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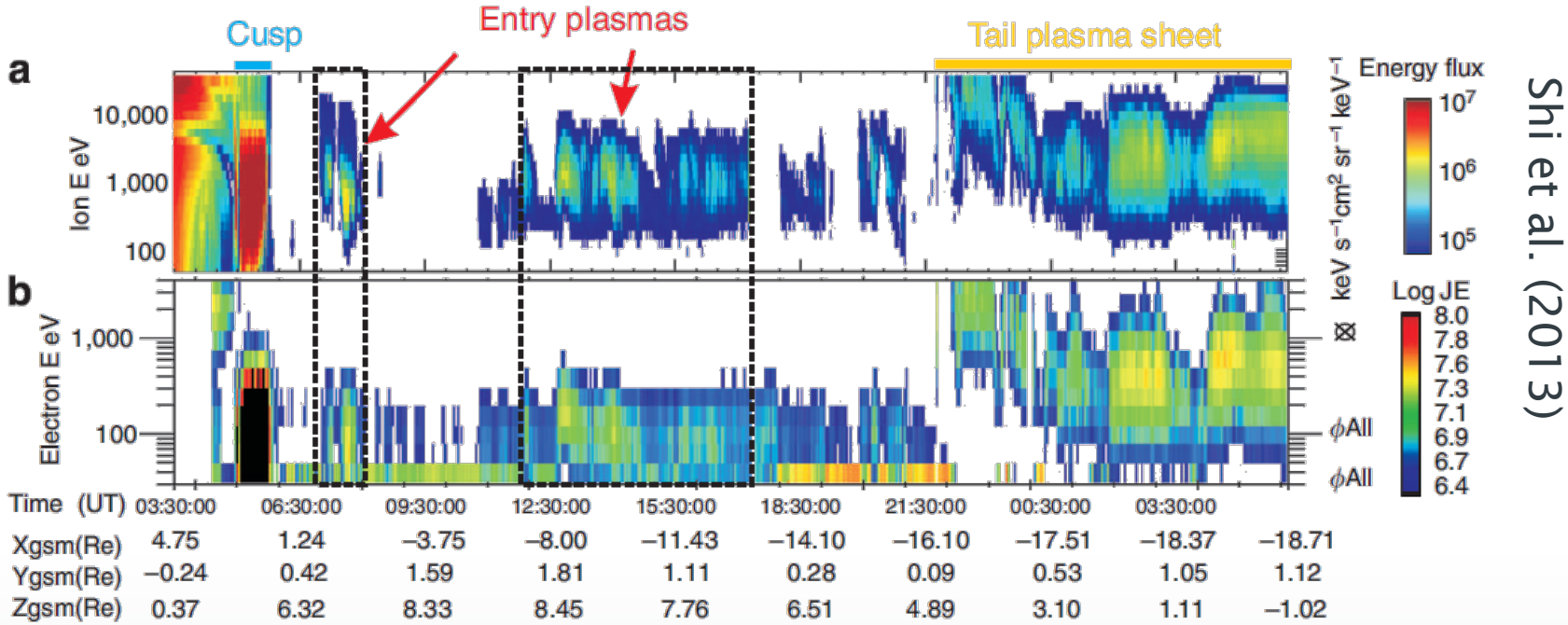
Magnetotail structure associated with transpolar arcs

Fear, R. C., S. E. Milan, R. Maggiolo, A. N. Fazakerley, I. Dandouras and S. B. Mende, Direct observation of closed magnetic flux trapped in the high-latitude magnetosphere, *Science*, **346**, 1506–1510, doi:10.1126/science.1257377 (2014)

The magnetotail under northward IMF



Shi et al. (2013)

- A small number of studies have reported the presence of uncharacteristically hot plasma in the magnetotail lobe at times when the IMF is northward
  - Huang et al., (1987, 1989); Shi et al., (2013); A. N. Fazakerley, personal communication

- Cause has been unclear; interpreted as:
  - 'Filaments' extending from plasma sheet (Huang et al.)
    - But noted no existing mechanism explained how
  - 'Entry plasmas' (Shi et al) from lobe reconnection
  - 'Ghost plasma sheet' – but not clear how (Fazakerley)

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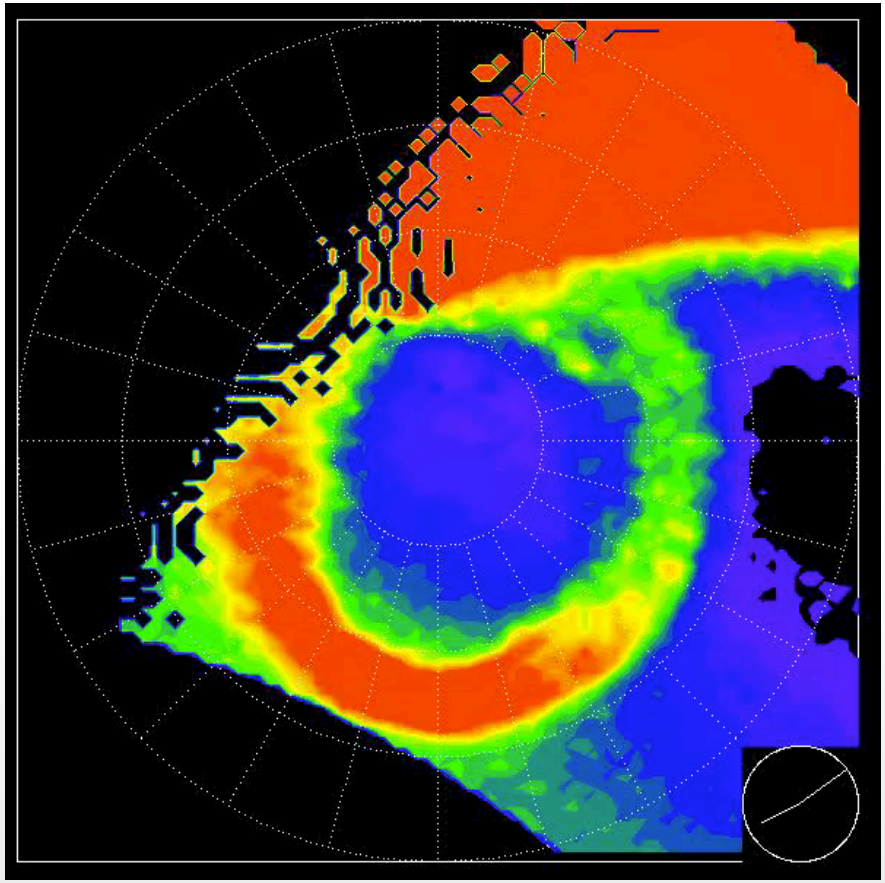
The link with transpolar arcs

- One of these studies (Huang et al., 1989) linked these signatures with transpolar arcs (or theta aurora) – another northward IMF phenomenon

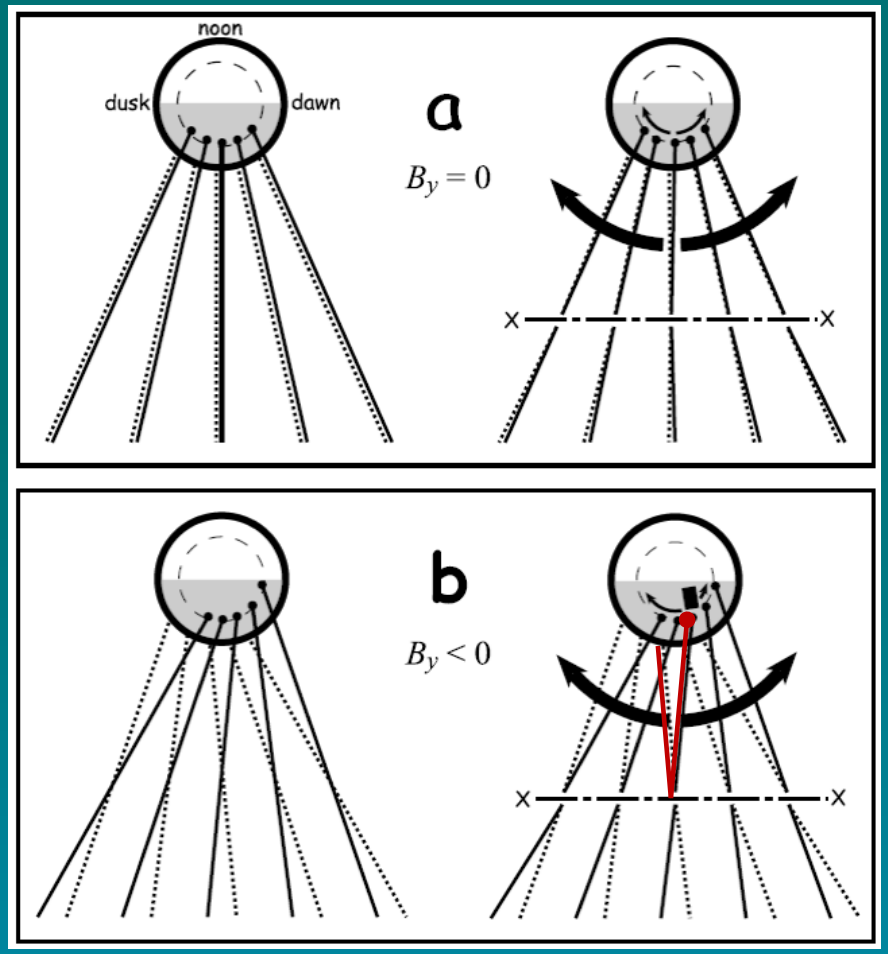
- A plethora of formation mechanisms have been proposed for transpolar arcs, but one particular candidate is based on magnetotail reconnection during northward IMF
(Milan et al., 2005)

Movie of event studied by Goudarzi et al. (2008)



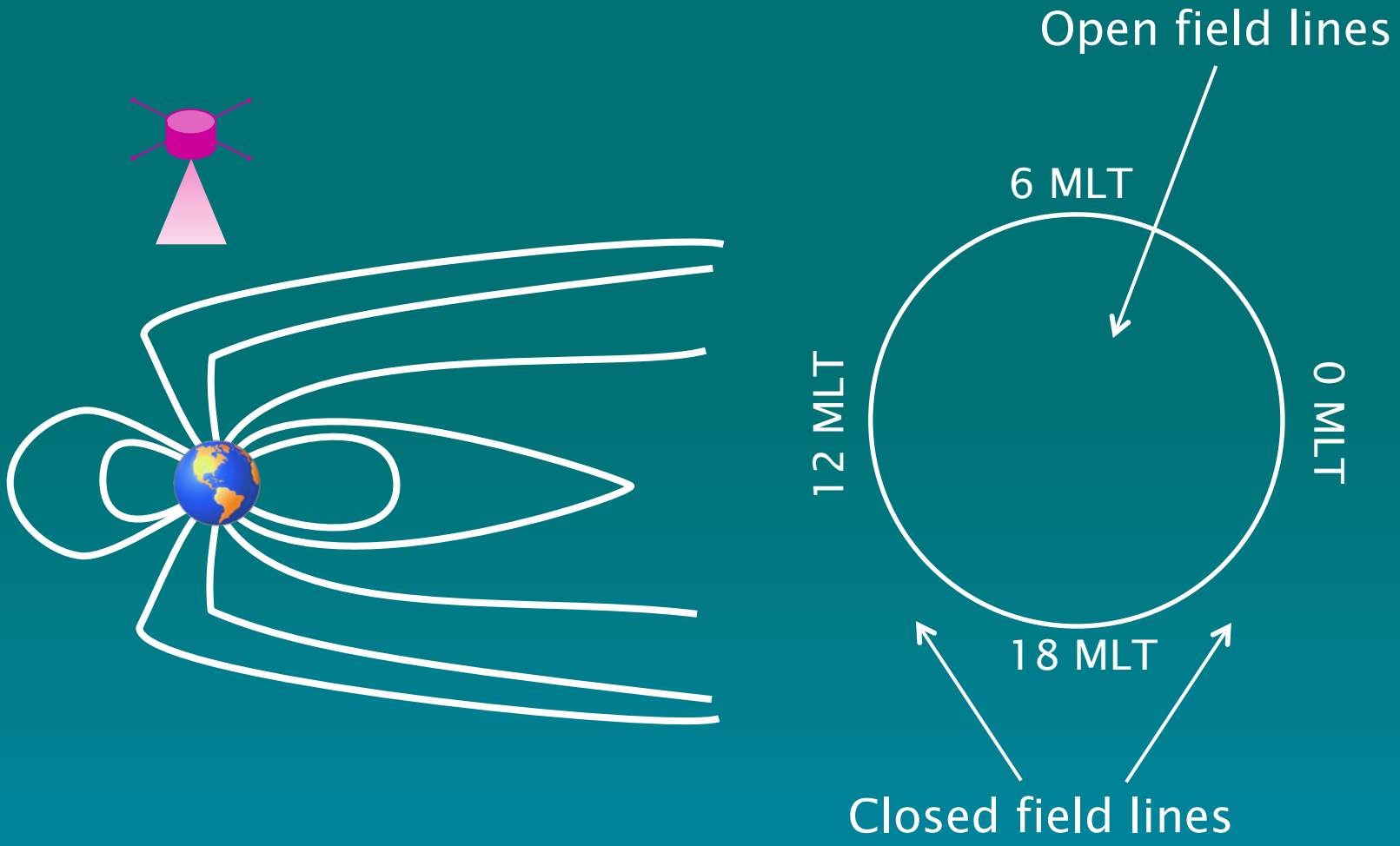
Reconnection mechanism (Milan et al., 2005)

Milan et al. (2005), after Grocott et al. (2004)



- IMF B_Y component can be transferred into magnetotail by dayside reconnection (Fairfield, 1979; Cowley, 1981)
- Return flow of closed tail flux is more complex (Grocott et al., 2003, 04)
  - Asymmetric flows across midnight
  - Oppositely directed in opposite hemispheres
- Milan et al. suggested that:
  - Flux near midnight sector cannot return in a straightforward way
  - The return flow is stymied
  - This leads to a build-up of closed flux which is unable to convect normally
  - Ionospheric signature of is a TPA

Reconnection mechanism for Transpolar Arcs



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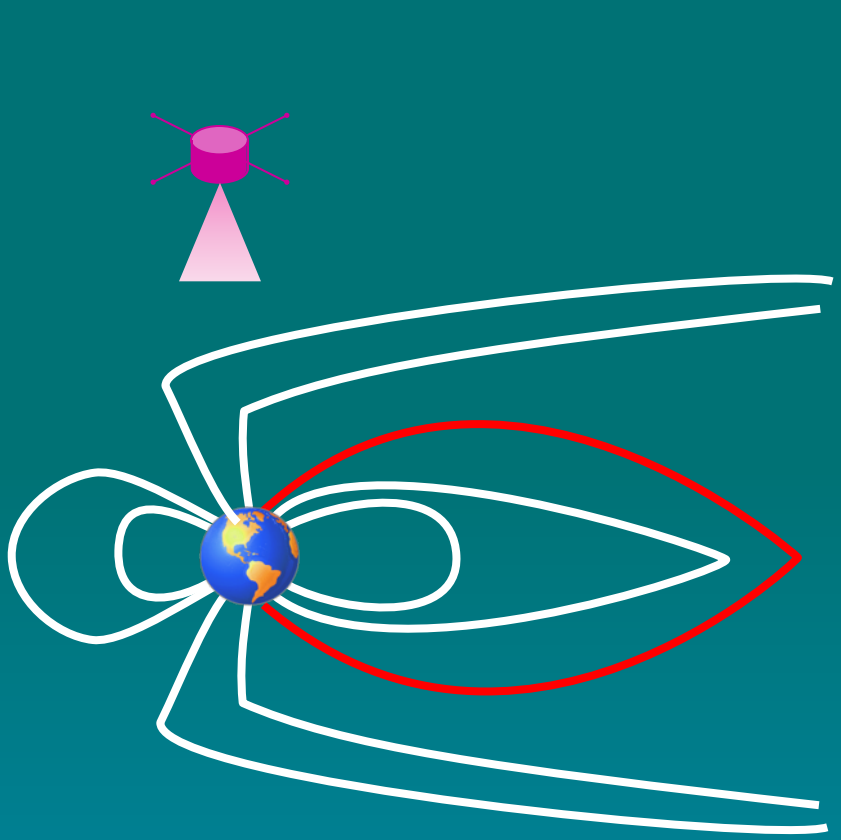
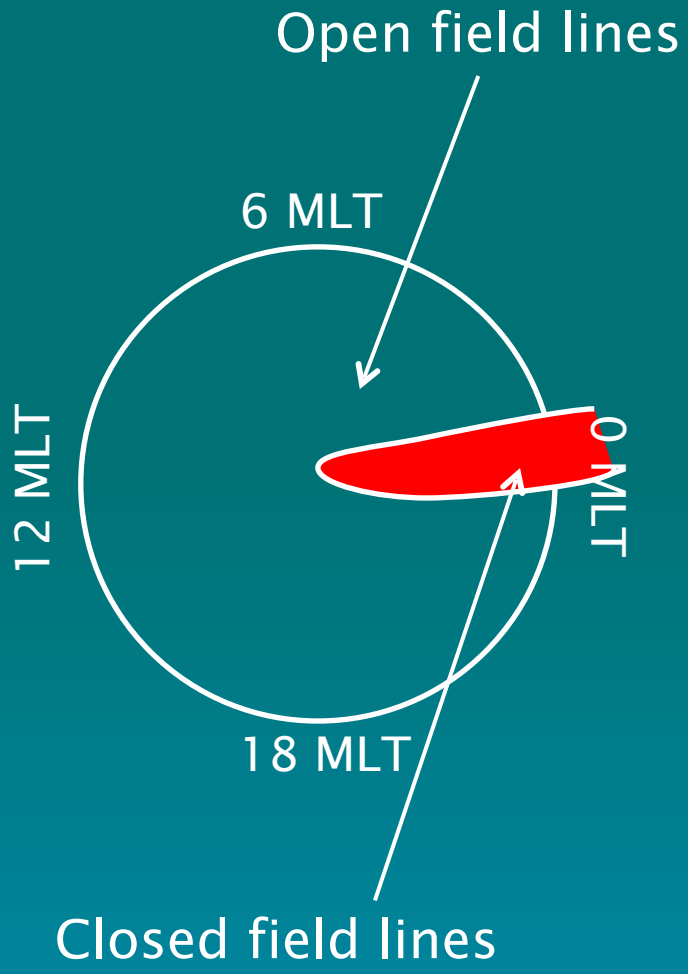
Reconnection mechanism for Transpolar Arcs





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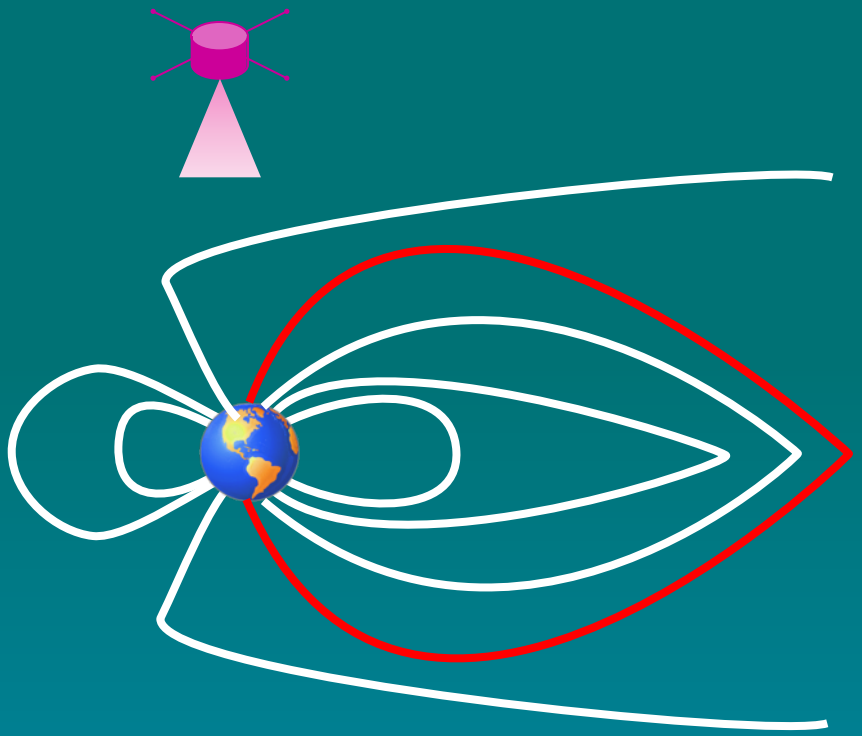
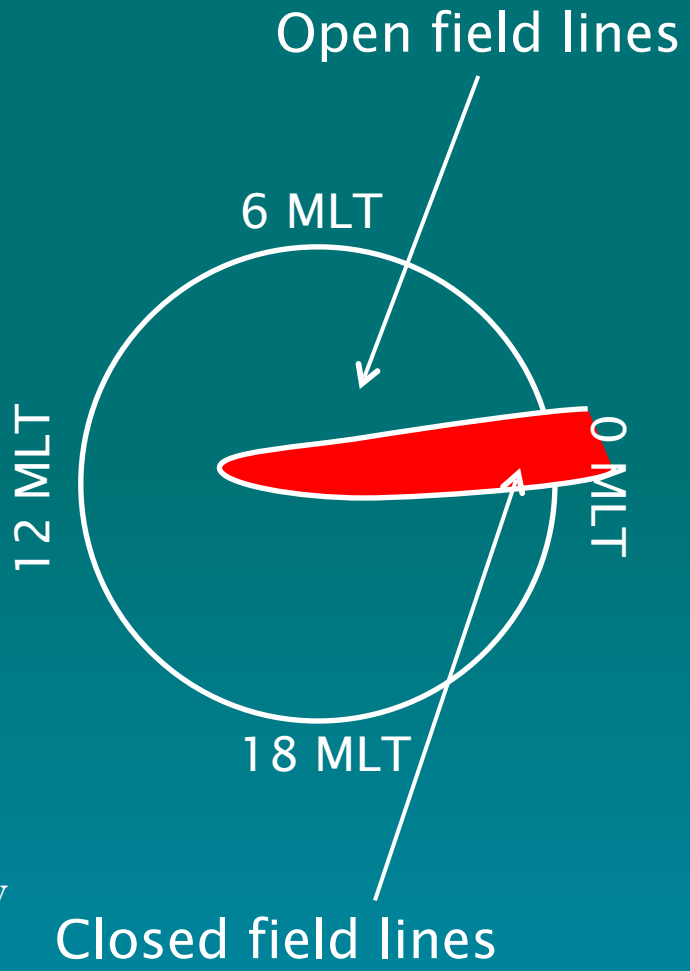
Reconnection mechanism for Transpolar Arcs





- Evidence: Delay observed in IMF dependence, and statistically associated with ionospheric signatures of magnetotail reconnection (Fear & Milan, 2012a,b)
- Predicts closed flux which is 'trapped' in the magnetotail
- Are 'filaments'/'entry plasmas' consistent with this mechanism?

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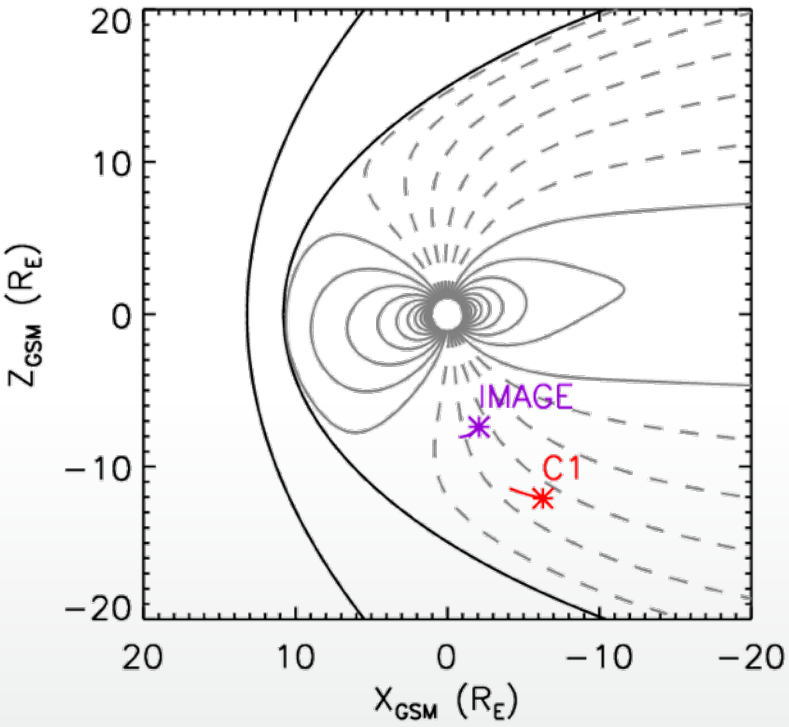
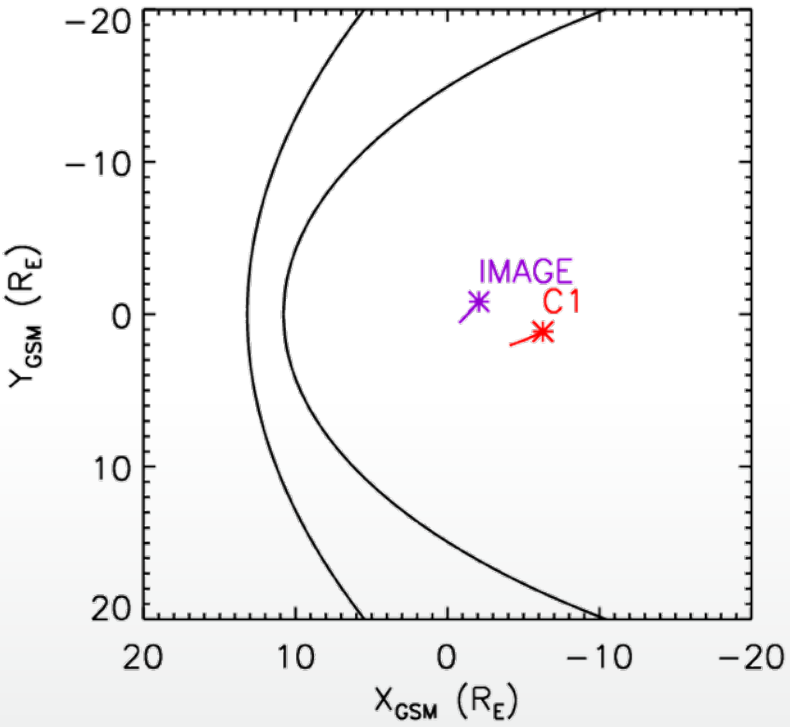
Locations of Cluster & IMAGE

Fear et al. (2014)





- Cluster in southern lobe (closer to nominal MP than nominal plasma sheet)
- IMAGE also above southern polar cap

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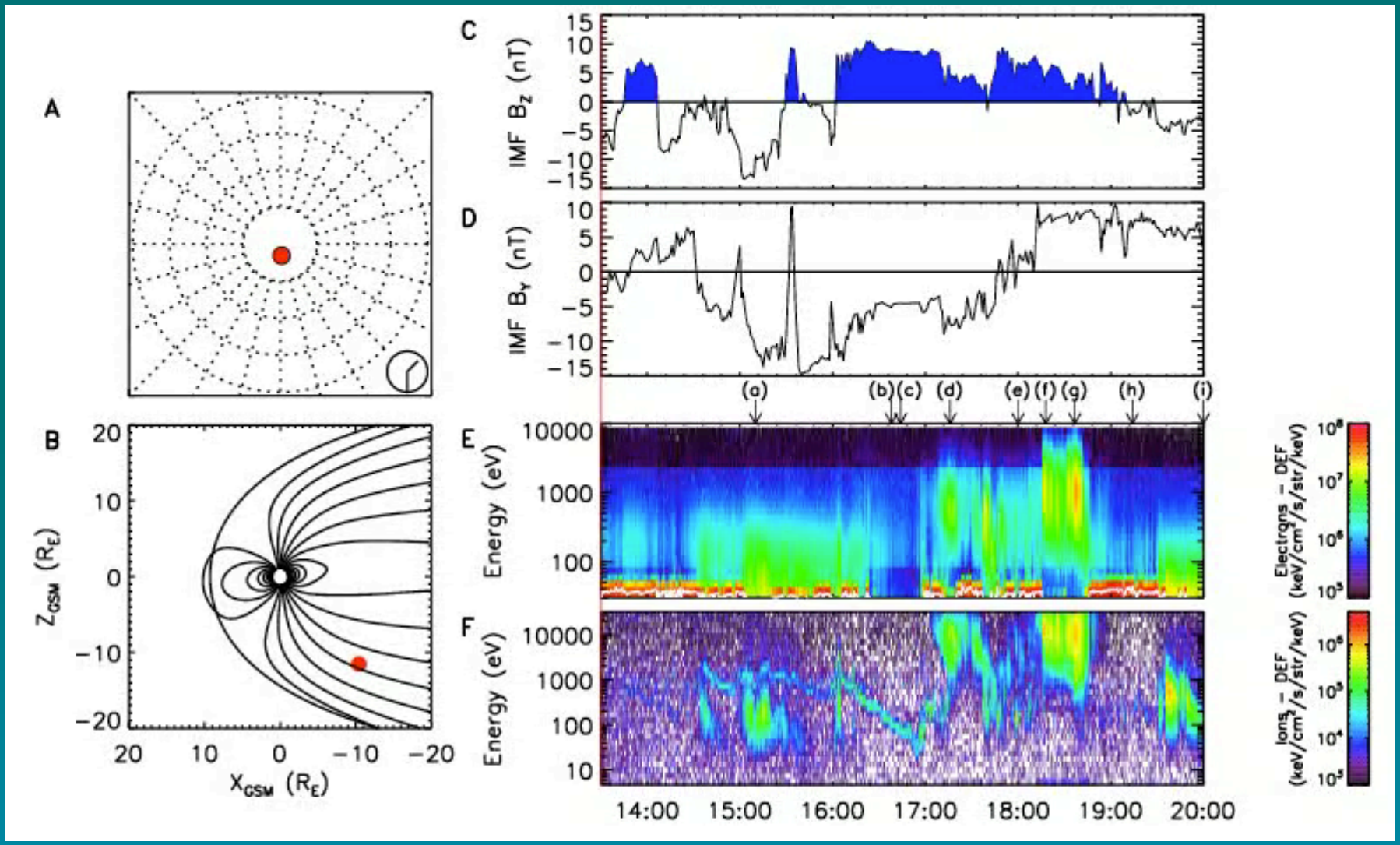
Cluster and IMAGE observations

Fear et al. (2014)



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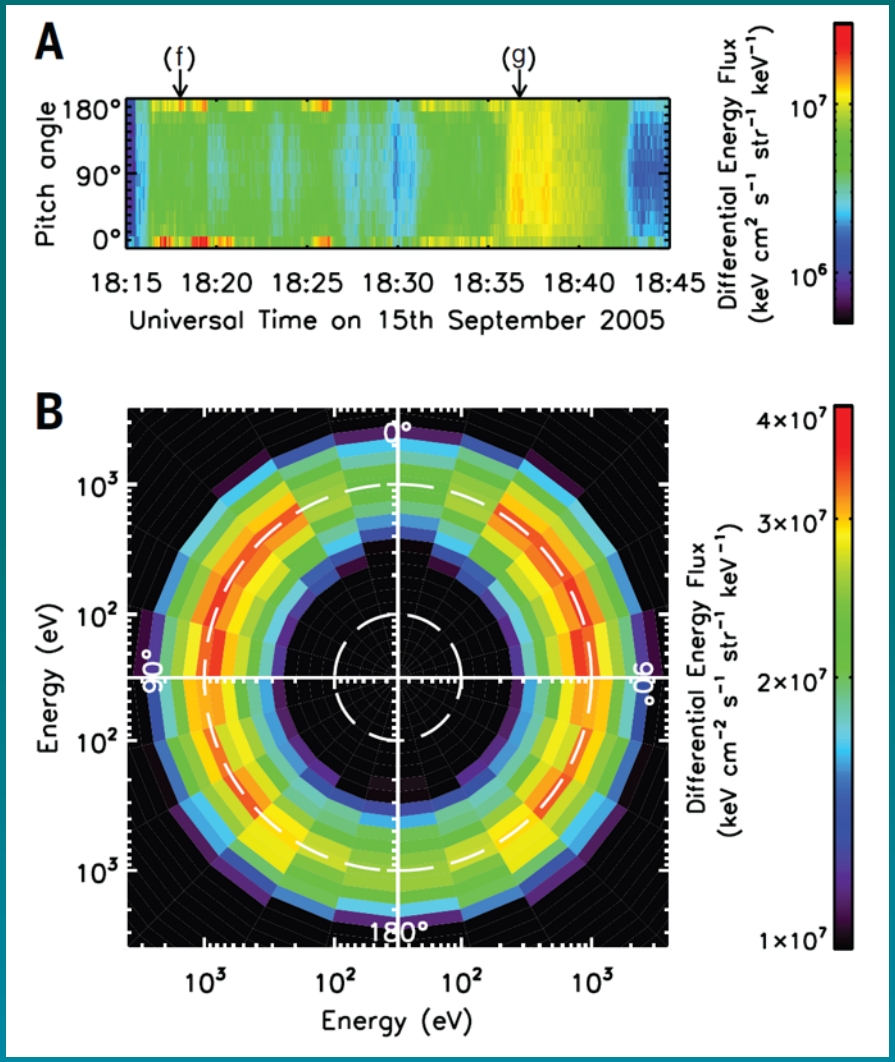
Cluster 1 electron observations

Fear et al. (2014)



- Plasma signatures consistent with closed field lines
- Cluster mostly observed bidirectional electrons
  - Outer plasma sheet (cf Walsh et al., 2011, 2013)
- Ions above 2 keV are isotropic (not shown)
  - Isotropy indicates plasma sheet
- Trapped electron population (double loss cone) observed ~1840 UT [time (g)]
  - Deeper into plasma sheet

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Summary and conclusions

- Presence of double loss cone in uncharacteristically hot lobe plasma indicates plasma is on closed field lines
  - Contrary to location of spacecraft, far from nominal plasma sheet (according to text book picture of magnetosphere)
  - Inconsistent with direct entry of solar wind

- Observations provide extremely strong evidence that transpolar arcs and uncharacteristically hot plasma are caused by "trapping" of closed flux following magnetotail reconnection (Milan et al., 2005)
  - Confirmation of magnetic field topology

- When a transpolar arc extends across fully to the day side (common!), this closed field line structure will extend a long way downtail!