3d Magnetic reconnection at the quasi-parallel shock

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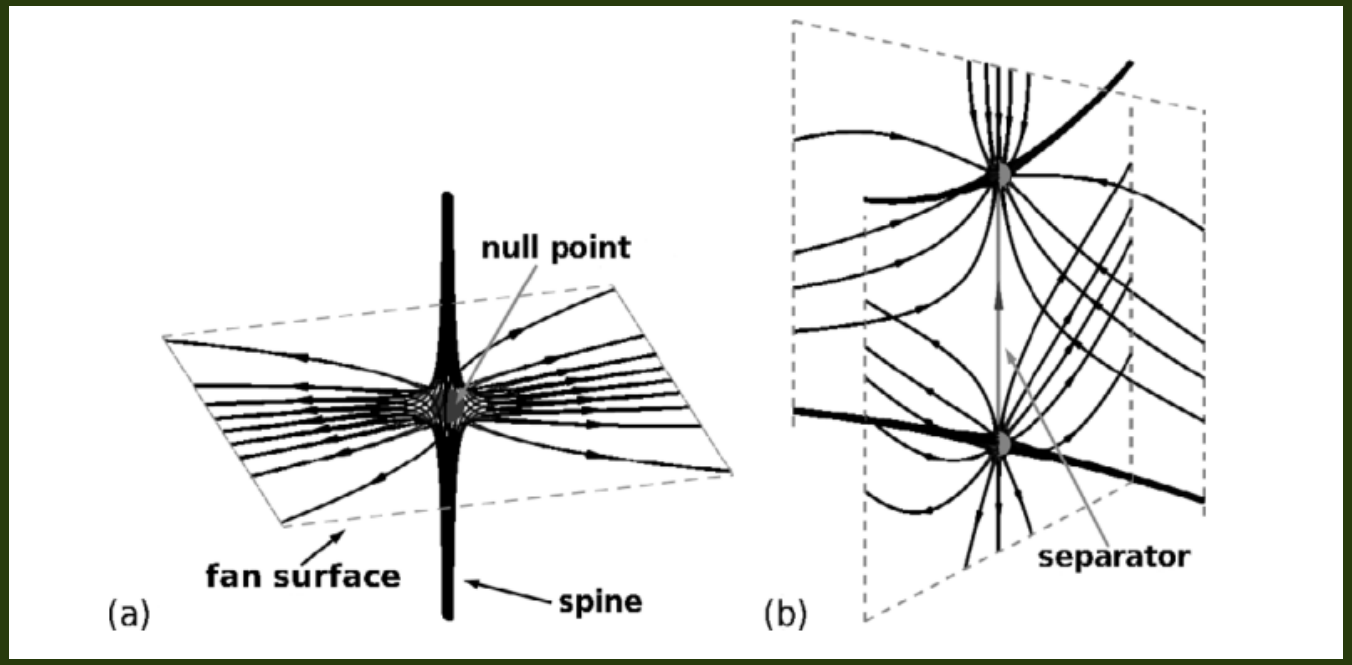
What does 3d reconnection look like at kinetic scales?

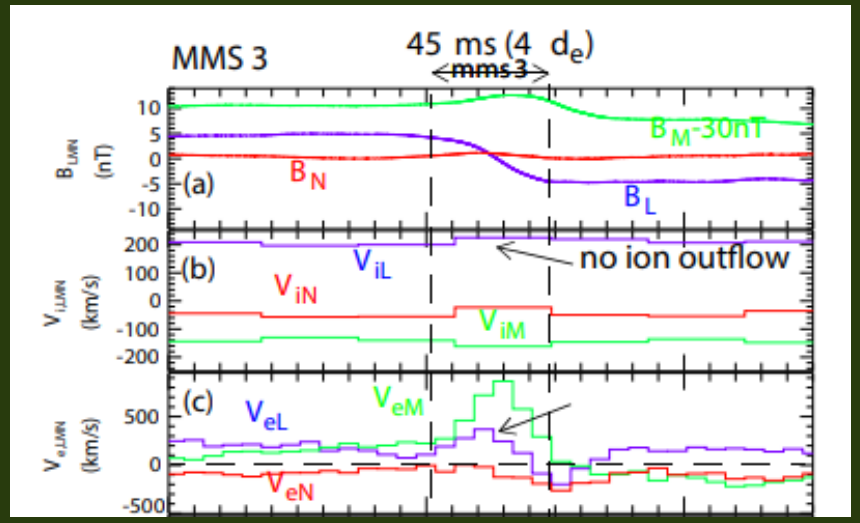
Can we observe it with spacecraft?



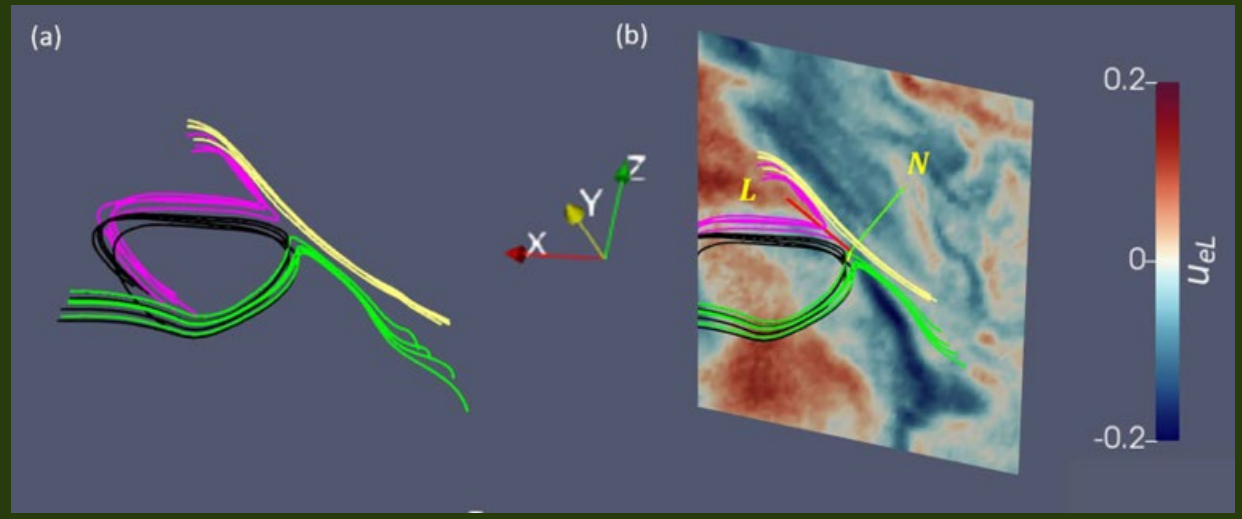
Parnell 2011+

Reconnection at quasi-parallel shocks

- Numerous current sheets develop at the bow shock, some of which are actively reconnecting



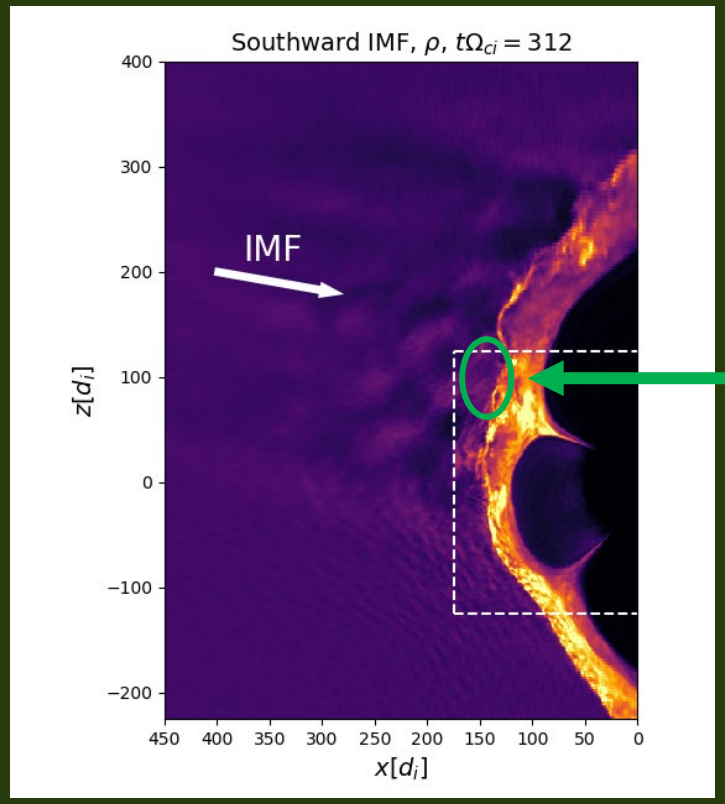
Phan+ (2018)

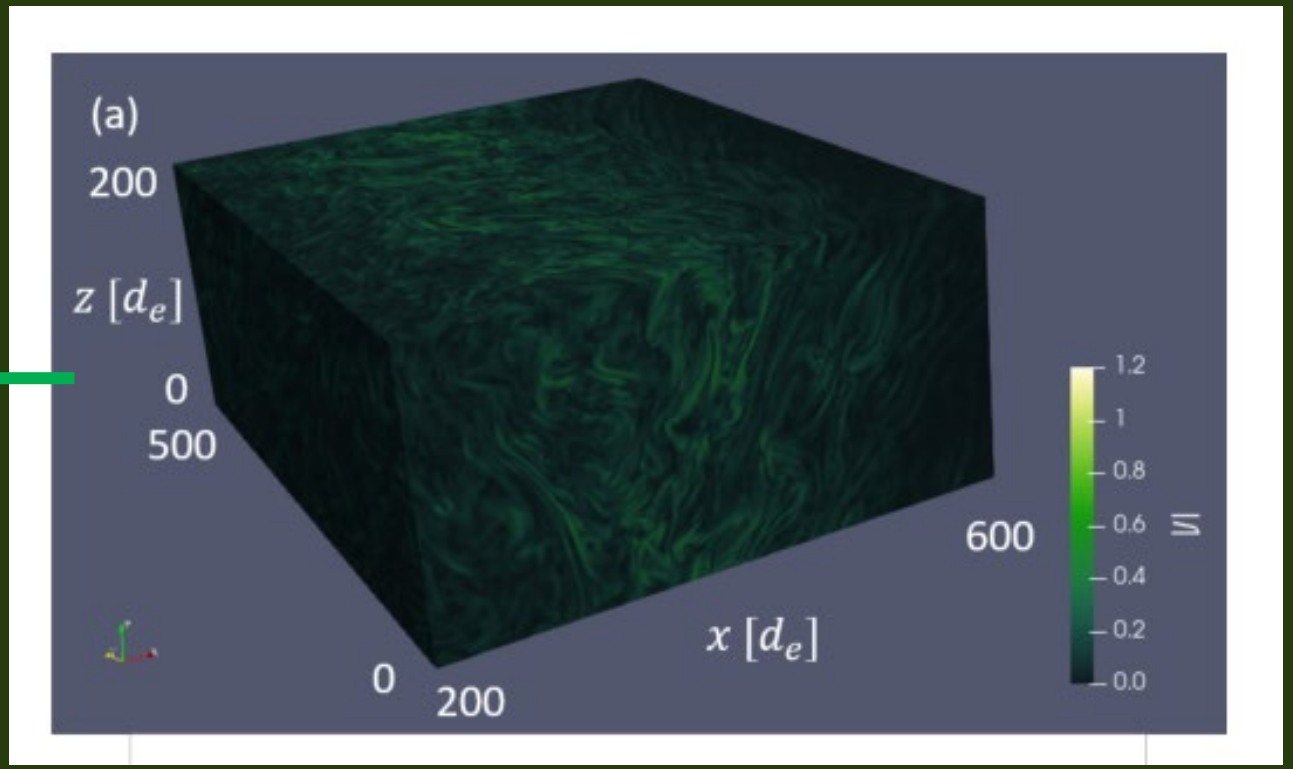


Ng + 2022

3D PIC Simulation

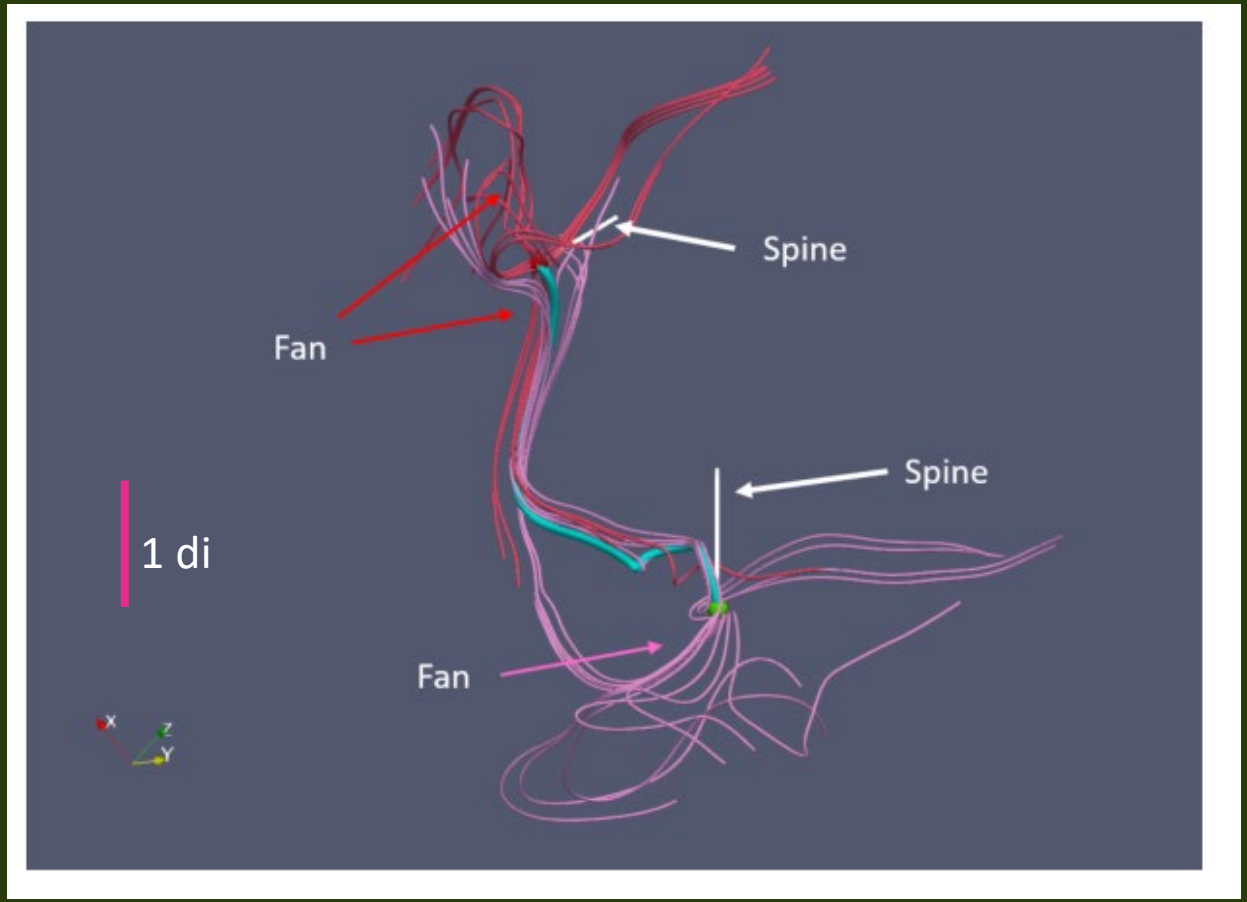
- 3D quasi-parallel shock
- Mass ratio 100
- $M_A = 12, \beta = 1.4$

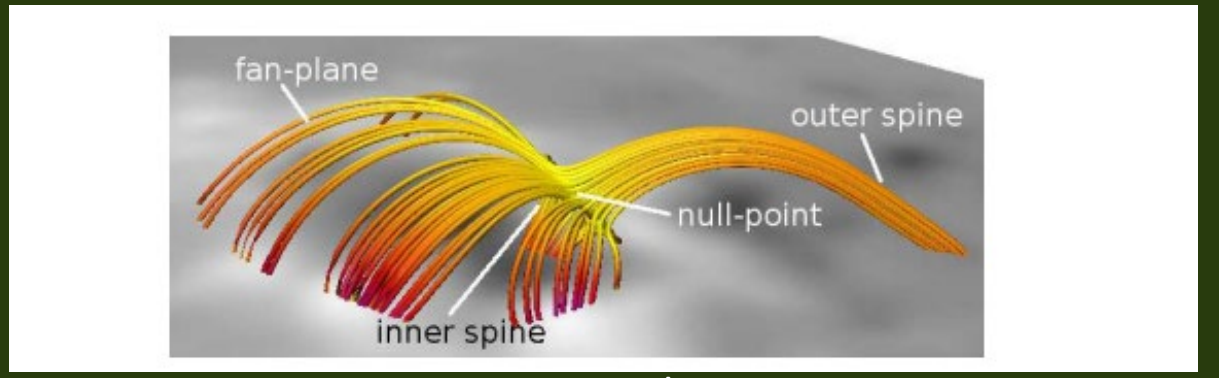




Null points

- Null points are detected and characterised
  - Top-left (red) – radial null
  - Bottom-right (green) spiral null





Baumann et al 2012

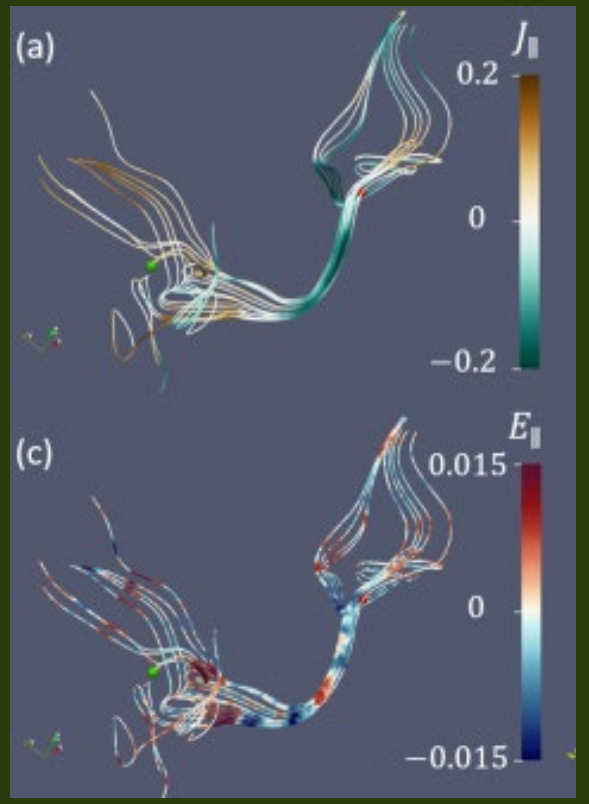
Separator reconnection signatures

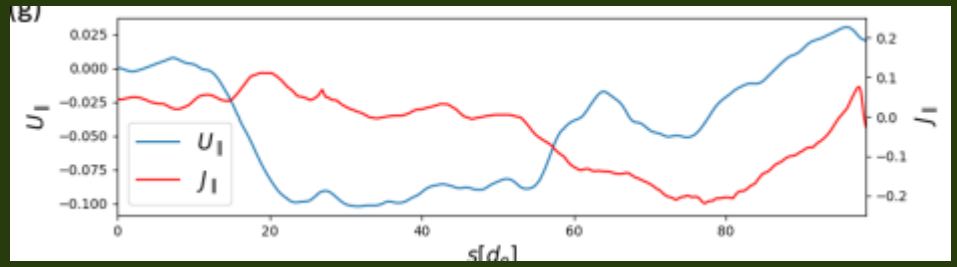
- Multiple signatures of separator reconnection

- 3D reconnection characterised by

$$U_{fl} = -\int_{fl} E_{\parallel} ds$$

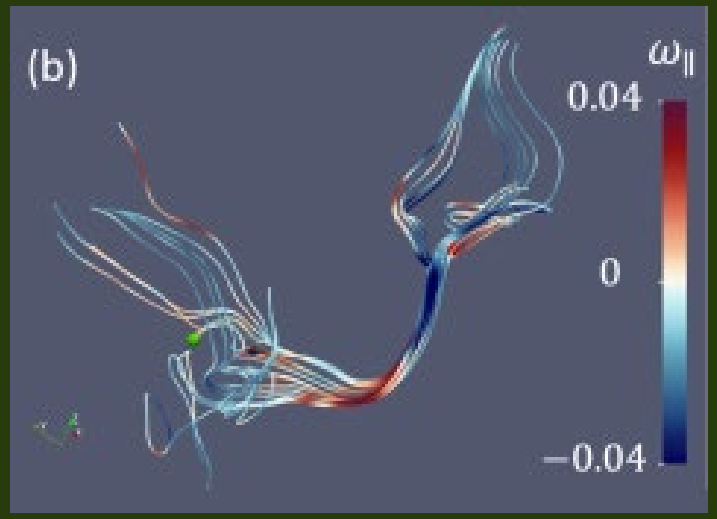
Schindler, Hesse, Birn 1988

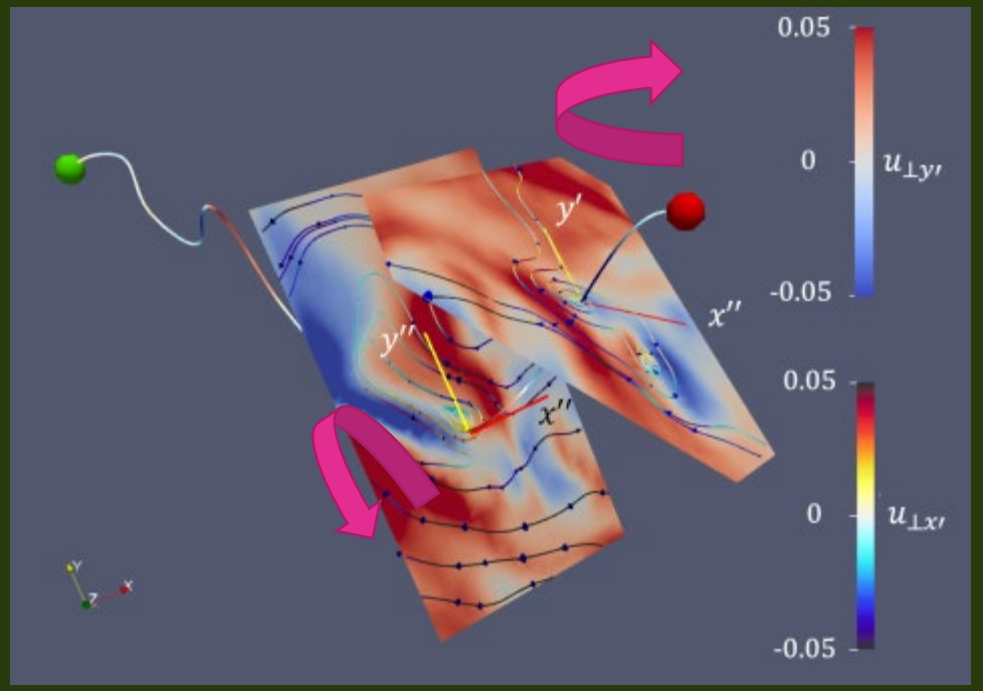




Counter-rotating flows are an important signature of 3d reconnection

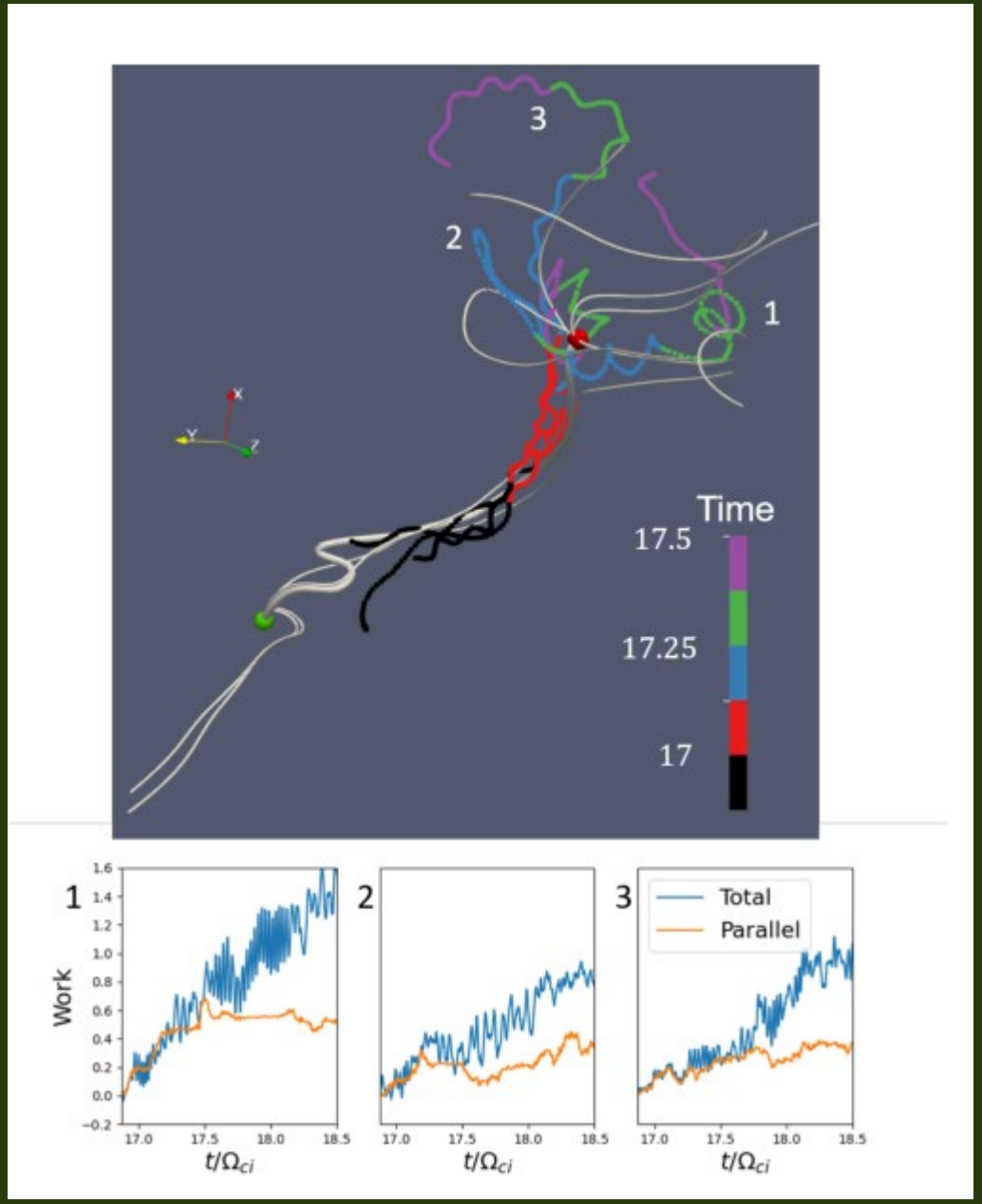
- MHD studies find that these flows can drive reconnection (Parnell 2010, Hornig+ 2003)





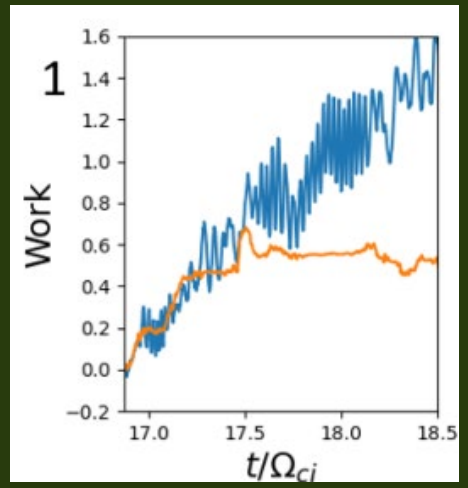
Electron acceleration

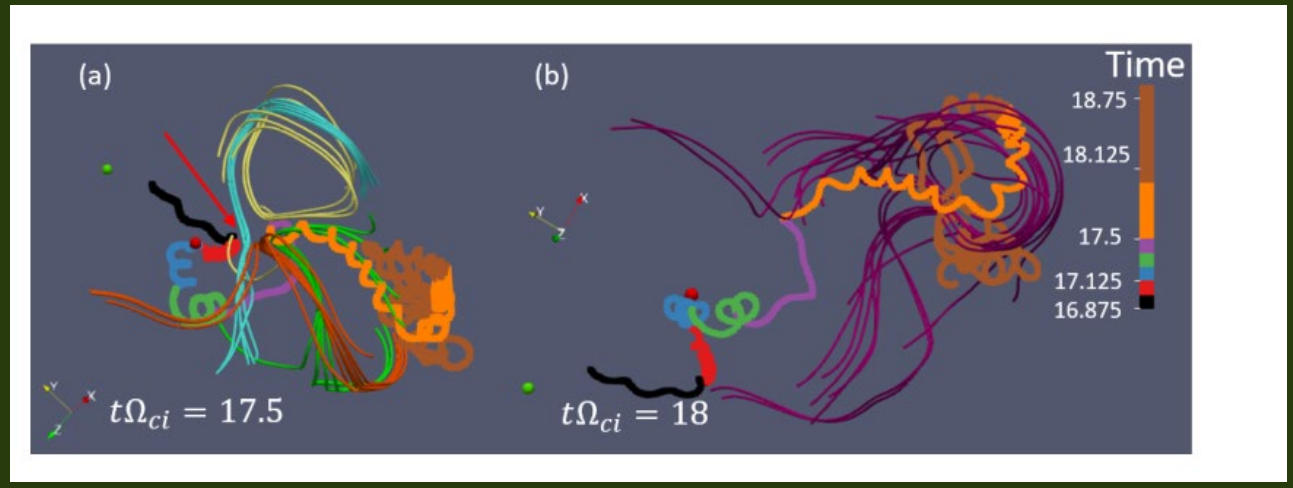
- Electrons undergo parallel acceleration as they pass along the separator
- Energy gain is consistent with integrated parallel field
- Perpendicular acceleration becomes important later



Further electron acceleration

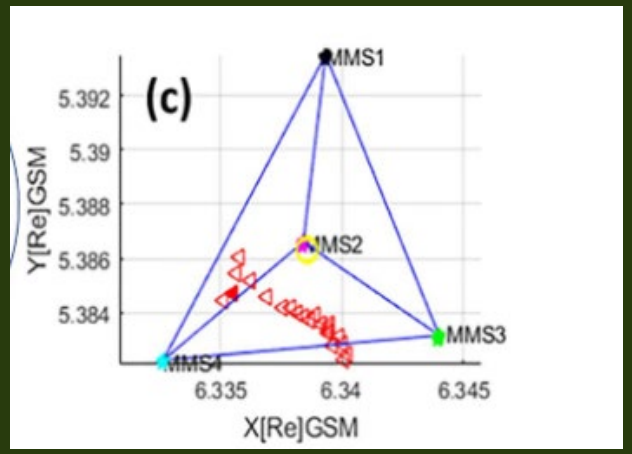
- This particle undergoes parallel acceleration at a second reconnection site, followed by perpendicular acceleration in a flux rope



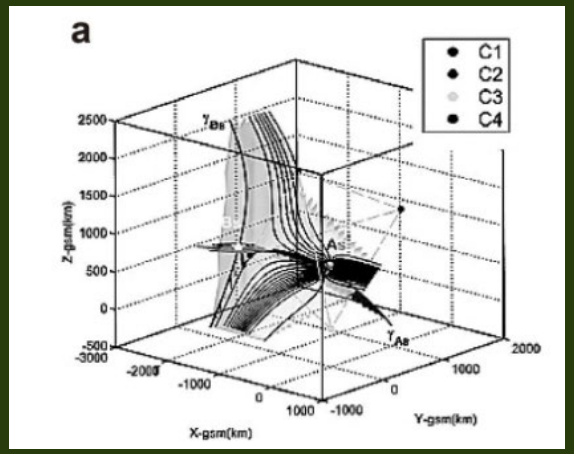


Observations of nulls in the magnetosphere

- Cluster and MMS observe/reconstruct null points and magnetic separators

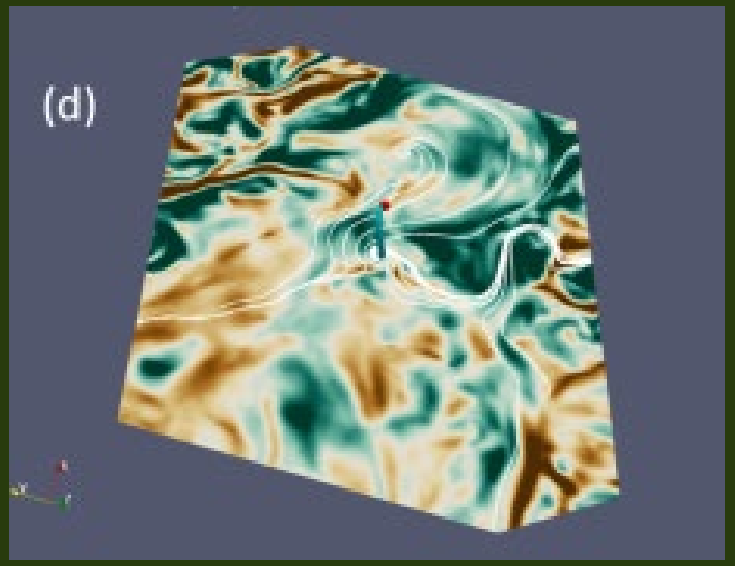


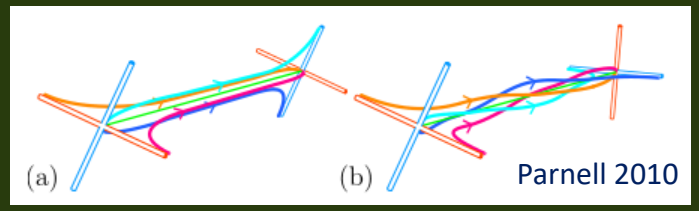
Ekwati+ (2023)
Flank



Deng+ (2009)
Magnetotail

3d reconnection sites don't necessarily have to look like X-points in 2d



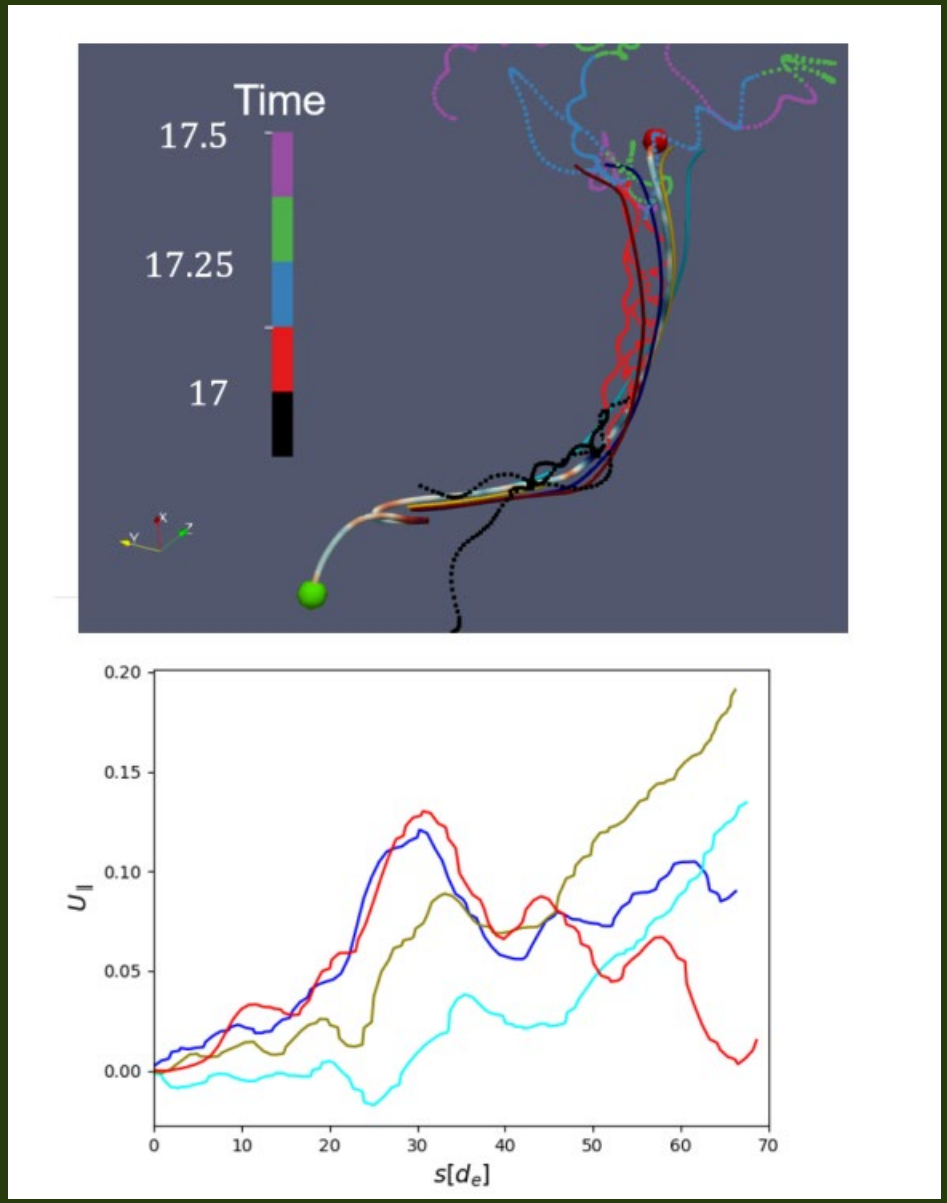


Parnell 2010

Summary

- We have characterised a 3d reconnection event
- Tracer particles show that parallel acceleration happens during reconnection along the separator with energy comparable to Te
- Acceleration by other mechanisms (eg Fermi, “normal” reconnection appears to be more significant later)

Backup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