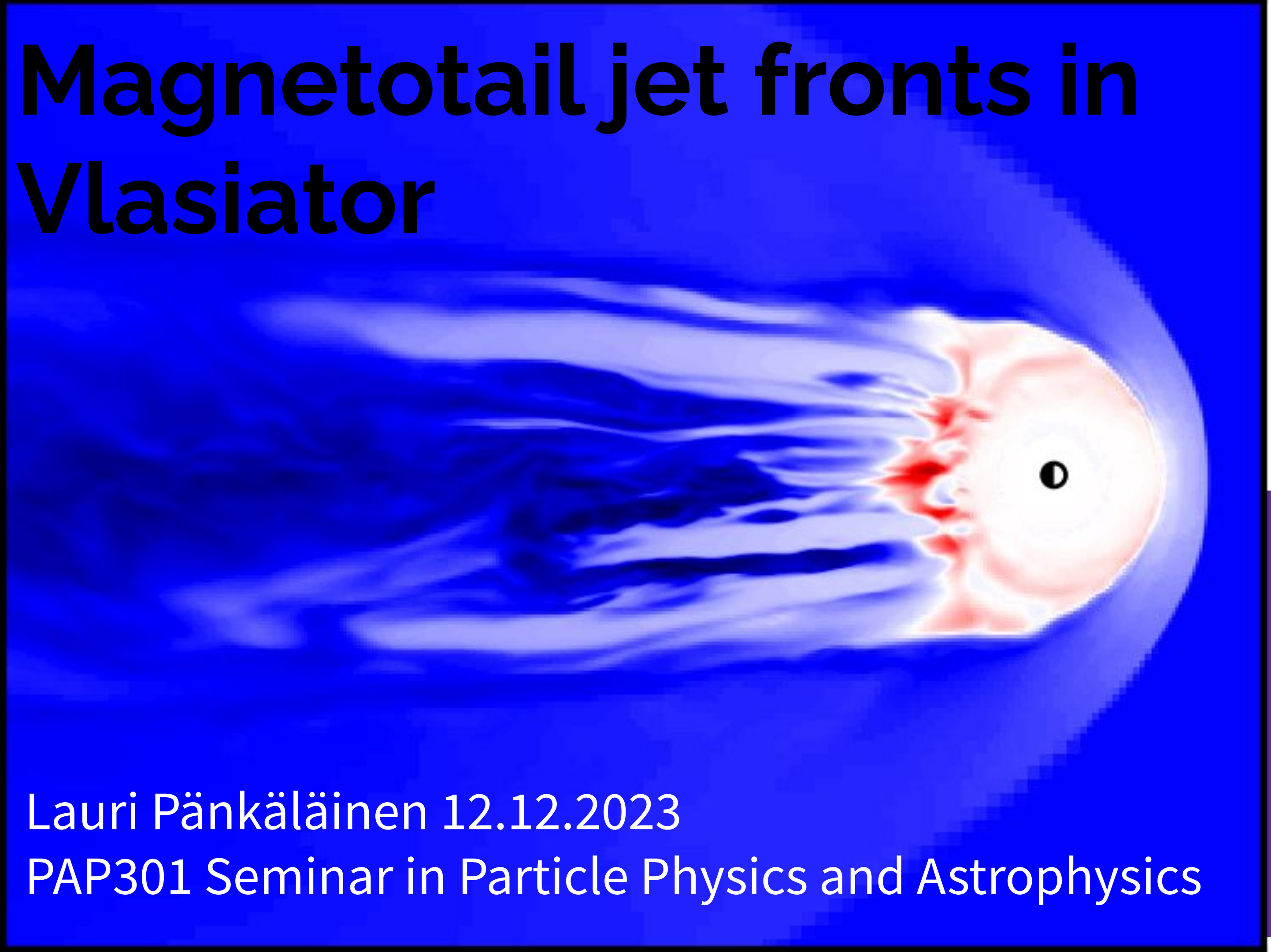
Magnetotail jet fronts in Vlasiator



Lauri Pänkäläinen 12.12.2023

PAP301 Seminar in Particle Physics and Astrophysics

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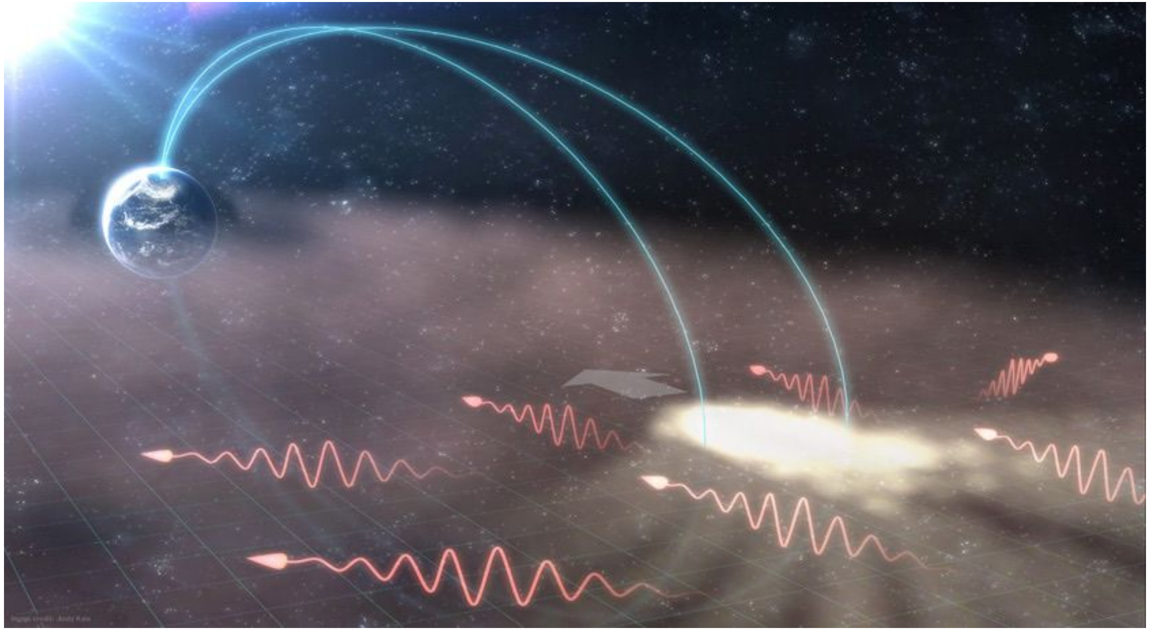
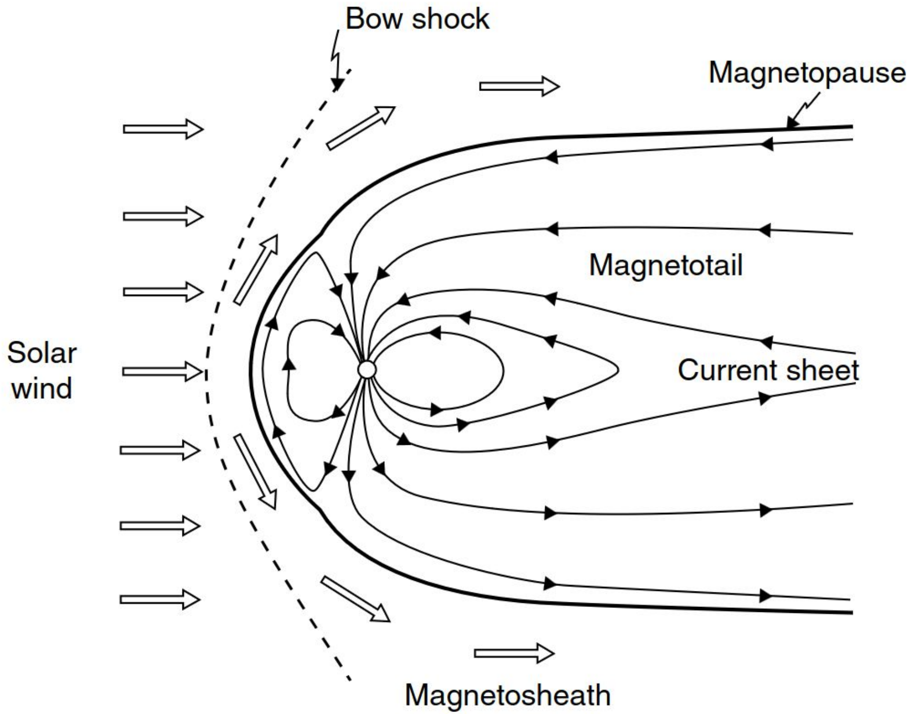


University of Alberta

Earth's magnetosphere

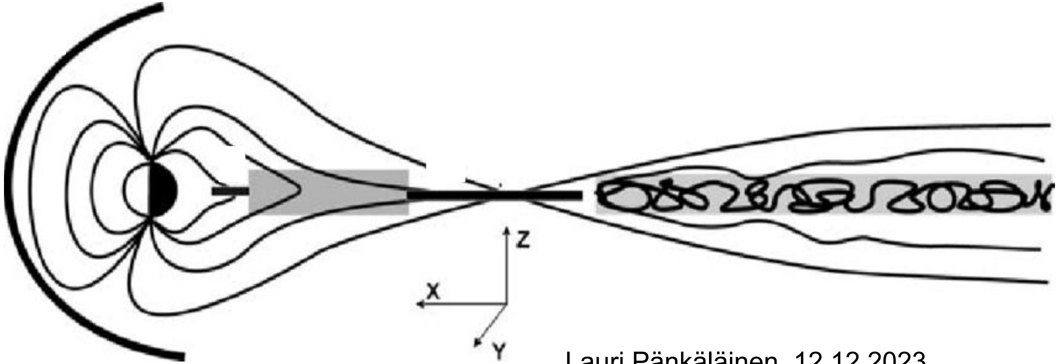
- Particle motion is dominated by the geomagnetic field
- Determined by the interaction with the solar wind
  - Charged particles from the solar corona
  - Carries the interplanetary magnetic field



Vasyliūnas (2015)

Earth's magnetotail

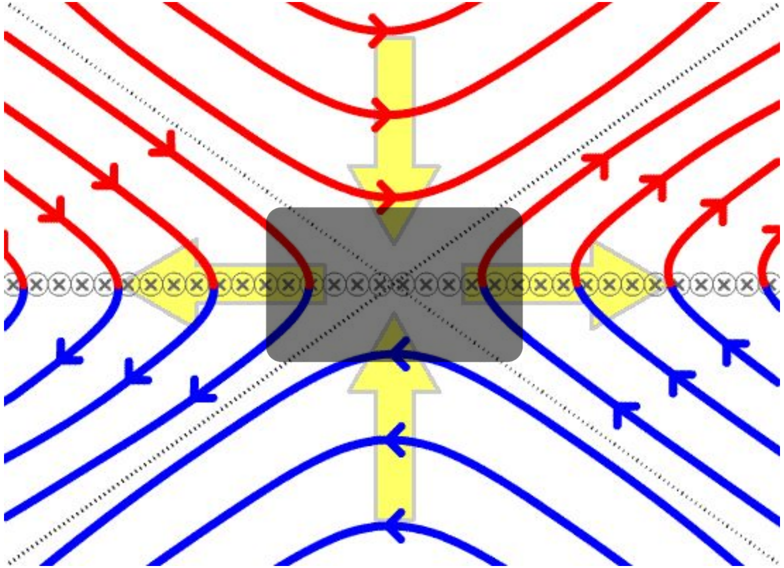
- Nightside of the magnetosphere
- Stretched by the solar wind
- Two lobes separated by the central plasma sheet
  - Higher temperature, lower magnetic field
  - Hosts the current sheet ($B_x \approx 0$)



Zelenyi et al. (2009)

Magnetic reconnection

- Magnetic field vanishes within a diffusion region
  - Field line topology changes
  - Different plasma domains mix
  - Magnetic energy is converted into particle heating and acceleration



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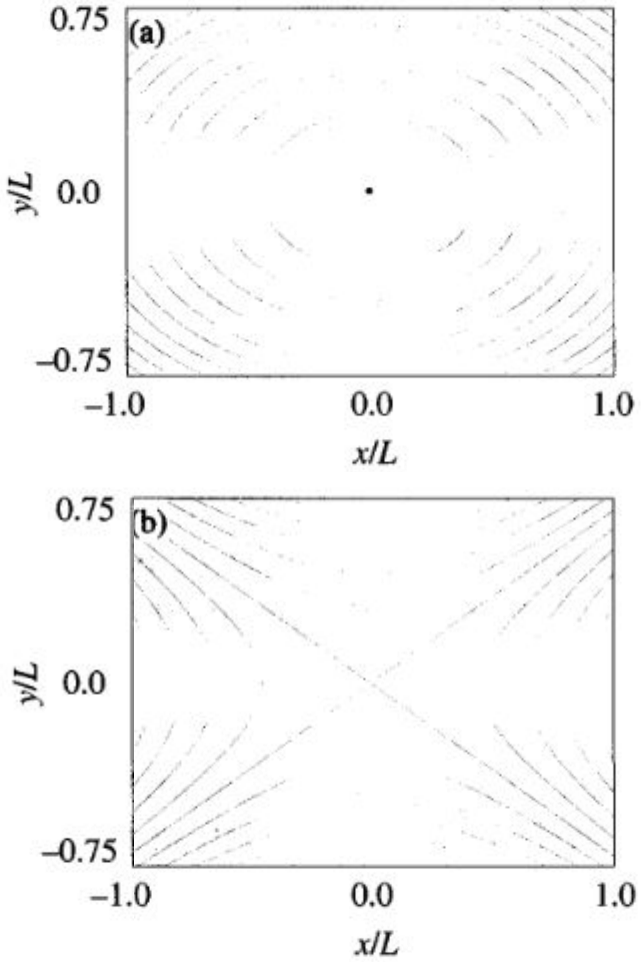
Magnetic null points ($\mathbf{B} = 0$)

- O-points: elliptical field lines
  - Magnetic islands
- X-points: hyperbolic field lines
  - Potential reconnection sites
- Three dimensions: X and O lines
  - Field component along the line can be non-zero

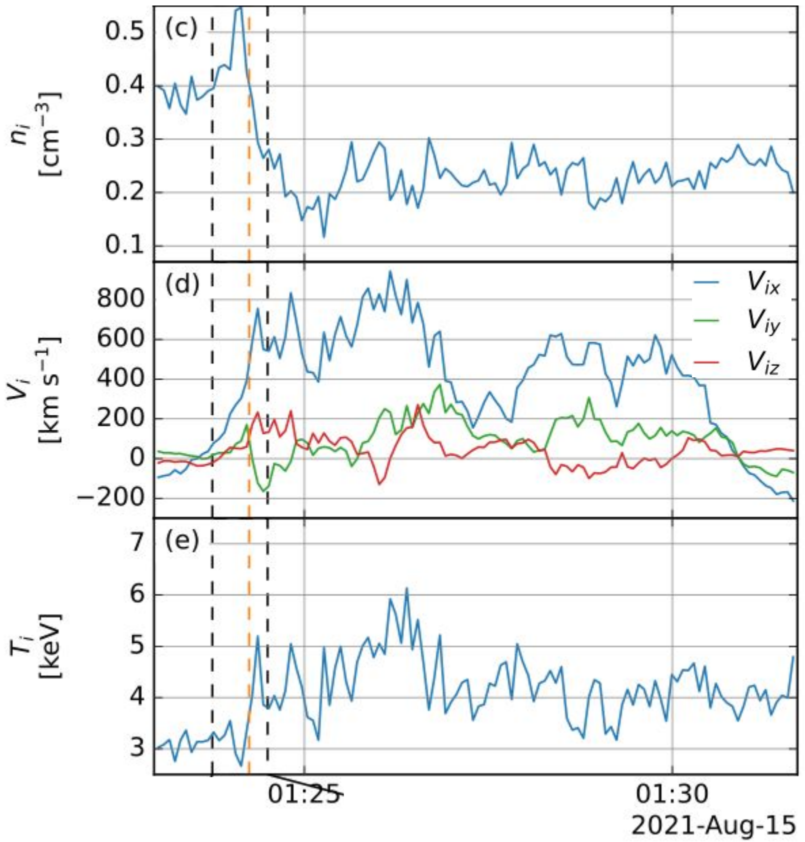


Priest and Forbes (2000)

Bursty bulk flows (BBFs)

- High-velocity plasma flows in the central plasma sheet
- Last for 1–10 minutes
- Density peaks before dropping, temperature increases
- Associated with reconnection

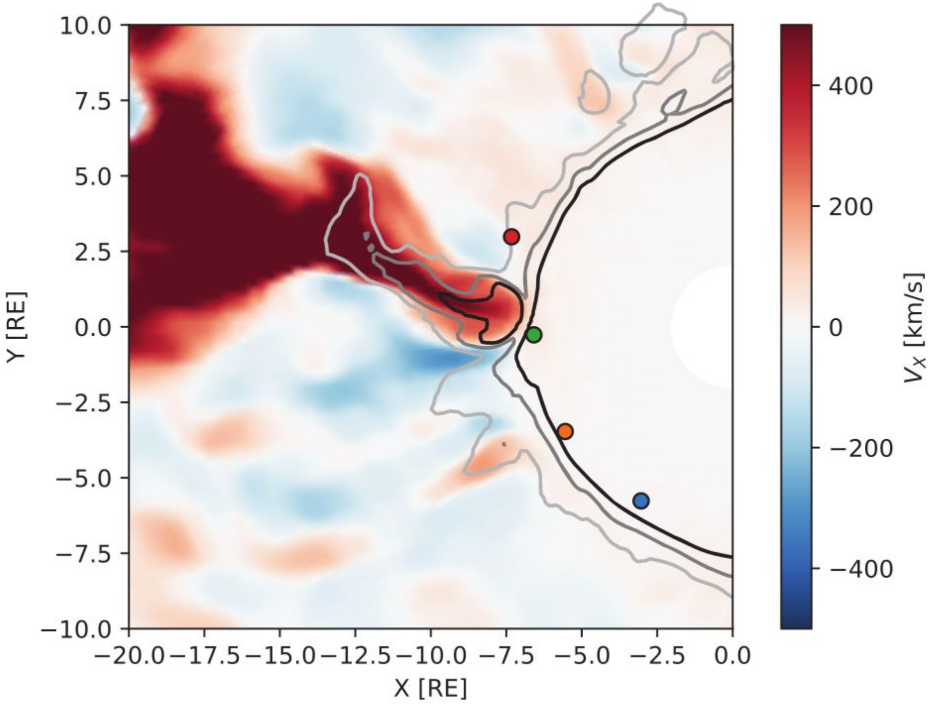
MMS data



Richard et al. (2022)

BBF statistics

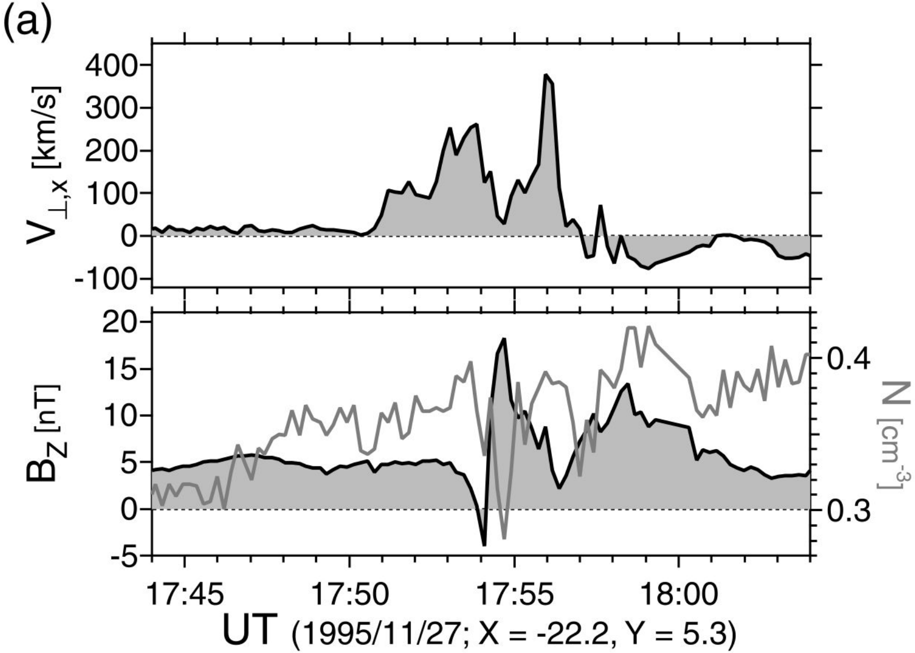
- Cross-sectional extent of 1–3 R_E (Earth radii)
- Observed 10–15% of the observation time, responsible for 60–100% of
  - mass and energy transport
  - magnetic flux



Merkin et al. (2019)

Dipolarization fronts (DFs)

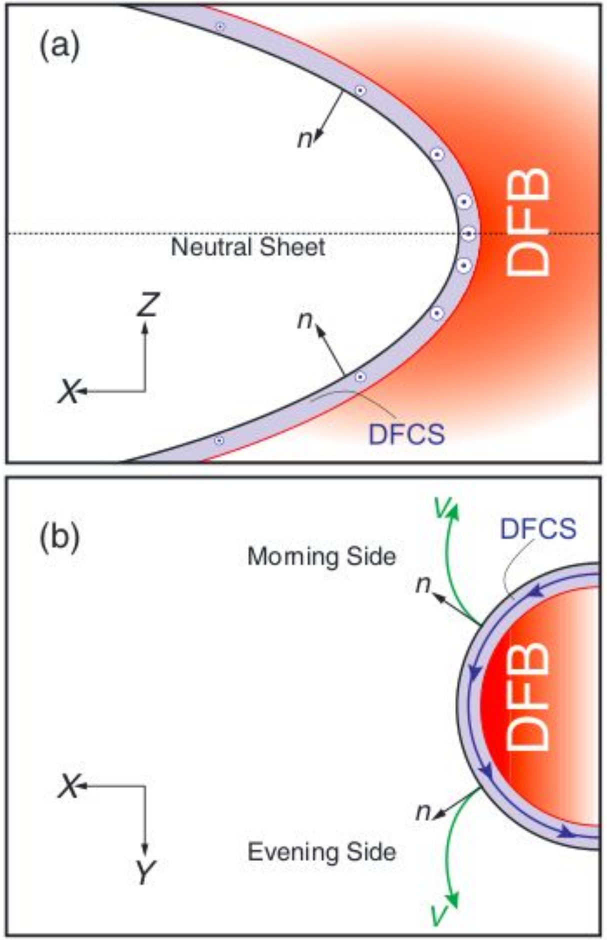
- Sudden enhancements of B_z in the magnetotail
  - Preceded by a “dip”
- Created by plasma instabilities linked to reconnection
- Often associated with bursty bulk flows



Ohtani et al. (2004)

DF features

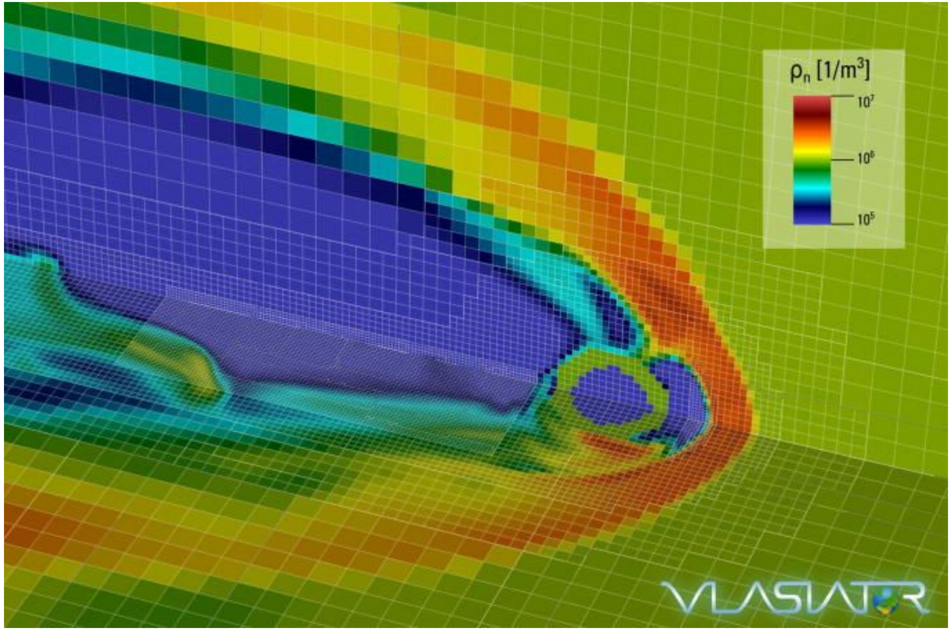
- Cross-sectional dimensions comparable to BBFs
- Saddle-shaped
- Involved in eg. energy conversion and magnetic flux transport



Liu et al. (2013a)

Vlasiator

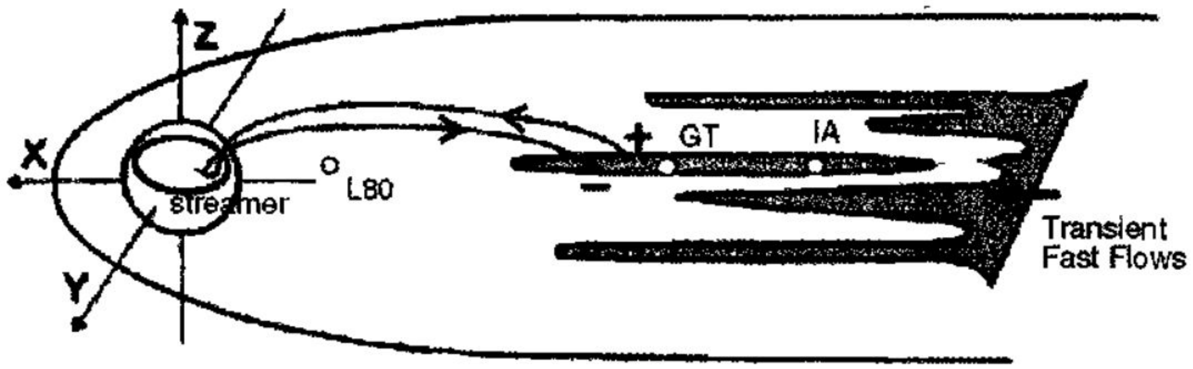
- A global 6D (3D3V) simulation of the Earth’s magnetosphere
- Hybrid-Vlasov approach:
  - Ion dynamics through the Boltzmann equation
  - Electrons charge-neutralizing fluid
  - EM fields from Maxwell’s equations



Ganse et al. (2023)

Research question

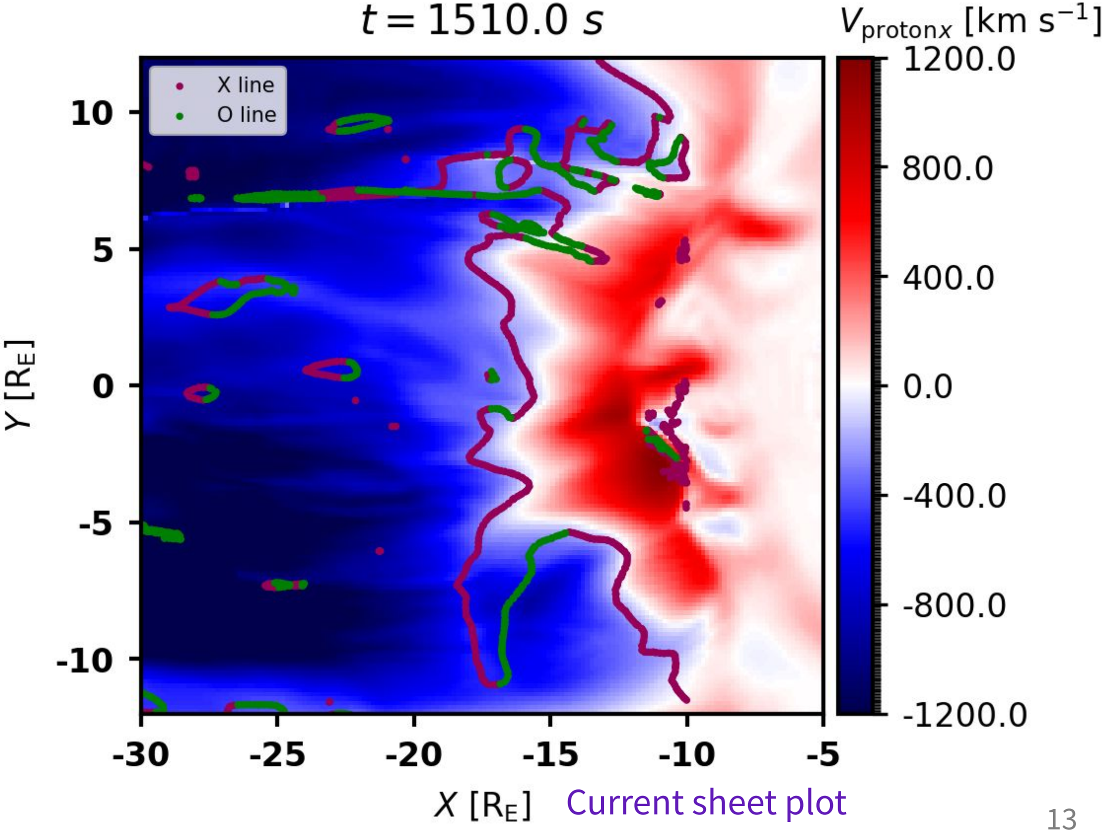
- Do we see signatures of BBFs and DFs in Vlasiator?
- If so, how do they compare to satellite measurements?
- What is the 3D nature of BBFs and DFs?



Sergeev et al. (1999)

Conditions in the simulated magnetotail

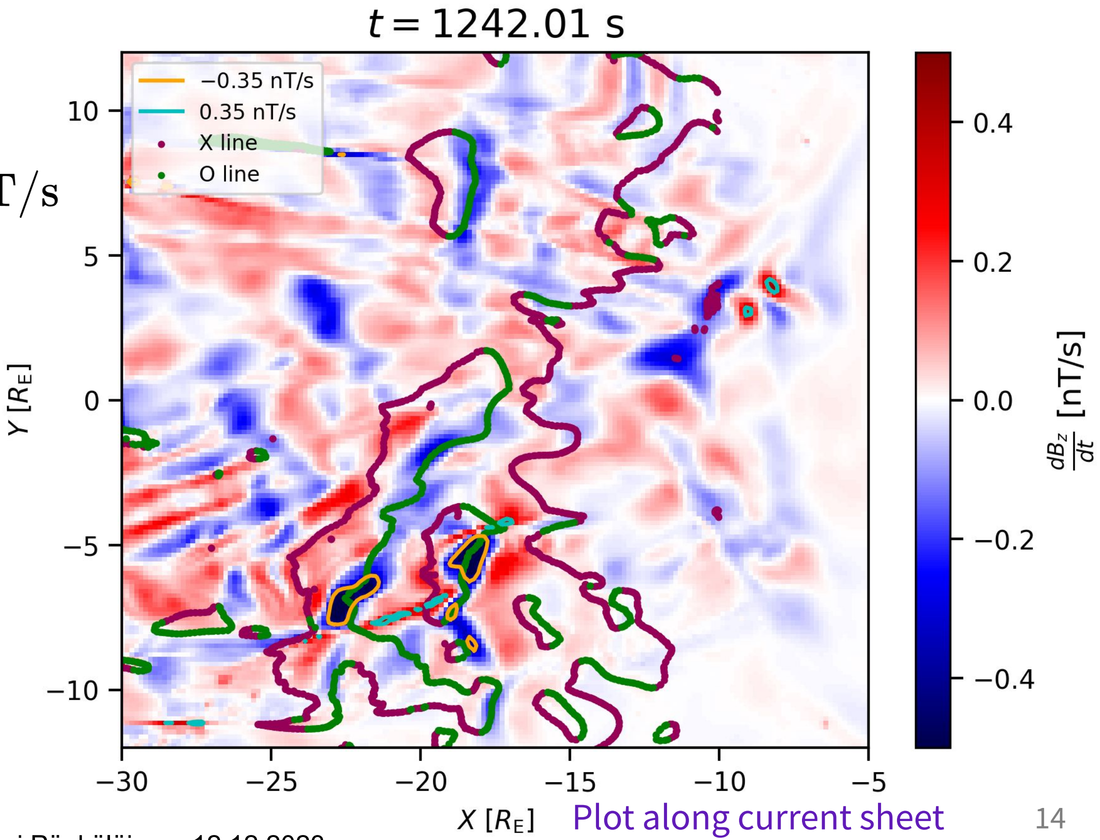
- Intense solar wind conditions
  - Main reconnection X line close to the Earth
- High velocity flows localized near the current sheet



Current sheet plot

Analysis of 24 dipolarization front events

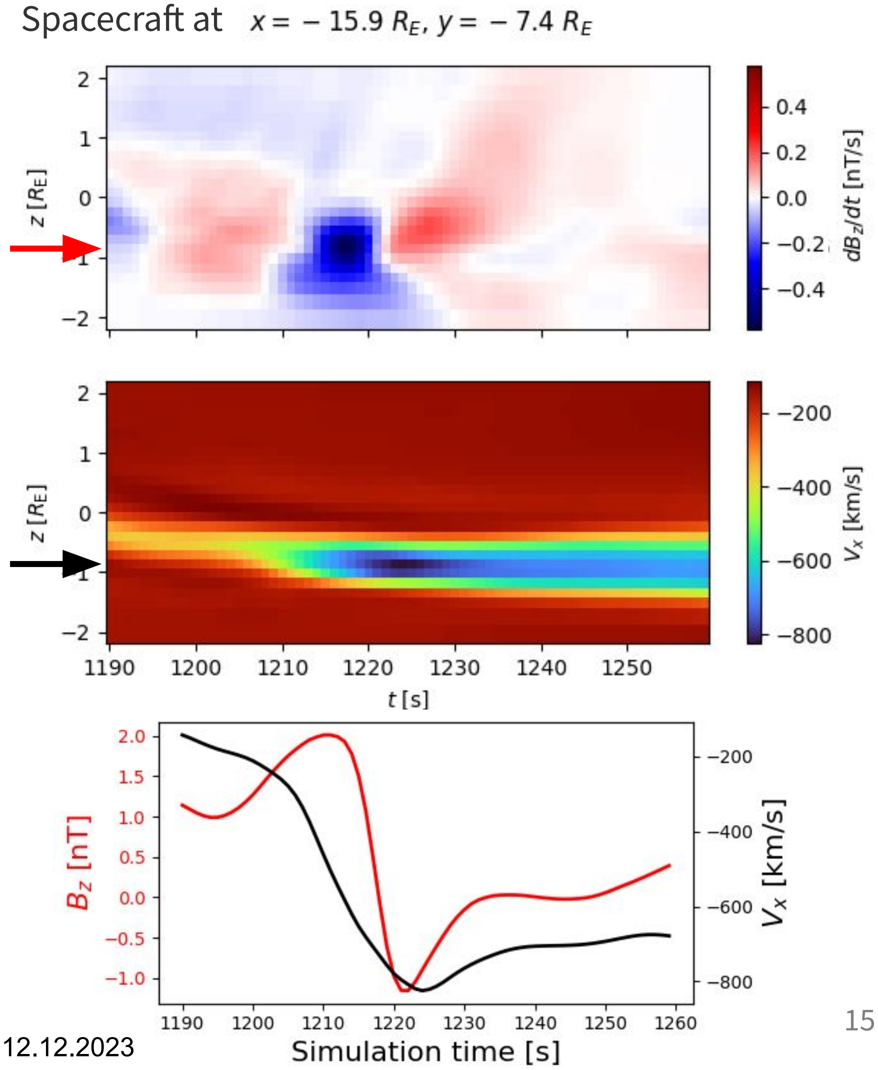
- DFs were identified as regions with $\left|\frac{dB_z}{dt}\right| > 0.35\,\mathrm{nT/s}$
- Earthward fronts mostly at the ends of high velocity “fingers”
- Tailward fronts on top of O lines



Plot along current sheet

Spacecraft view of DF events

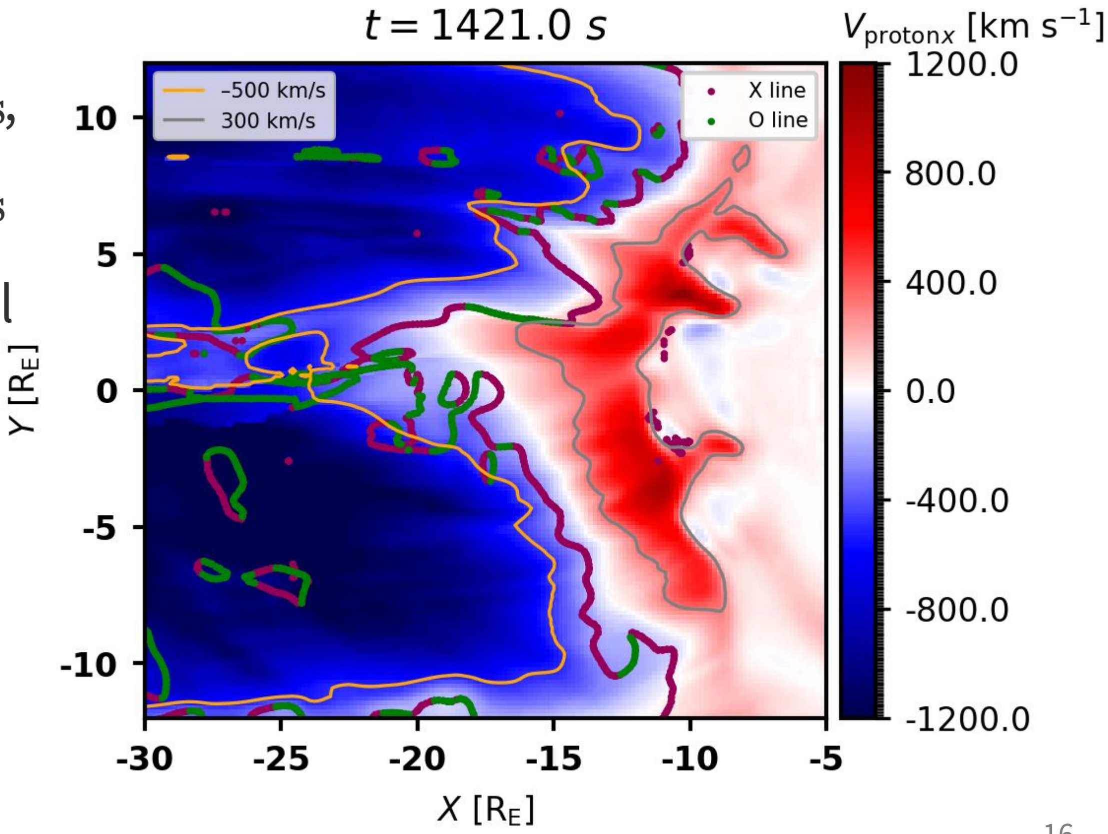
- Front sizes consistent with previous studies
- Saddle-like shape in only three earthward fronts
- Change in B accompanied by velocity increases
    - Not necessarily BBF fronts



BBFs in the simulation

- Peak above $|V_x| > 300\,\mathrm{km/s}$, boundaries $|V_x| = 100\,\mathrm{km/s}$
- No clear fronts in the global view
  - Simulated satellite measurements show clear fronts

Plot along current sheet



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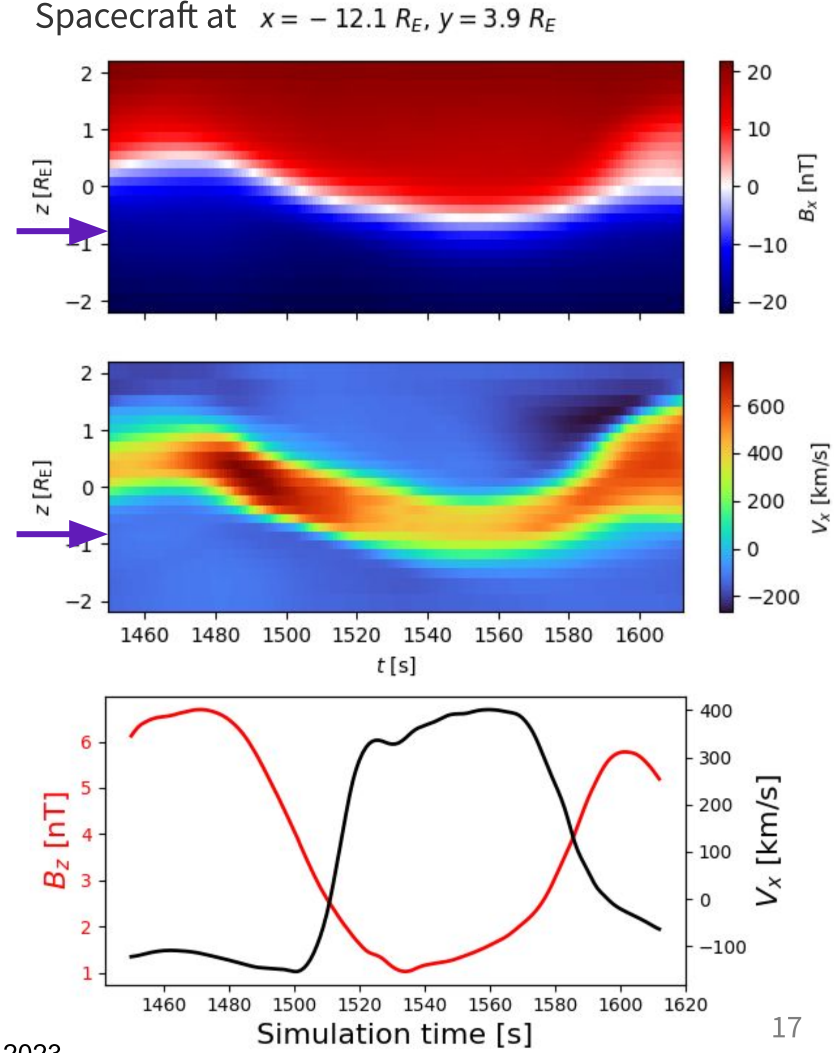
BBFs in spacecraft frame

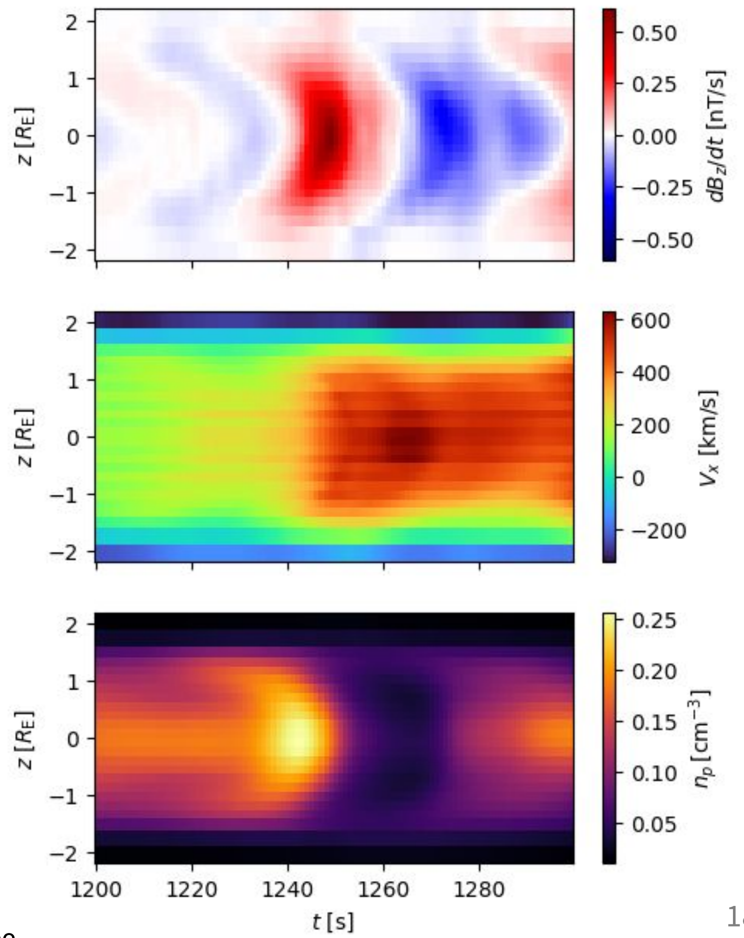
- Signature origins:
  - New high velocity domains
  - Deformation of the outflow region
  - Vertical movement of the current sheet
- “Fingers” most similar to previous results



Do the results matter?

- Real measurements could have similar origins
  - Identification help from simulations?
- Possible sources of error:
  - Small dataset, coarse resolution
  - Different conditions

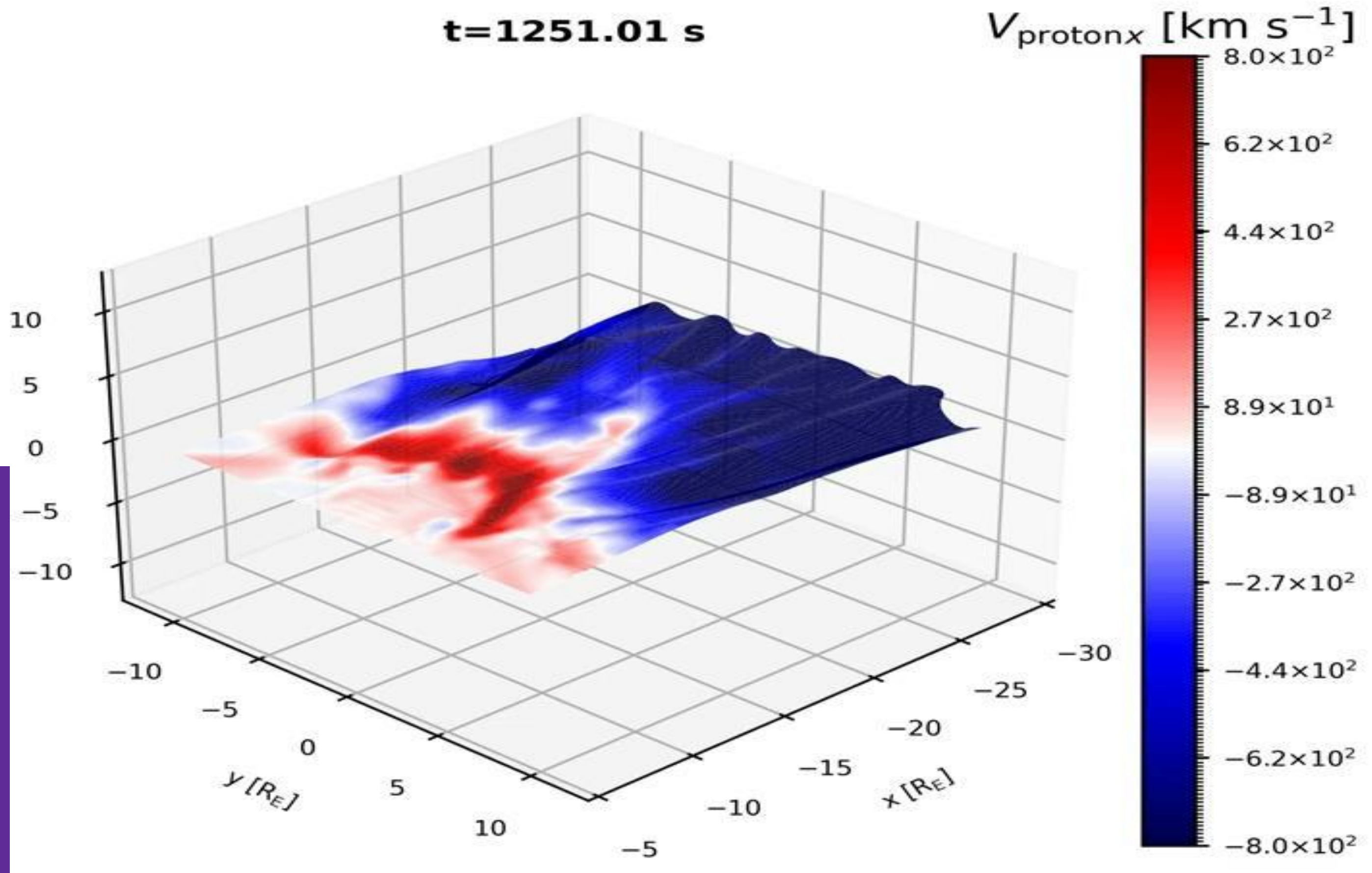
Spacecraft at $x = -8.0\ R_E, y = 3.9\ R_E$



Summary

- Magnetotail has jet front activity
  - Associated with magnetic reconnection
- Earth- and tailward dipolarization fronts differ in simulation
- Different bursty bulk flows look similar in spacecraft frame
- Simulations could help with interpreting *in situ* data

Thank you!


t=1251.01 s
$V_{protonx}$ [km s^{-1}]
8.0×10²
6.2×10²
4.4×10²
2.7×10²
8.9×10¹
−8.9×10¹
−2.7×10²
−4.4×10²
−6.2×10²
−8.0×10²
10
5
0
−5
−10
y [R_E]
x [R_E]
−30
−25
−20
−15
−10
−5