Reconnection in the Outer Heliosphere

Marc Swisdak

SHIELD Summer School
04 June 2025

The Heliosphere

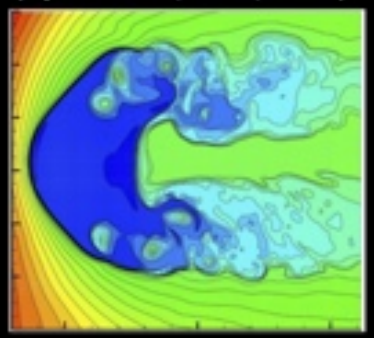
The heliosphere is the cavity carved out of the local interstellar medium by the solar wind

There are several important boundaries

The general shape of the heliosphere is under debate

In one popular idea, the shape is determined partly by the magnetic field on the inside – the Parker spiral

"Croissant" shaped?
(***Opher et al., 2015, 2017***)



(V1 is closer to here)

Termination Shock

Voyager 1

Heliosheath
(outer) (inner)

Supersonic
solar wind

Voyager 2

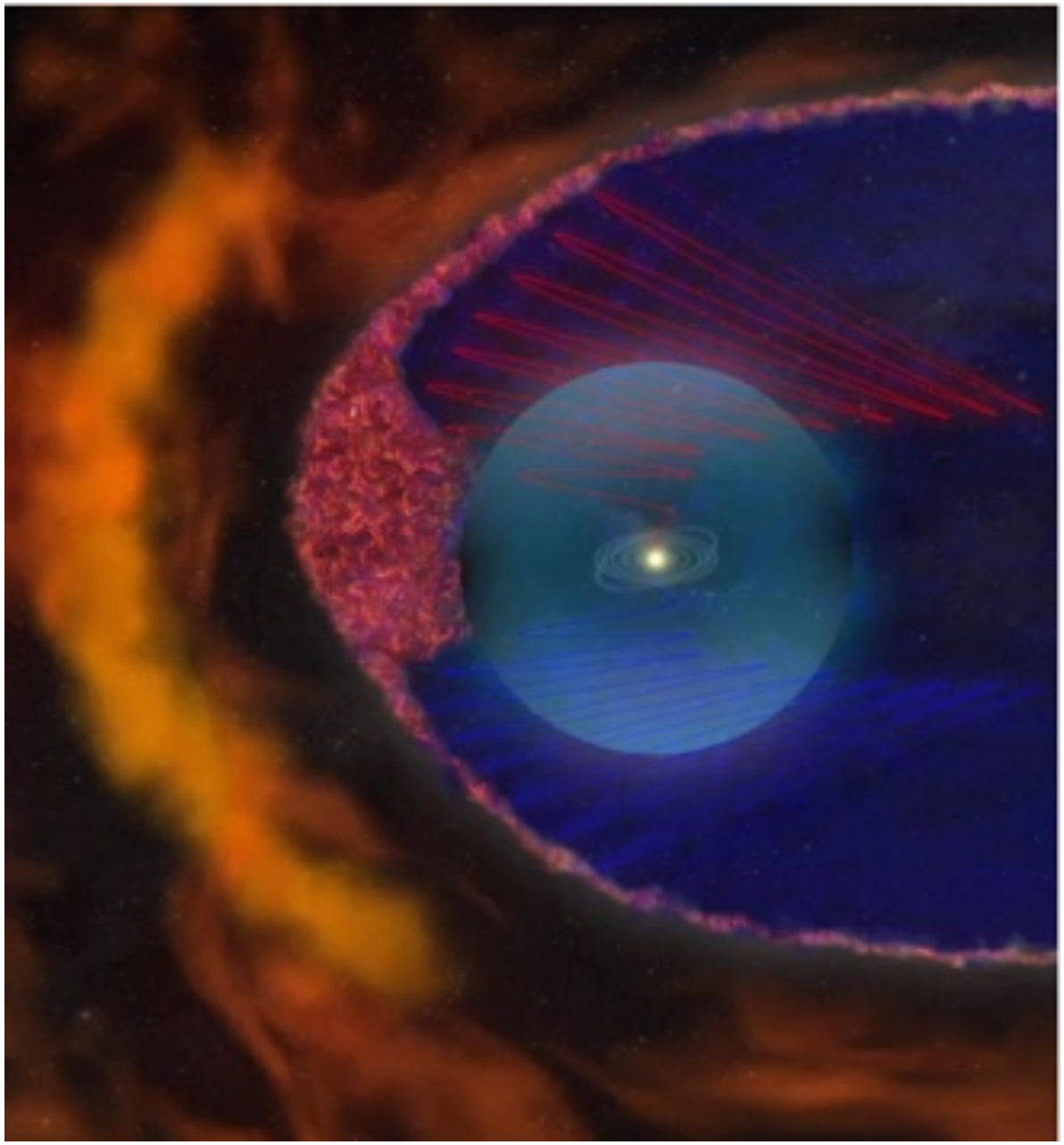
Bow Shock ?

(V2 is closer to here)

Heliopause

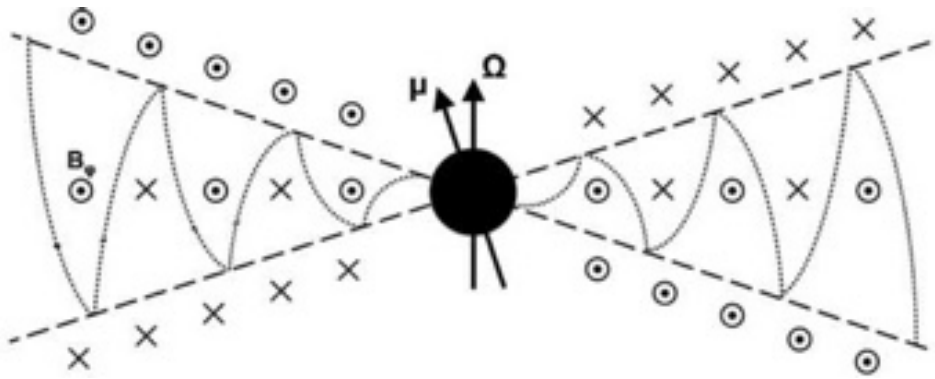
Magnetic Reconnection in the Heliosphere

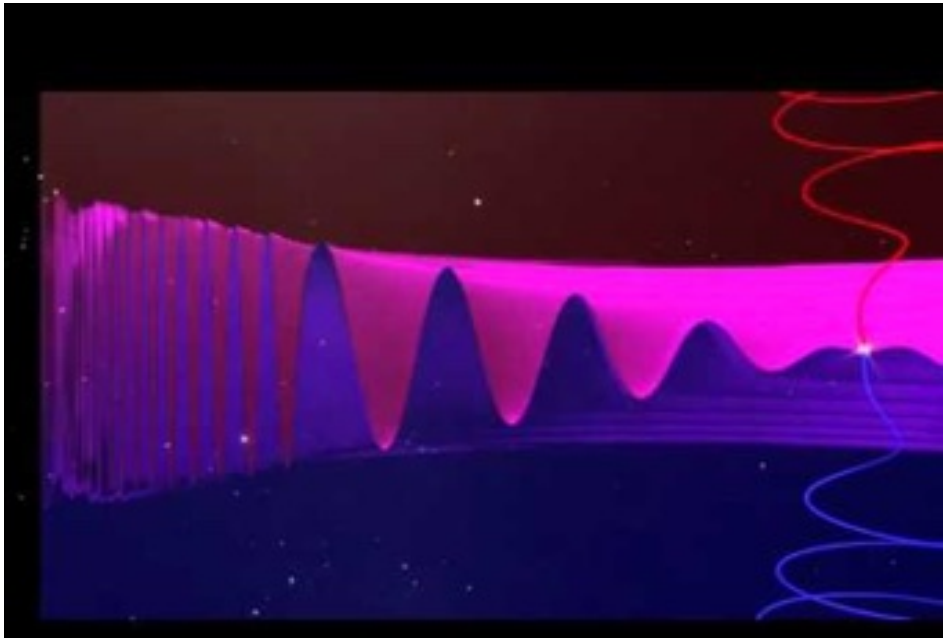
Heliosheath Reconnection



The Parker Spiral and the Heliospheric Current Sheet

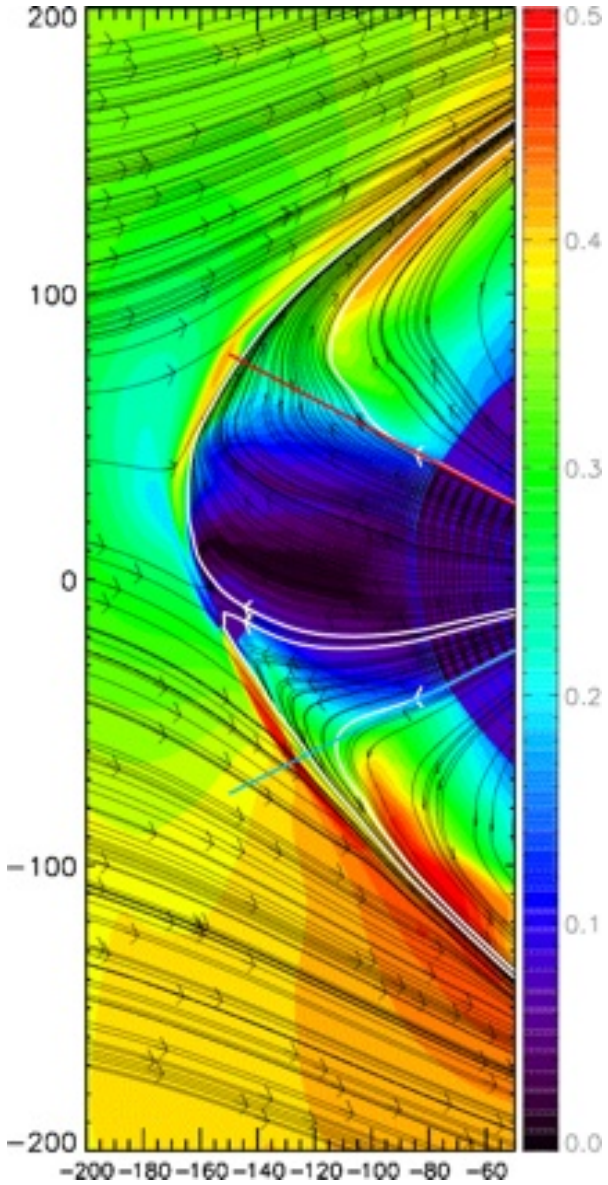
- Frozen-in solar wind produces a current sheet
- Rotation produces a spiral/helical shape
- Mis-aligned axes produce a ballerina skirt

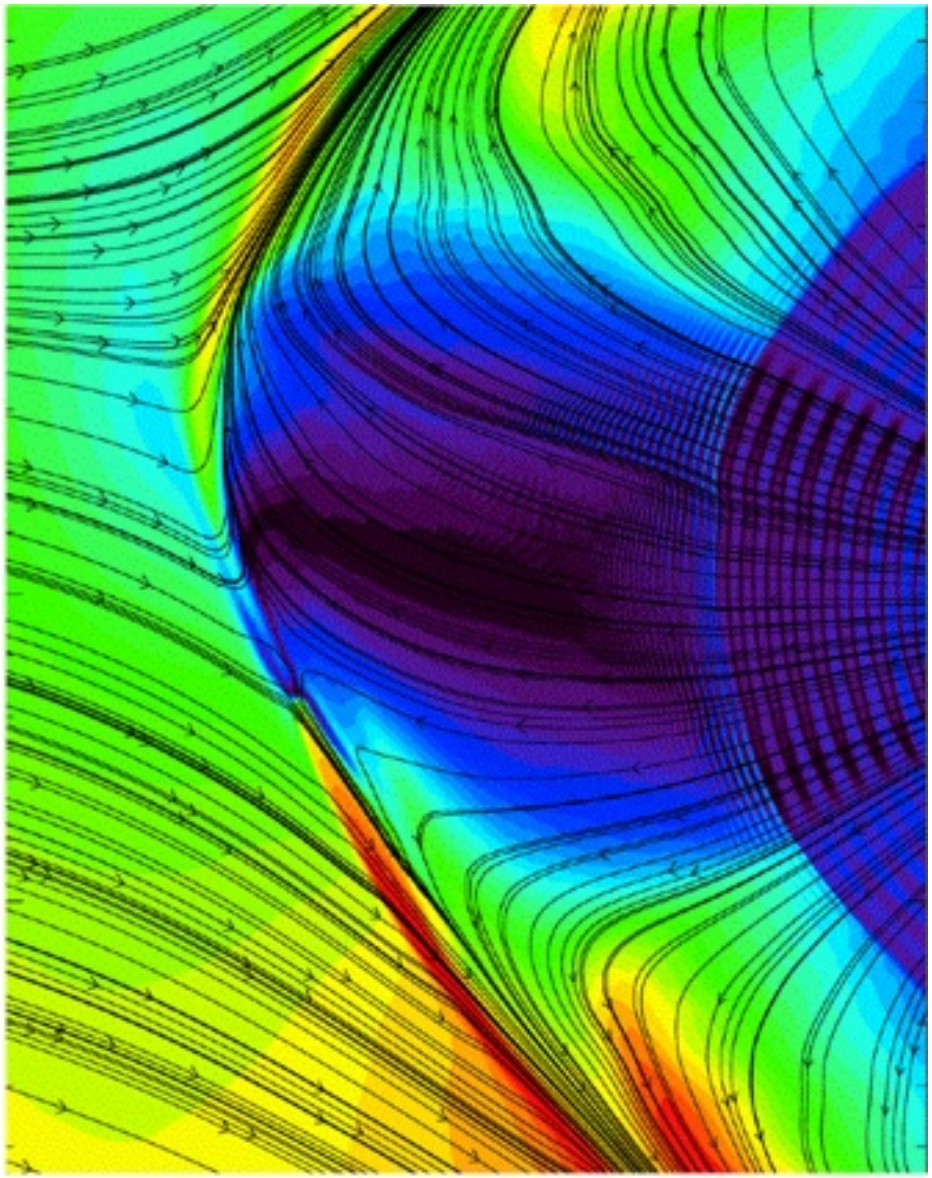




- Finite latitudinal extent
- Spacings narrow at TS.

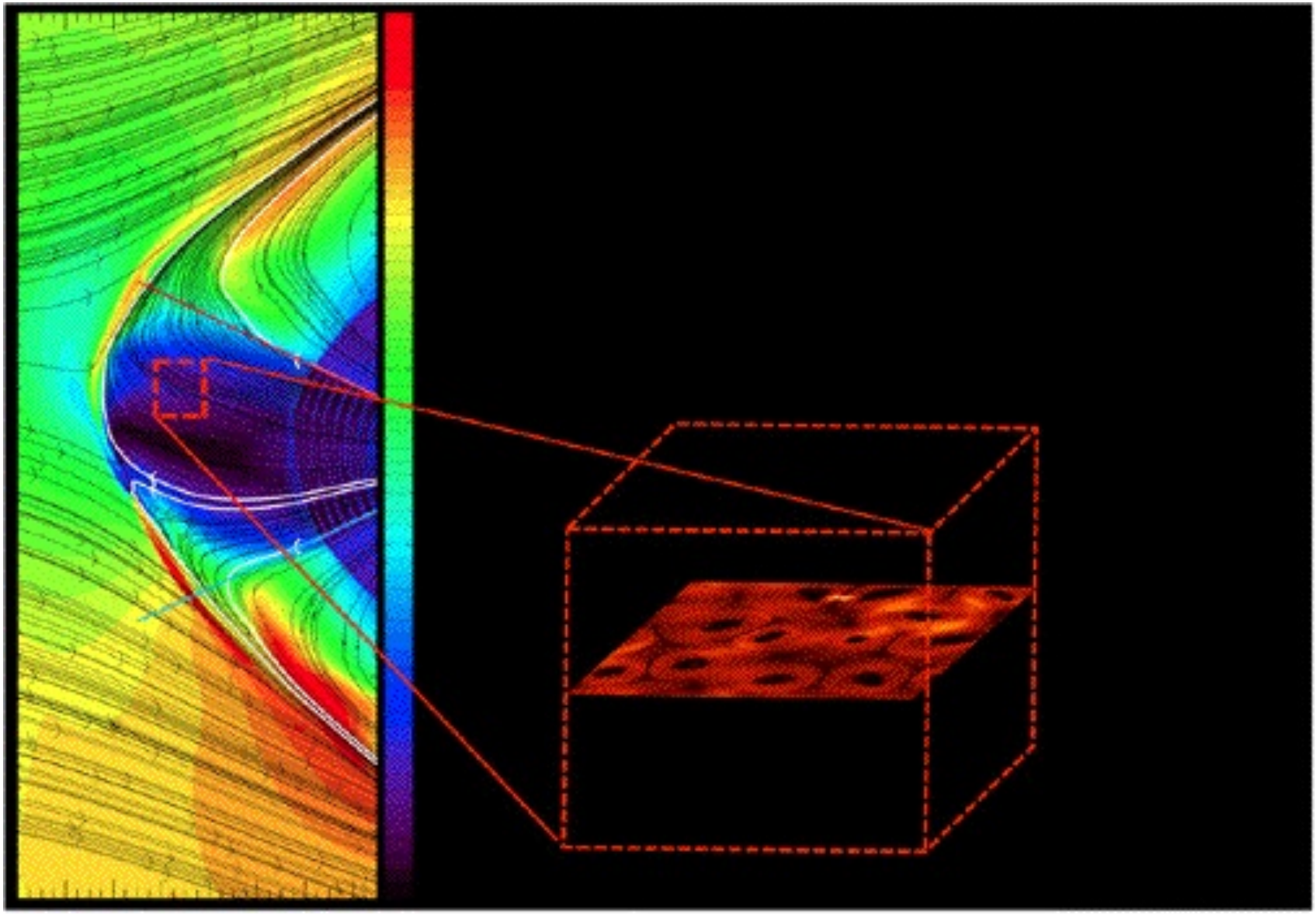
MHD Heliosphere Simulation



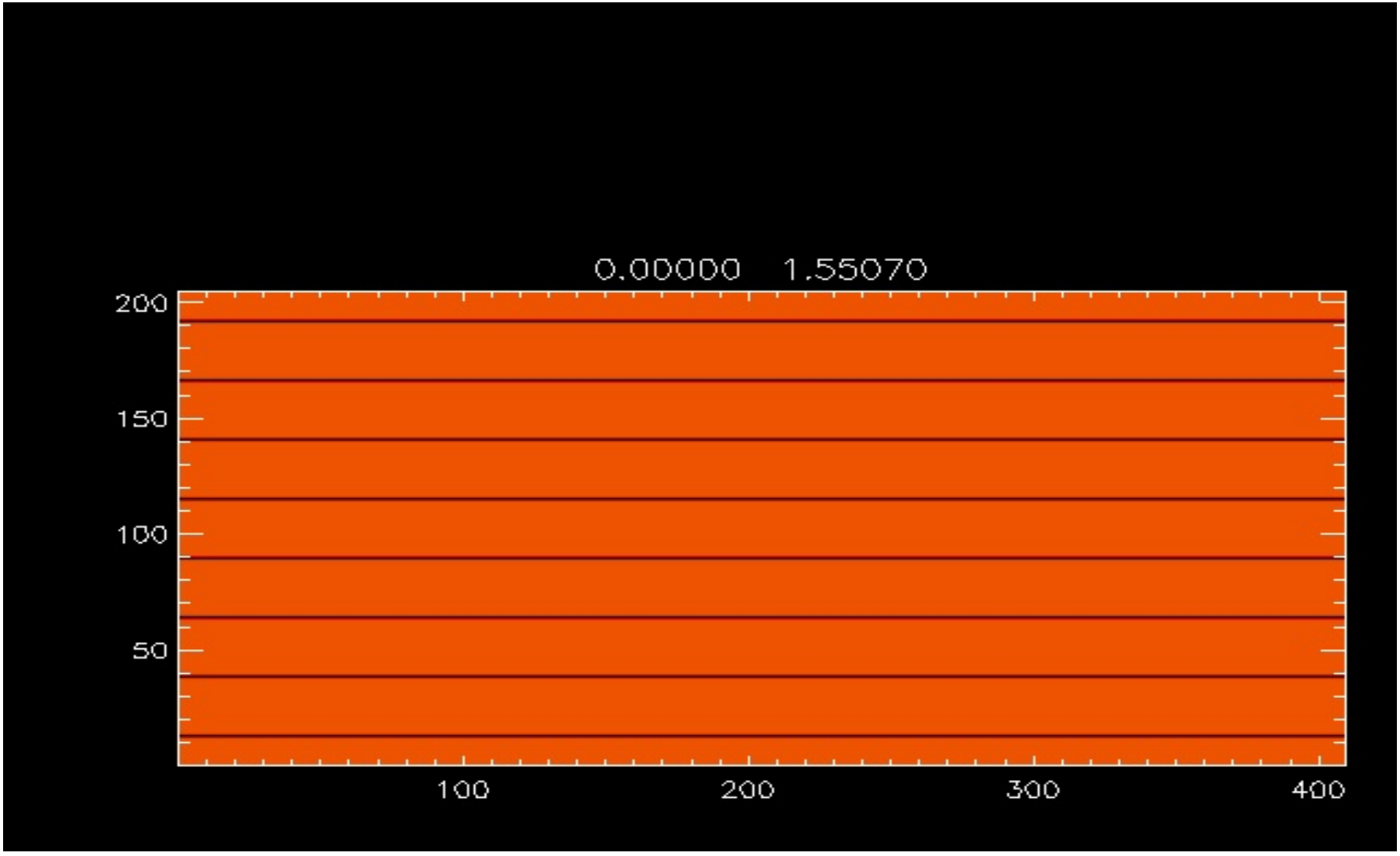


Opher et al., ApJ, 734, 71 (2011)

2D PIC Simulation of Heliospheric Current Sheets

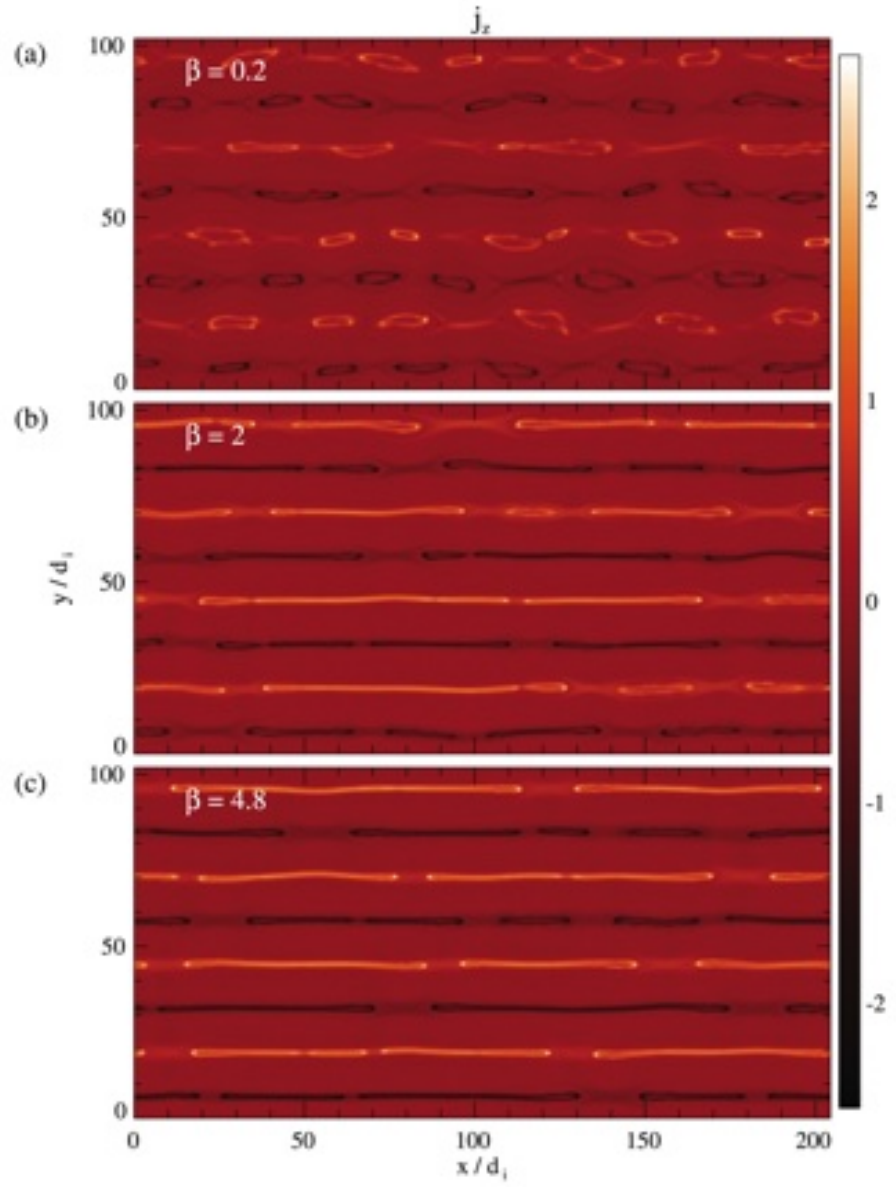


Reconnection of Multiple Current Sheets



Reconnection in Symmetric Sector Zone

Schoeffler et al., *ApJ*, 2011



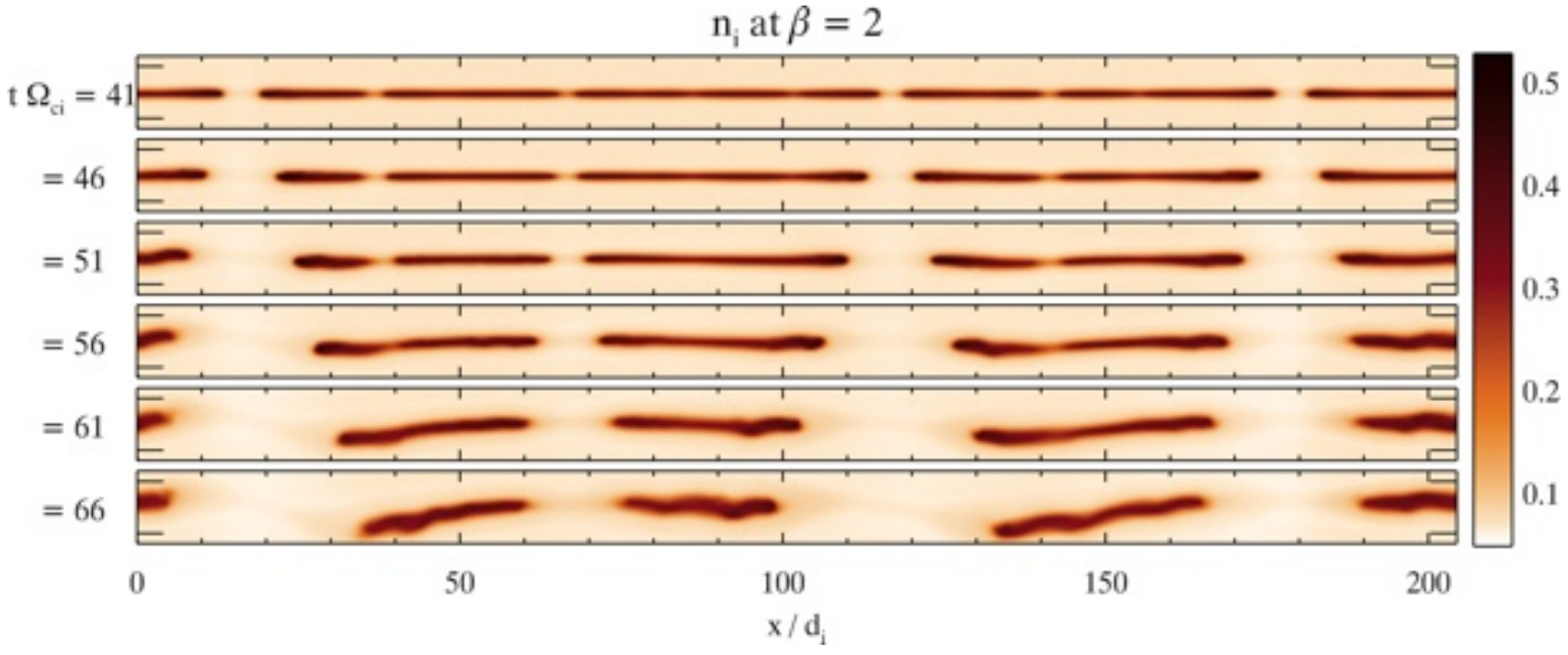
$$\rho\frac{d\mathbf{v}}{dt} = -\boldsymbol{\nabla}\left(P_\perp + \frac{B^2}{8\pi}\right) + \boldsymbol{\nabla}\cdot\left[\left(1 - \frac{\beta_{||} - \beta_\perp}{2}\right)\frac{\mathbf{BB}}{4\pi}\right]$$

Firehose Onset

$$\beta_{||} - \beta_\perp > 2$$

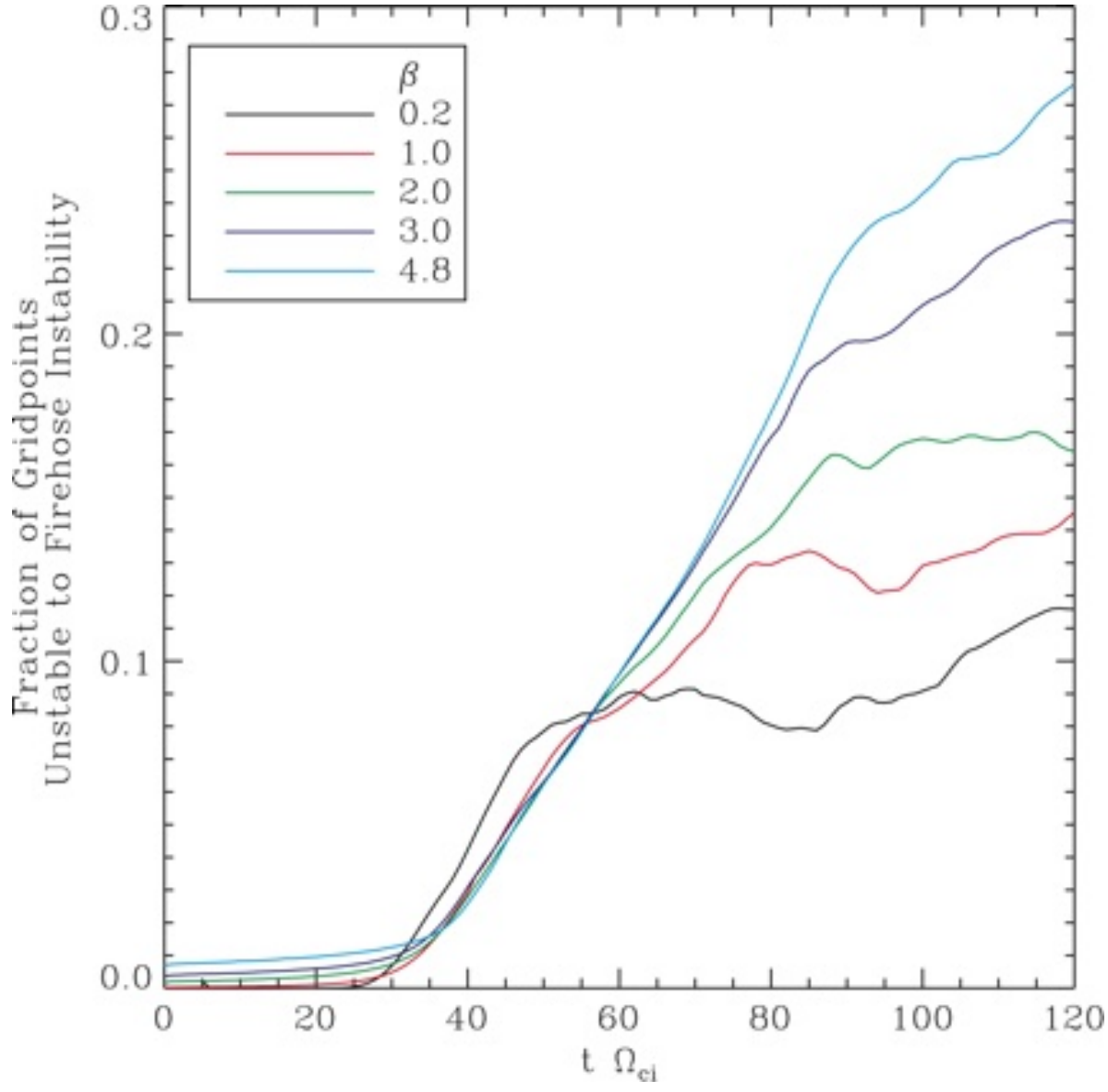
Contraction of Islands During Reconnection

Schoeffler et al., 2011



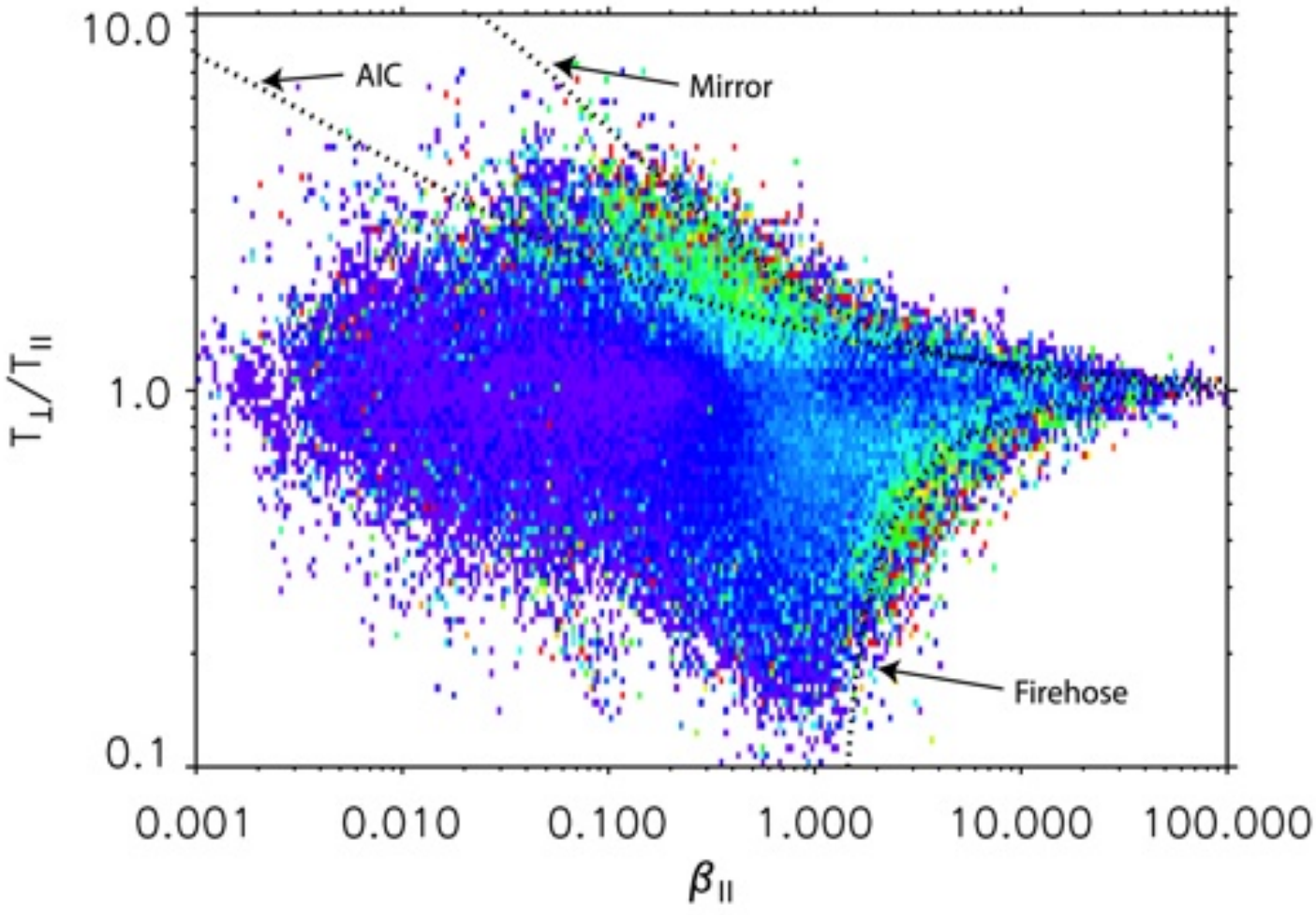
Fraction of Domain Showing Firehose Instability

Schoeffler et al., 2011



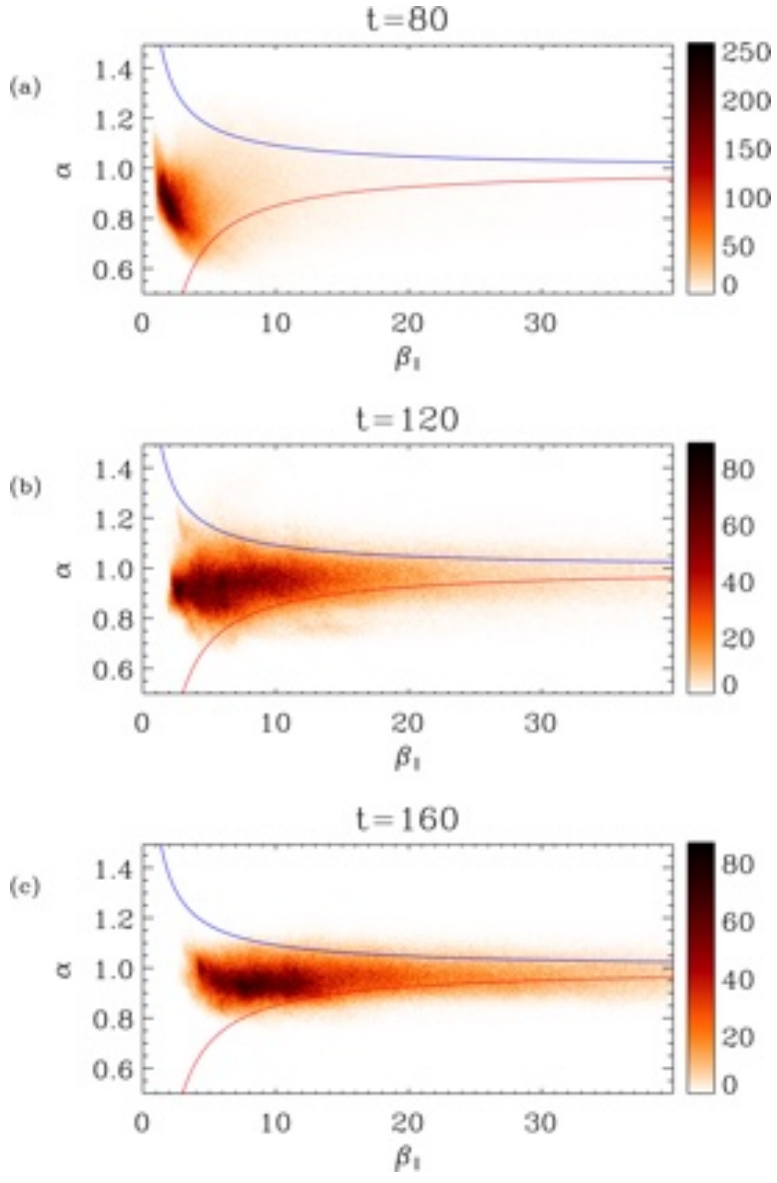
Brazil Plots

Bale et al., 2009



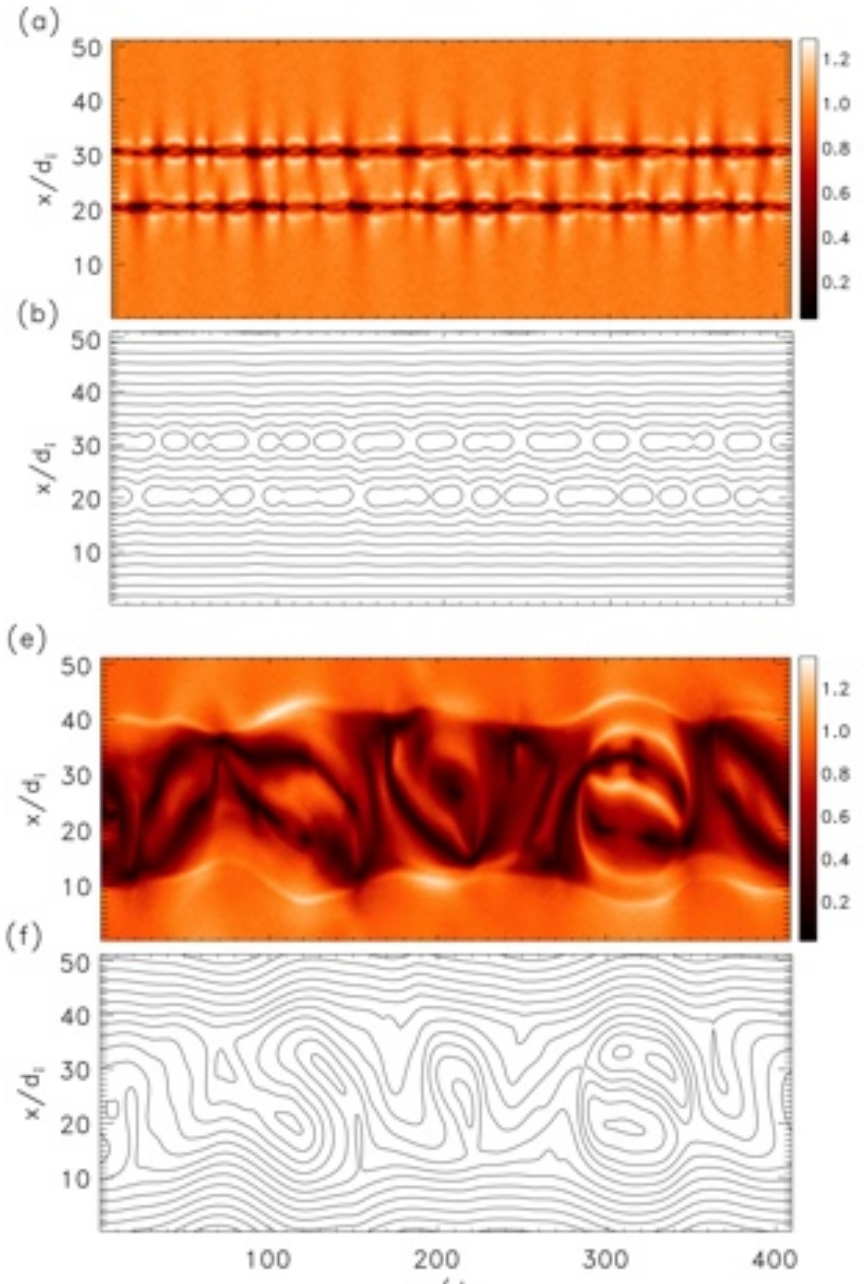
Brazil Plots from Heliospheric Reconnection

Schoeffler et al., 2011

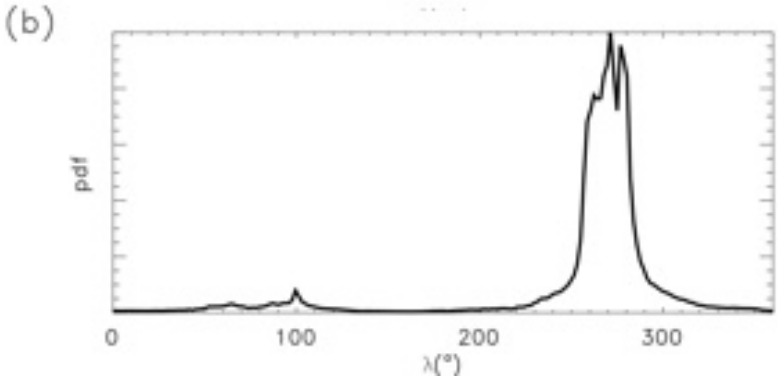


Reconnection in Asymmetric Sectors

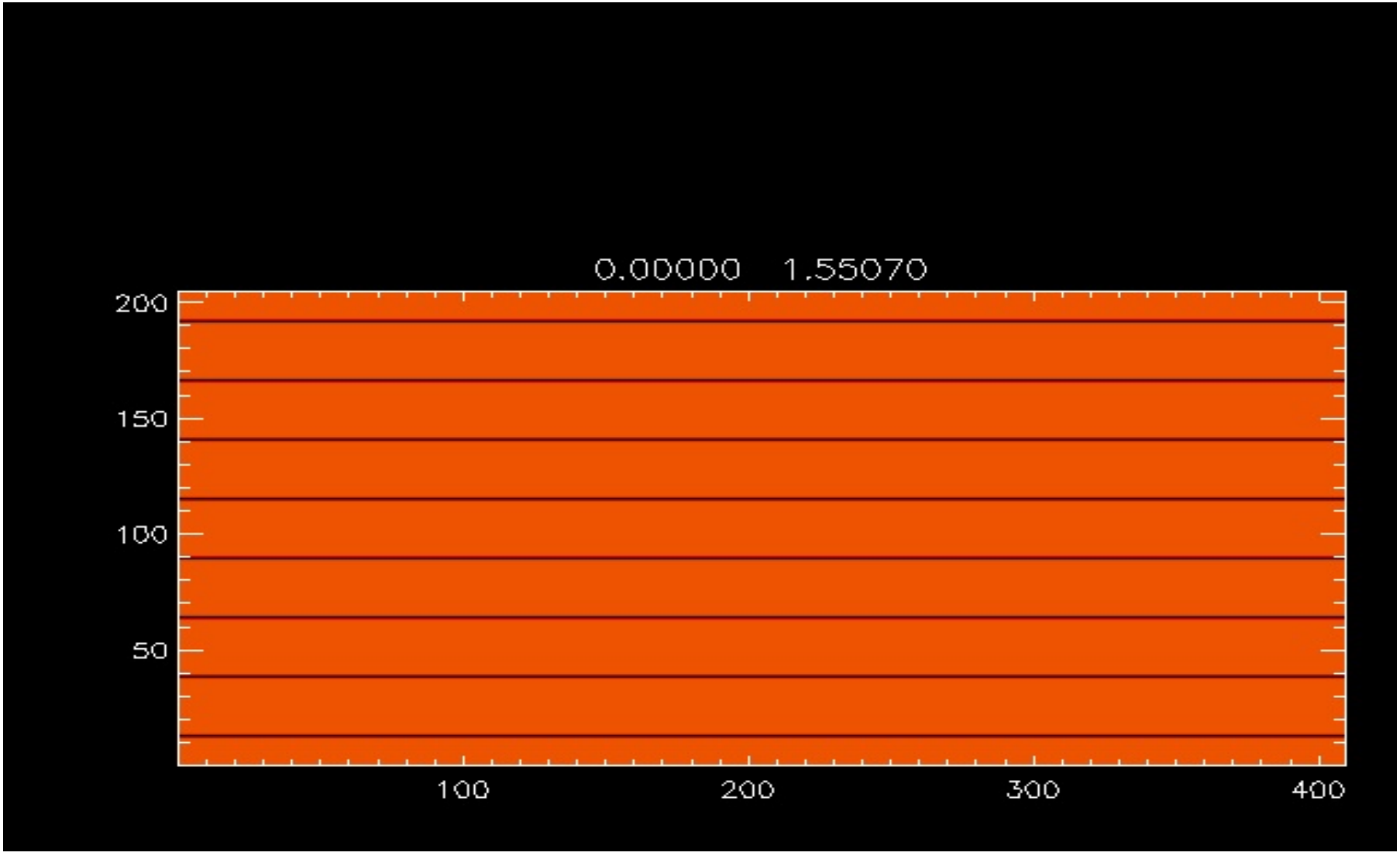
Drake et al., *ApJ*, 2017



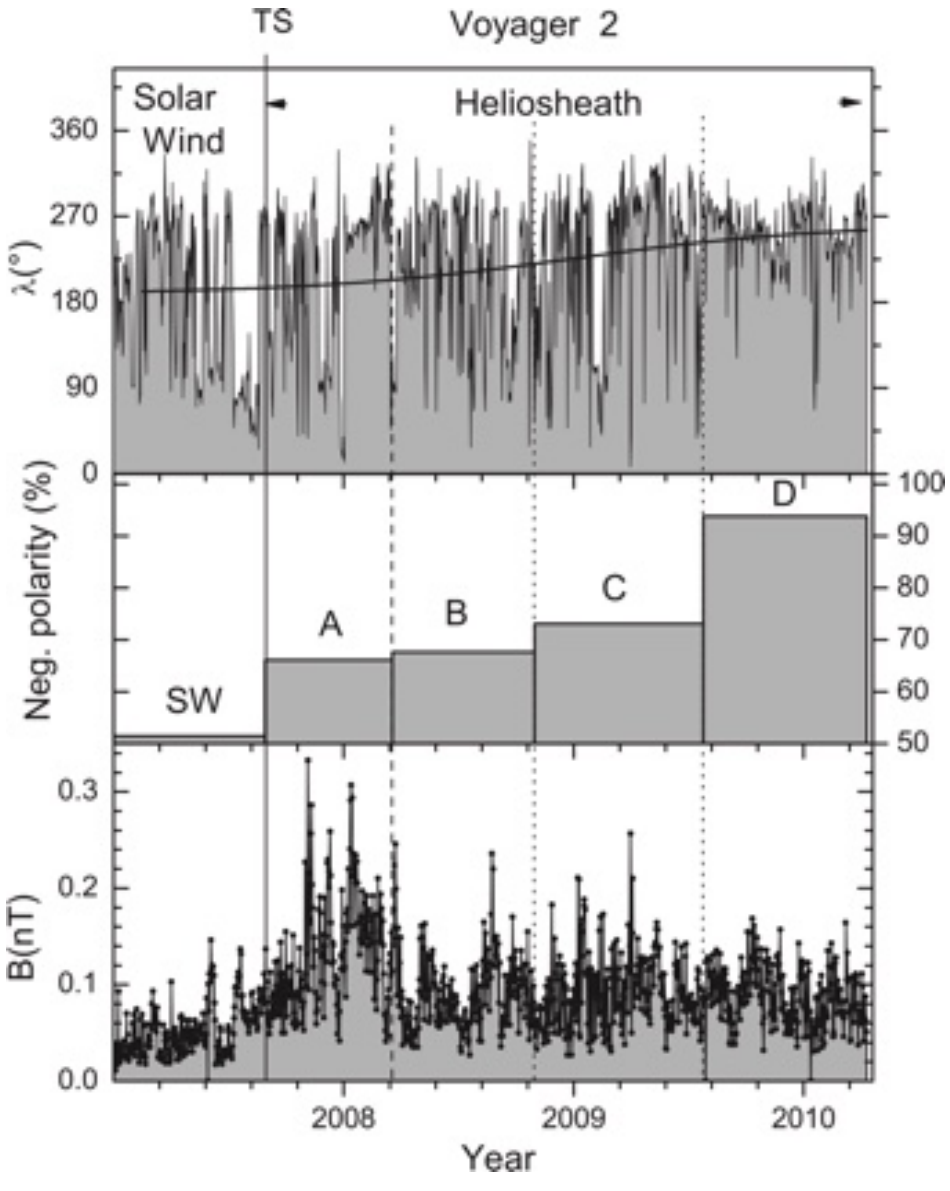
- Bands of dominant flux survive at late time
- Sharp reduction in number of sectors
- Loss of one sign of magnetic flux

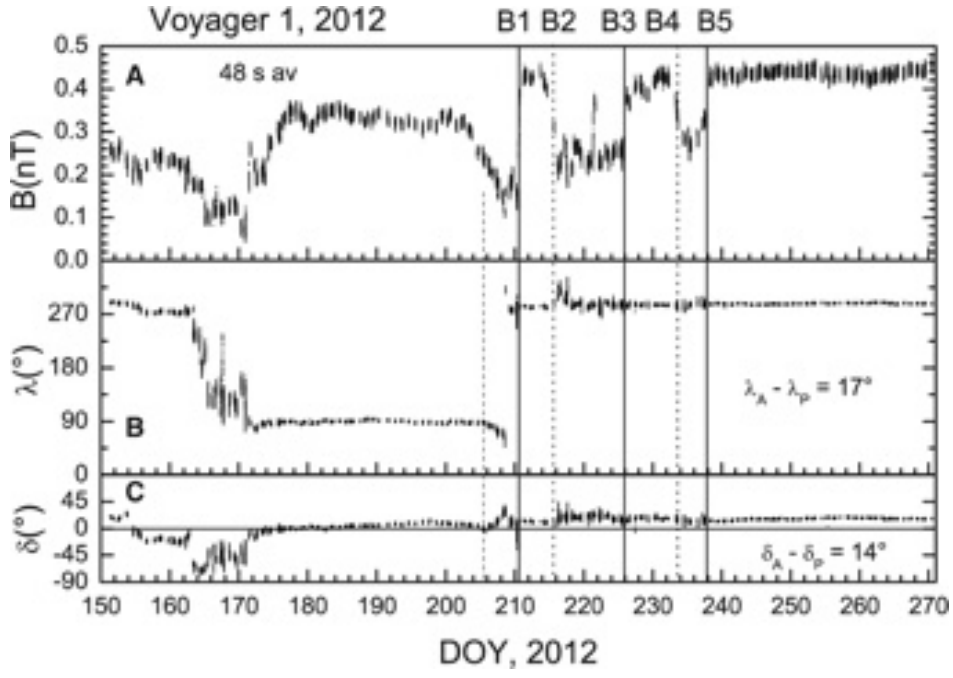


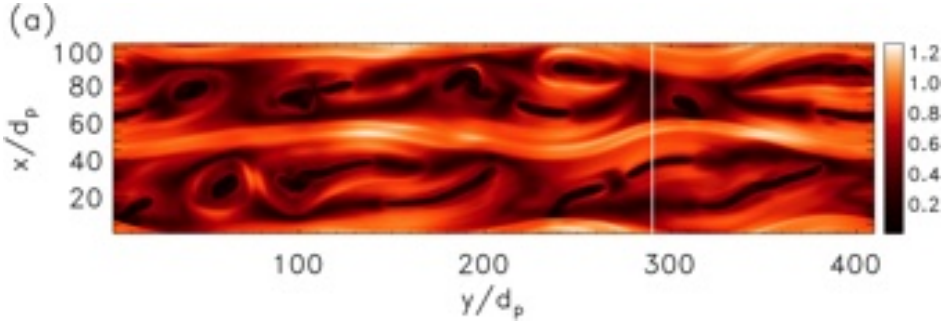
Reconnection of Asymmetric Sheets



The Implications of Asymmetric Flux Regions

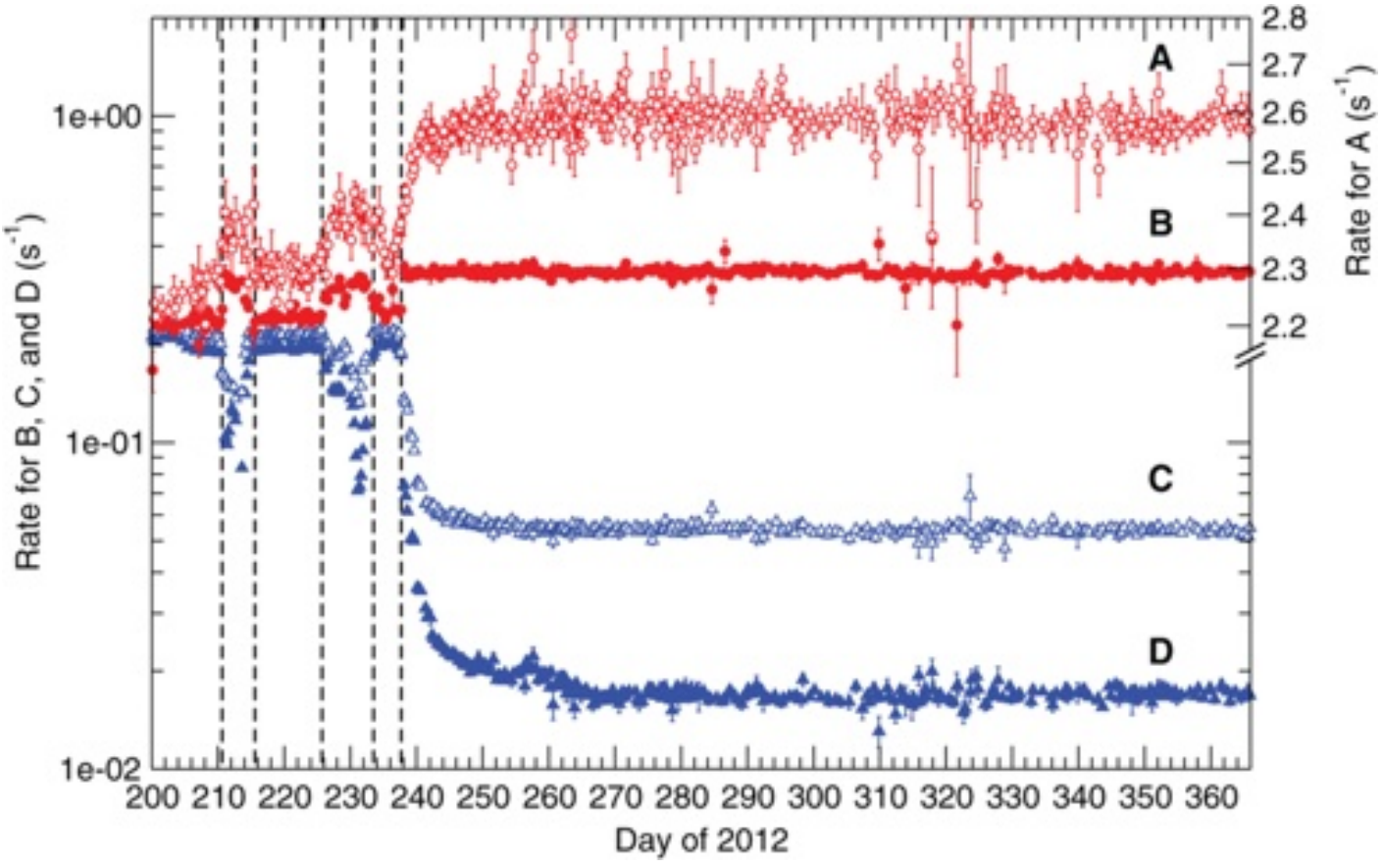






Burlaga and Ness, (2011)

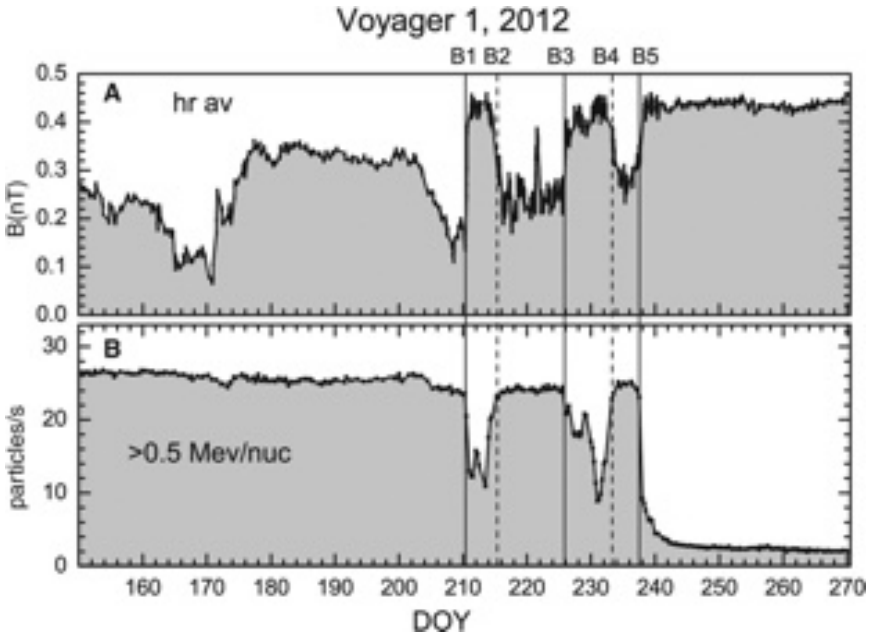
Voyager 1 Particle Data: 2012 Events

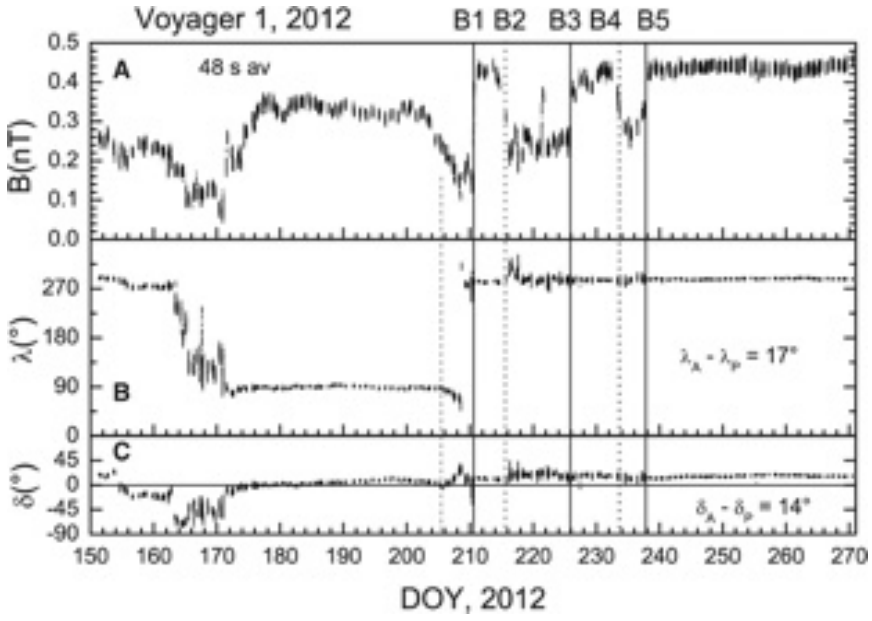


Stone et al., Science, (2013)

- Anti-correlated increases in GCRs, decreases in ACRs.
- Strongly suggestive of a boundary crossing.

Voyager 1 Field Data: 2012 Events



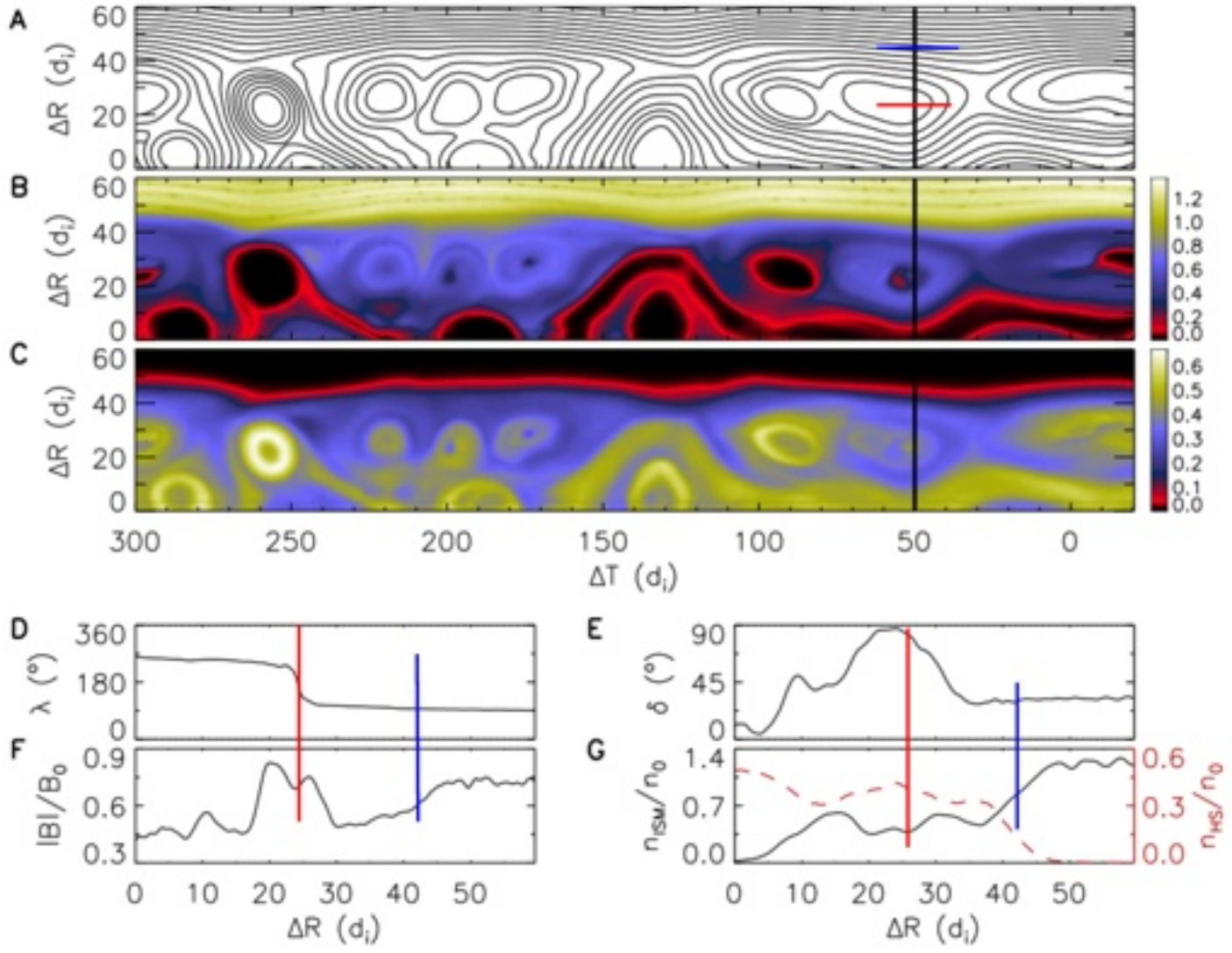


Burlaga et al., Science, (2013)

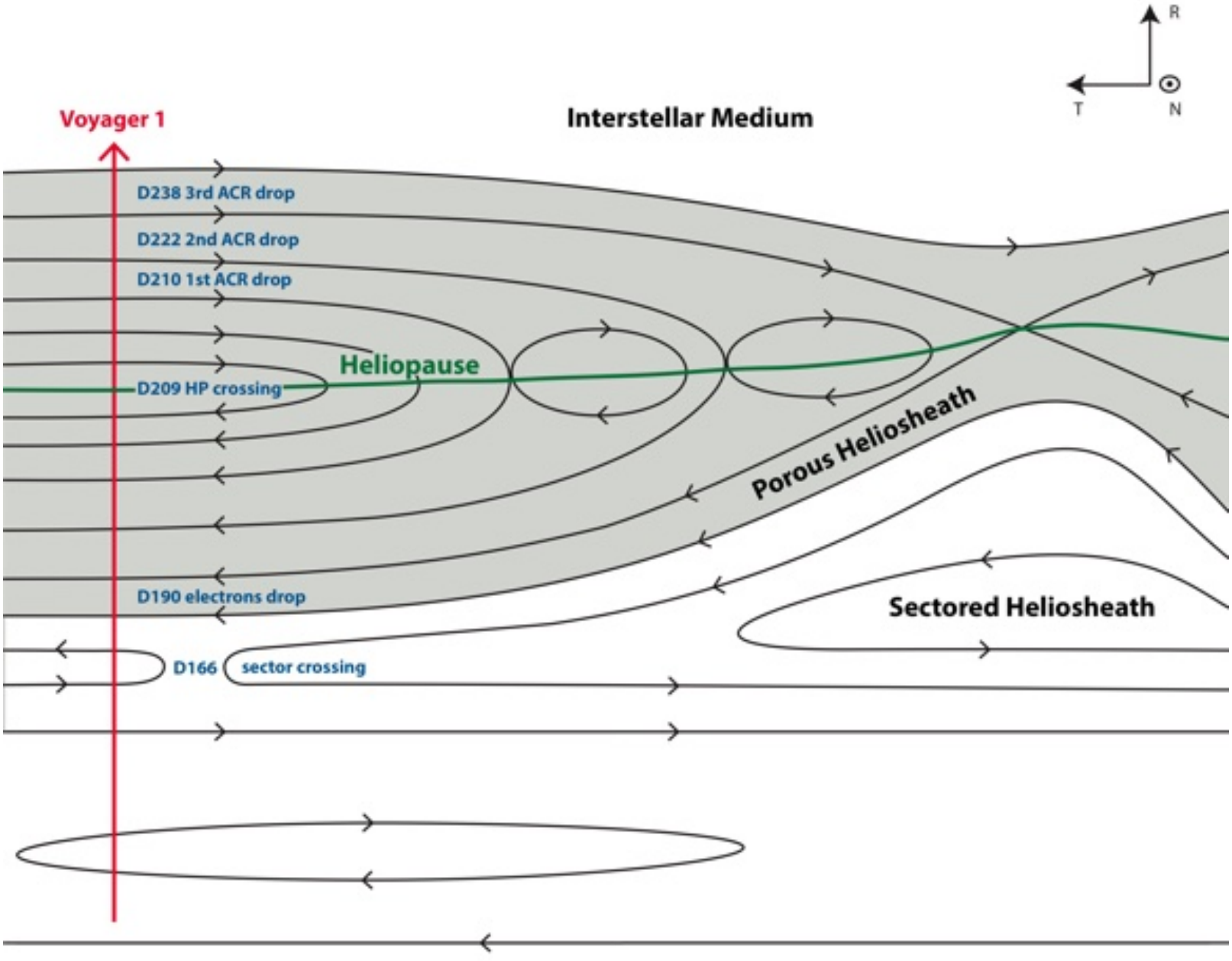
- Changes in B correlated with the changes in the particles.
- Little change in field direction: Suggested no boundary crossing.

Heliopause Reconnection: PIC Simulations

Swisdak et al., *ApJL*, 2013

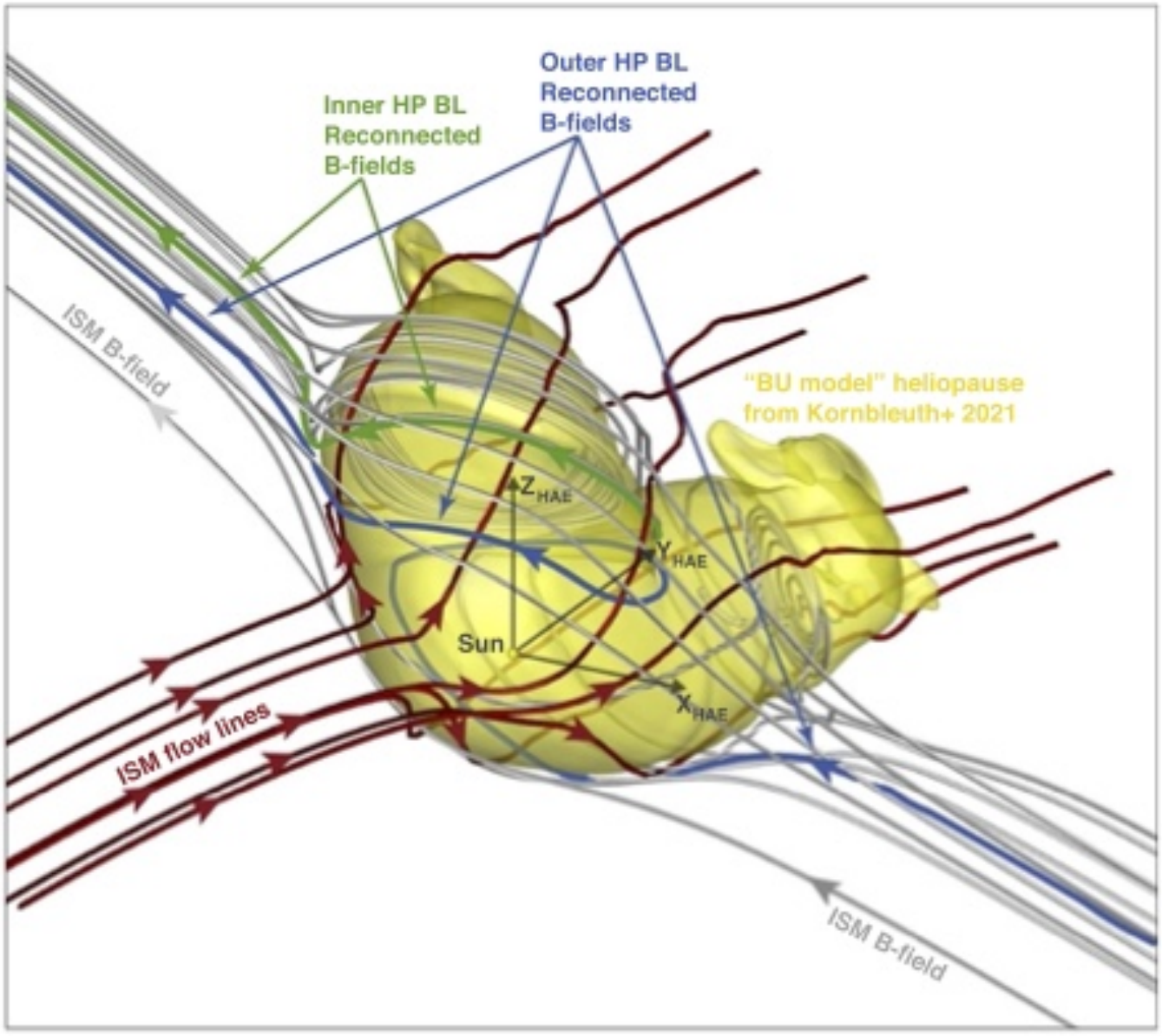


Heliopause Reconnection: Cartoon



Heliopause Reconnection

Turner et al., 2024



Conclusions

- Outer heliosphere reconnection has notable properties
  - High $\beta \rightarrow$ importance of firehose
  - Asymmetric flux distributions
- Understanding reconnection is crucial for understanding observations
- Important undiscussed topic:
  Effects on energetic particle production

Work in Progress