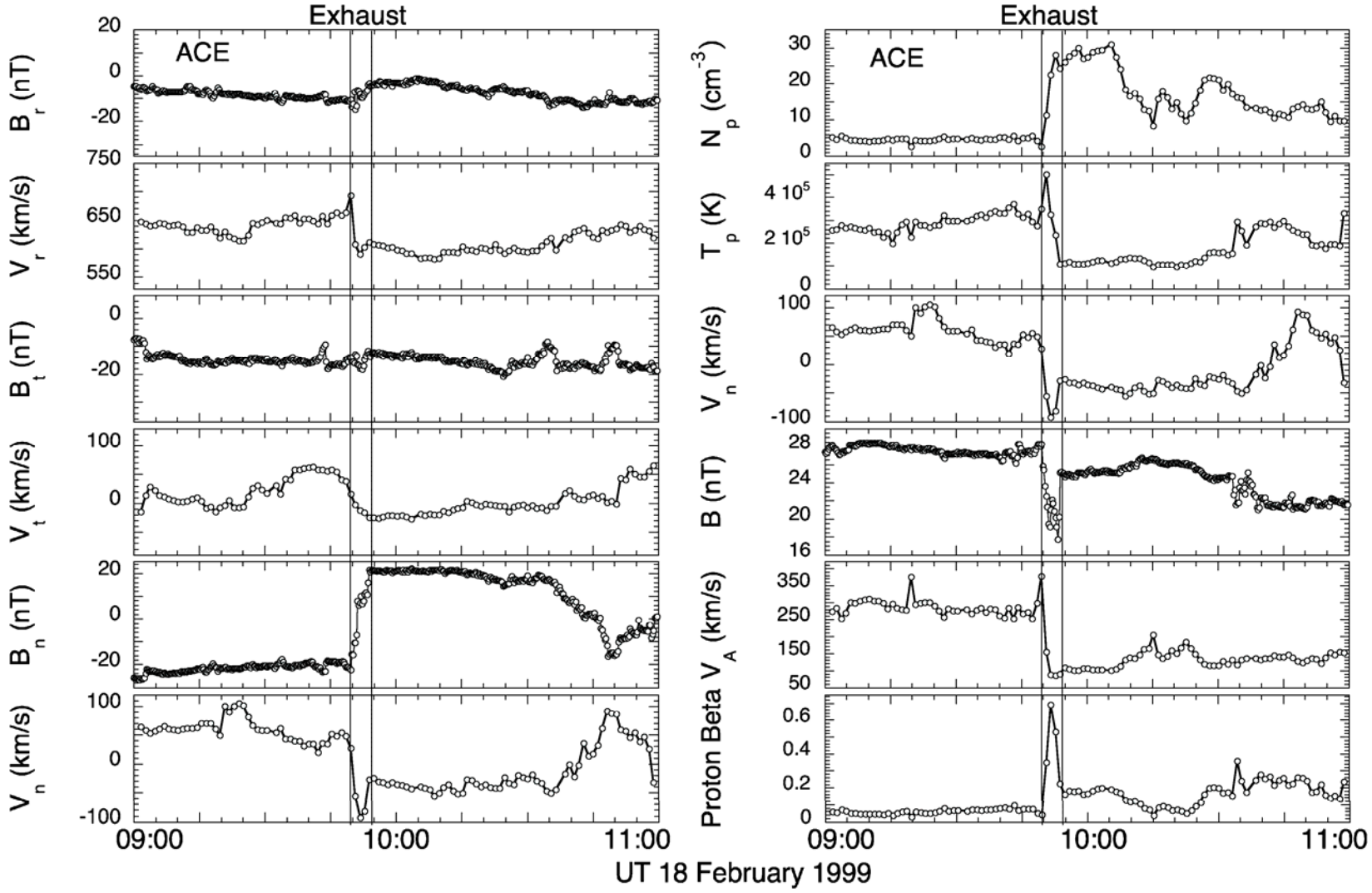
A Reconnection Exhaust at the Leading Edge of an ICME





Reconnection occurs only occasionally at ambient wind/ICME interfaces.

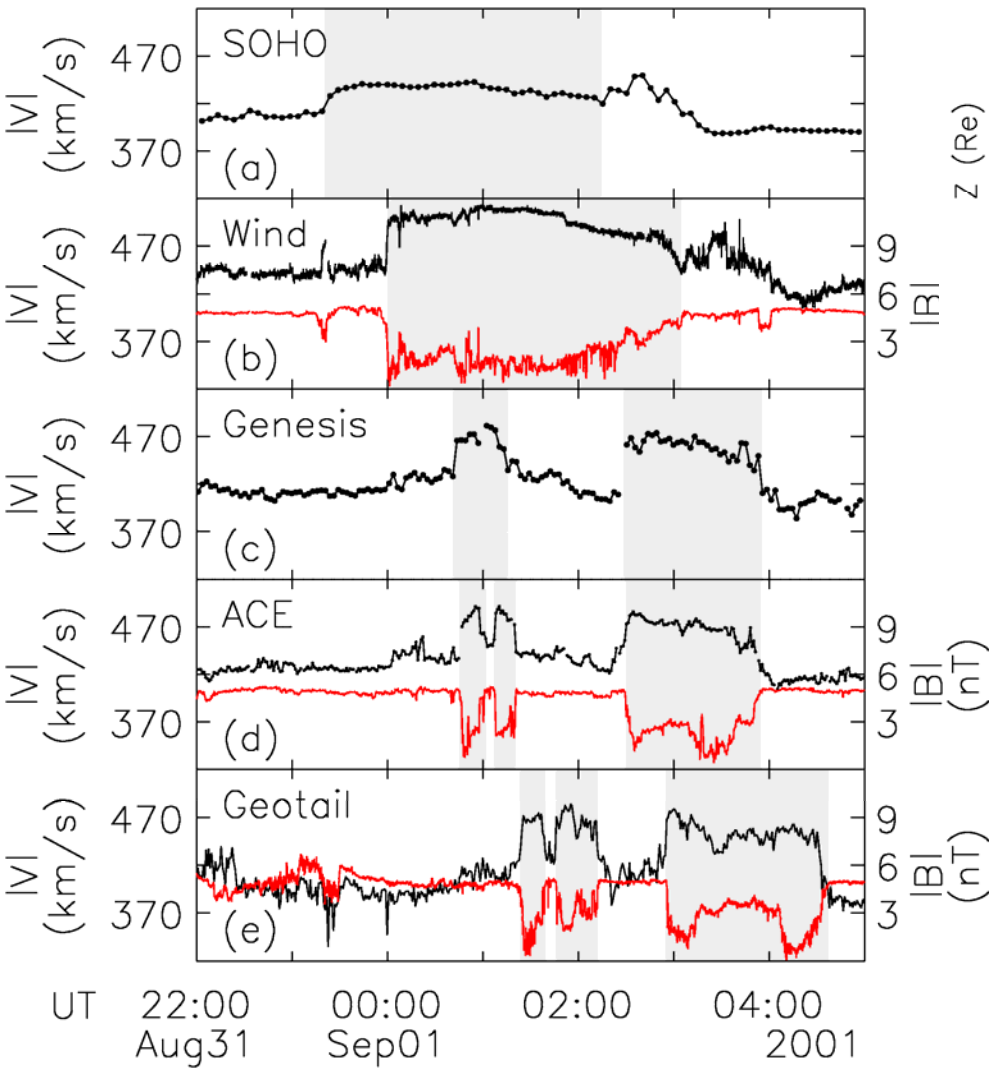
An Expanded View of the Exhaust

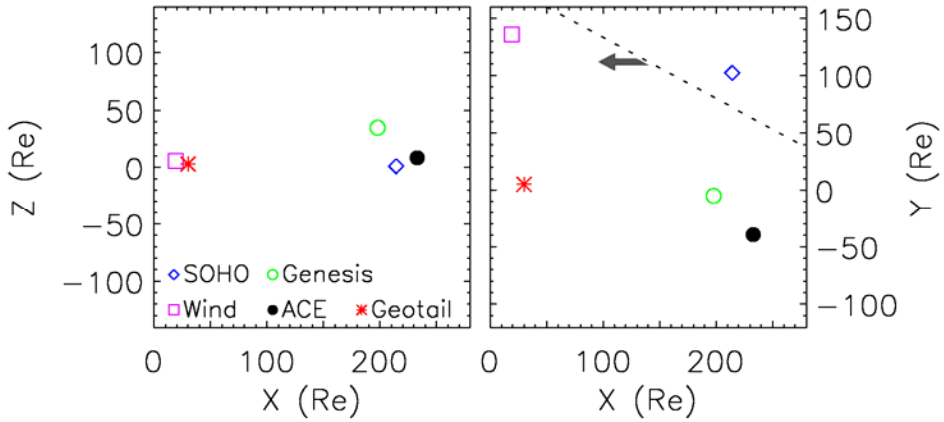


Field shear = 120˚

$|\Delta \boldsymbol{V}| / \langle V_A \rangle = 0.51$

Prolonged Reconnection at an Extended and Continuous X-line





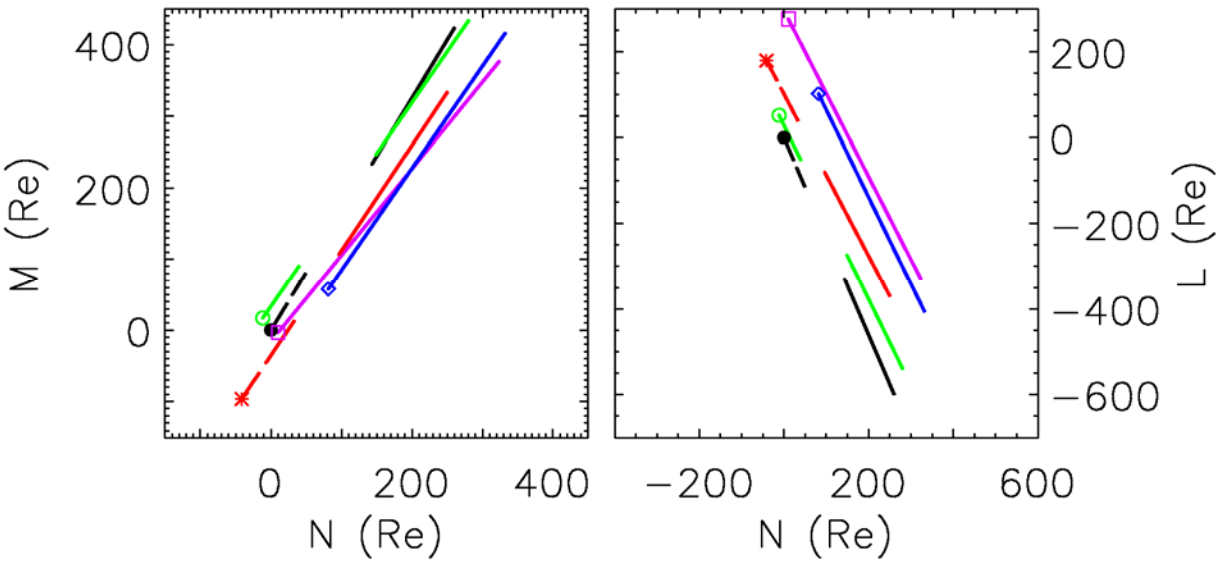
Wind and SOHO each observed reconnection jet for ~3 hours.

Grazing intersection with exhaust that extended at least 531 Re in direction of the X-line.

Total event lasted ~5 hrs.

Prolonged reconnection at an extended and continuous X-line.

Spacecraft Trajectories Across the Exhaust in L,M,N Coordinates



Exhaust width at least 1.85 x 10^6 km.

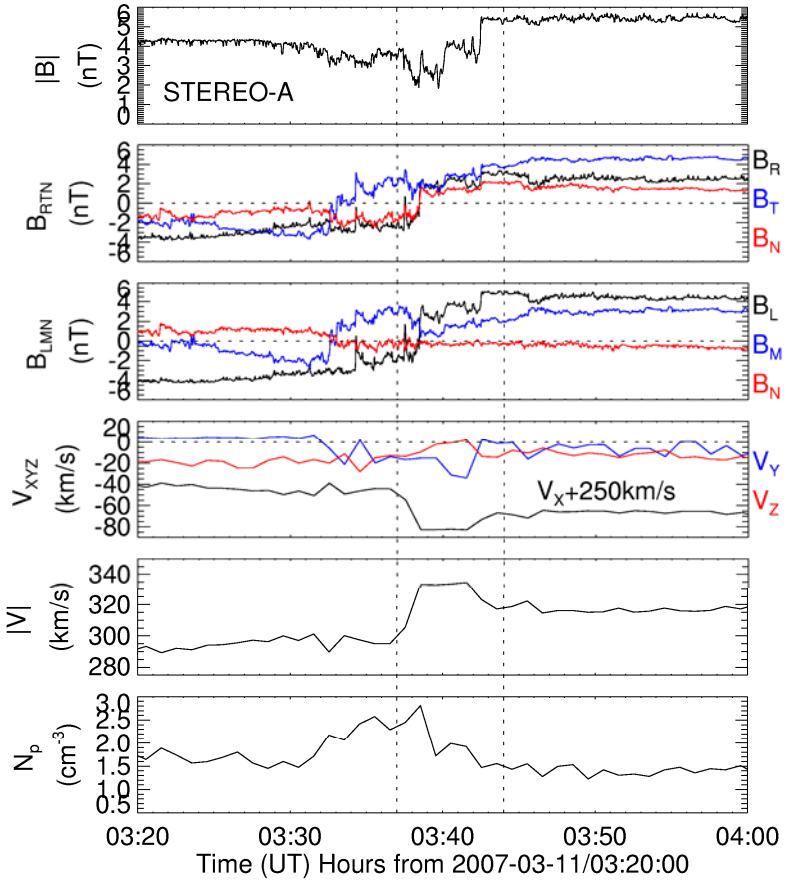
Exhaust extended at least 3.4 x 10^6 km in direction of X-line.

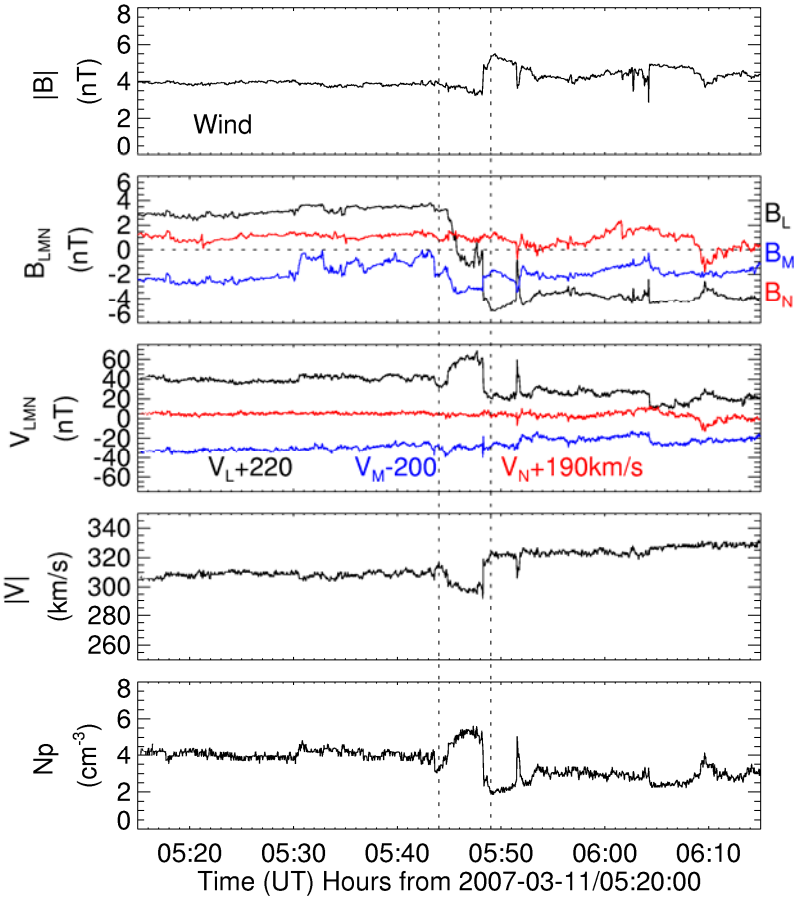
Exhaust may have originated in reconnection close to Sun, in which case it would have reduced by at least 2 parts in 10^5 the open flux in heliosphere.

Energy extracted from the current sheet was ~1.2 x 10^{24} ergs - comparable to energy released in a large geomagnetic storm, but small compared to energy released (10^{32} ergs) in a large flare or CME.

Results of MVAB for STEREO-A and Wind

**Note: RTN coordinates for B*

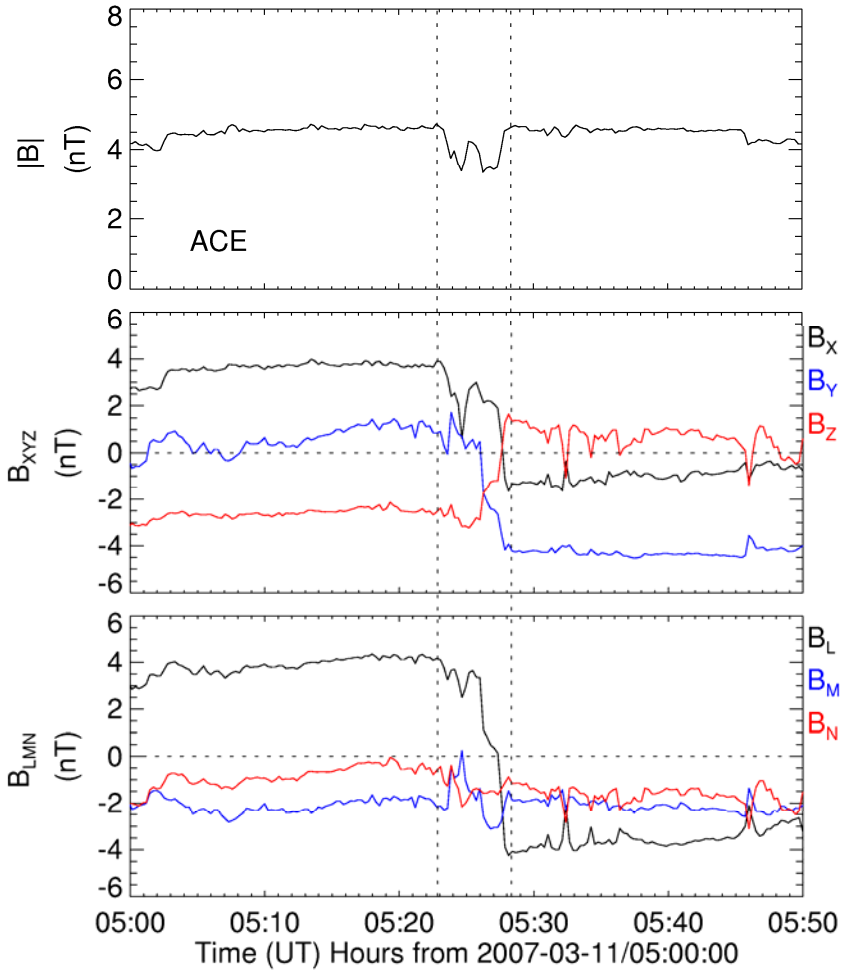




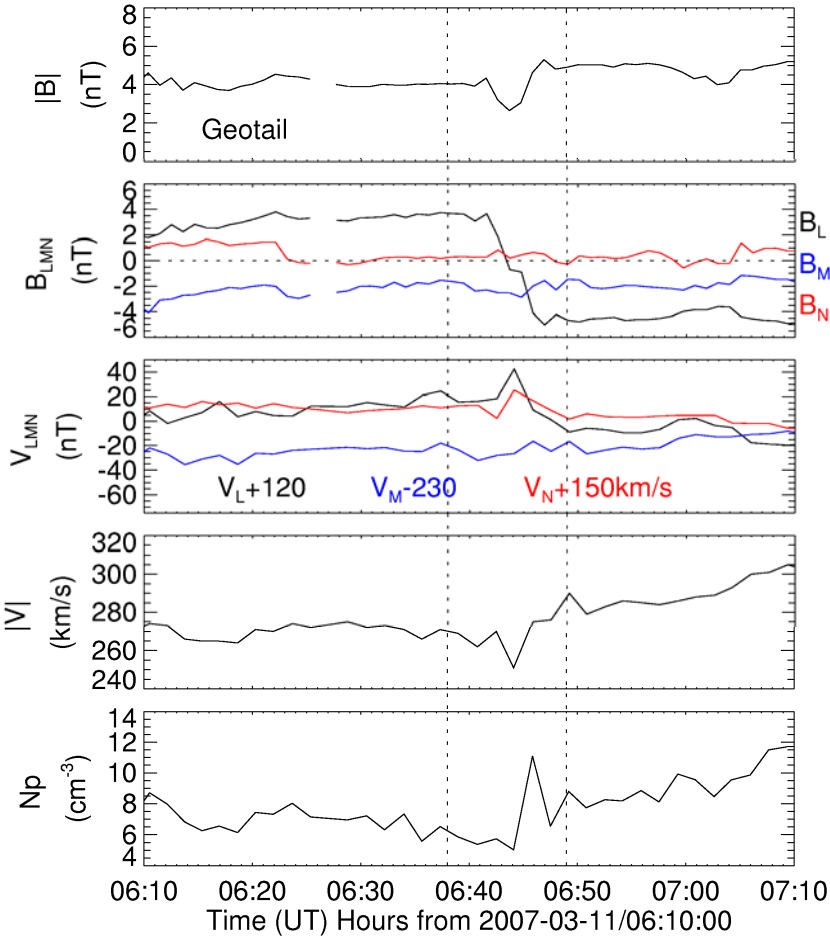
N = (0.529, 0.111, 0.841) gse M = (-0.377, 0.919, 0.304) gse

N = (0.544, 0.031, 0.838) gse M = (-0.519, 0.798, 0.307) gse

X-line was in M-direction, which was tilted slightly to gse x-y plane



N = (0.299, 0.451, 0.841) gse
M = (-0.753, 0.652 -0.082) gse



N = (0.487, 0.185, 0.853) gse
M = (-.753, 0.584, 0.304) gse

Oppositely Directed Exhausts From a Common Reconnection X-Line

**Note: STEREO field data in RTN coordinates; Wind data in GSE coordinates*
All Velocity data in GSE