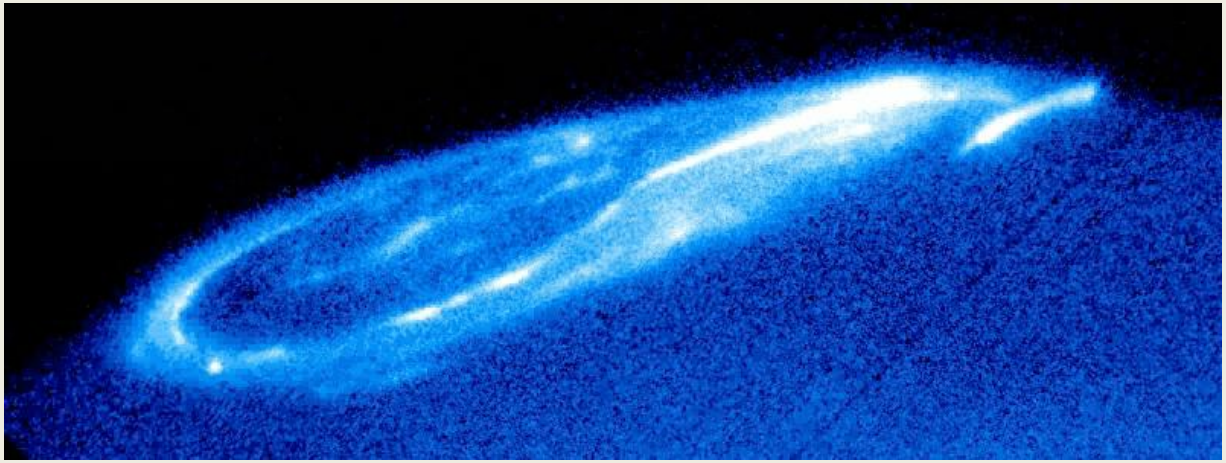
Multi-event analysis on Jovian magnetotail reconnection



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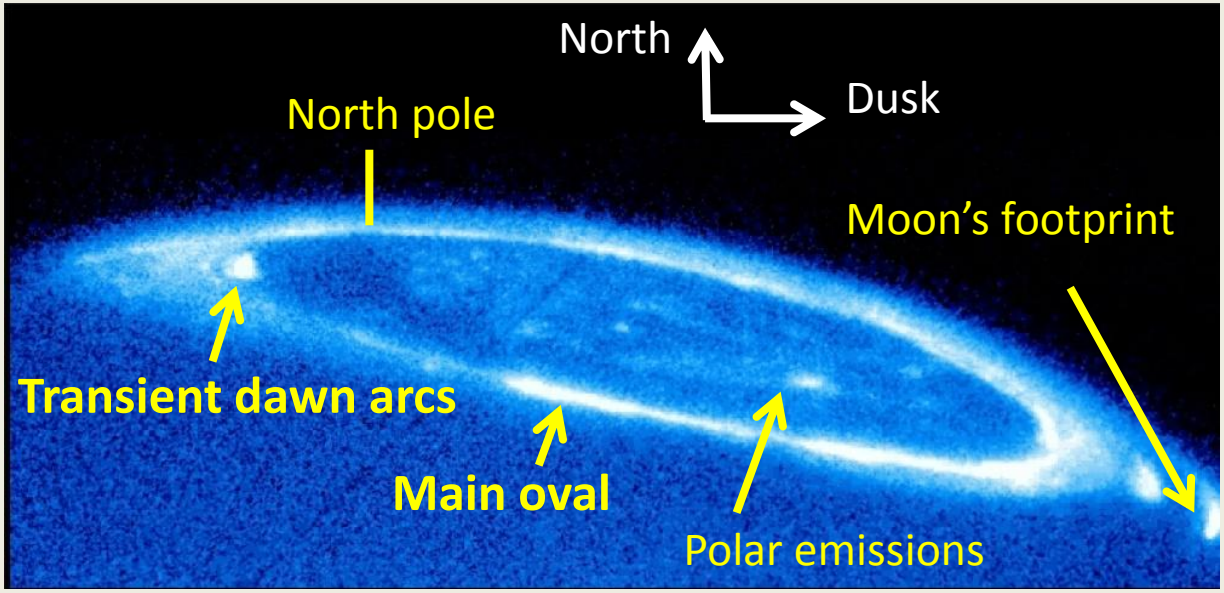
S. V. Badman, A. Masters, N. Krupp,
A. Retinò and M. Fujimoto

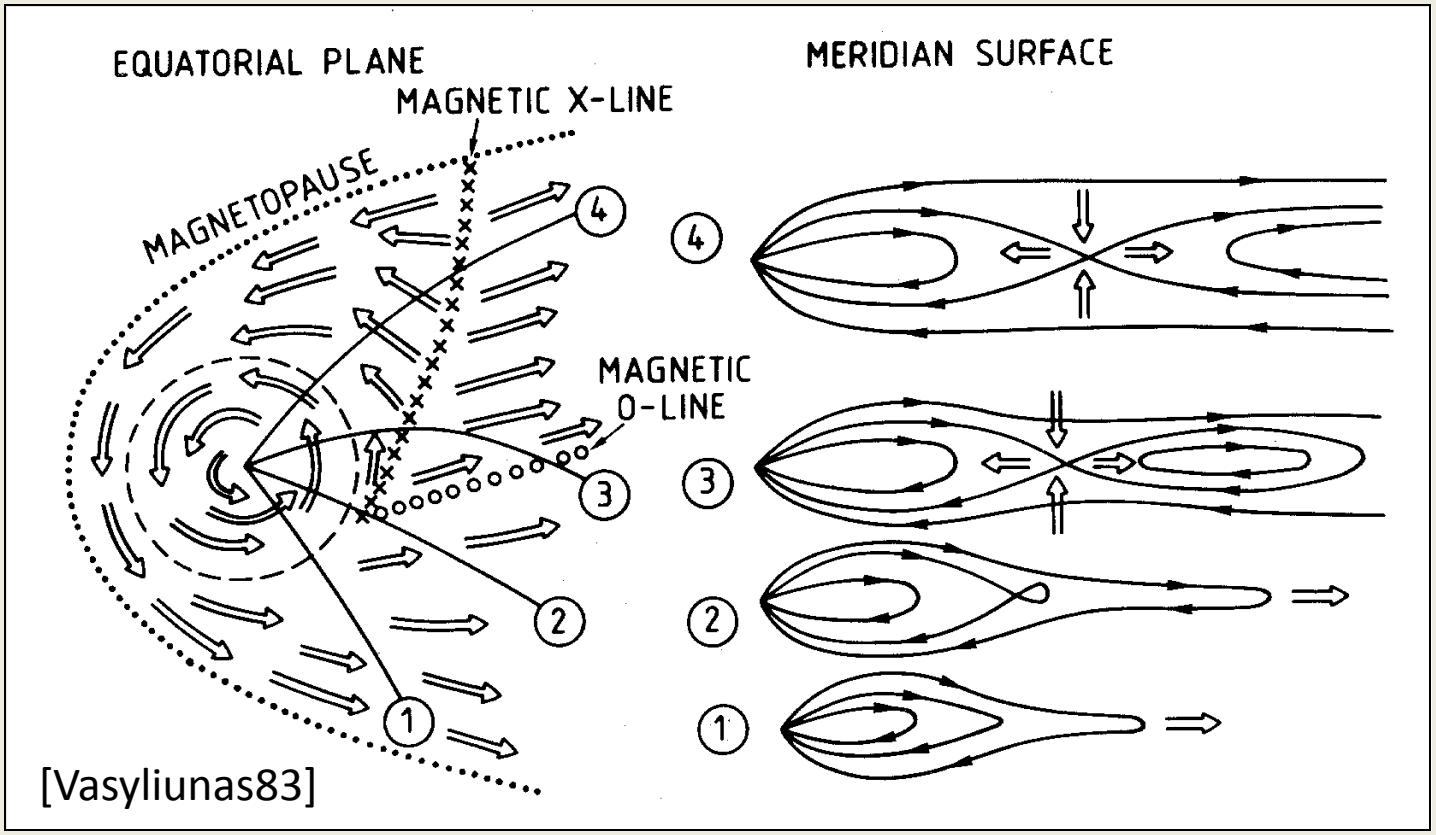
Several kinds of Jovian aurora



http://www.lpap.ulg.ac.be/jupiter/stis_animations.html

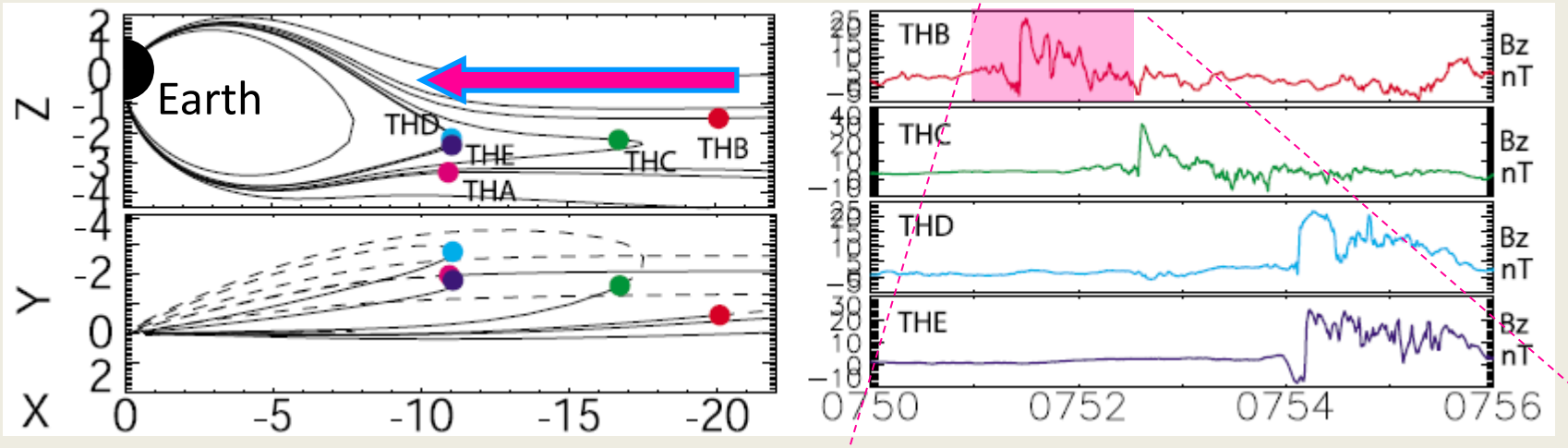
- Prominent main oval
  - Powered by the planetary rotation
- Moon's footprints and polar emissions
- More ephemeral aurora: transient arcs
  - Poleward of main oval ➔ mapped to the magnetotail (>50 Rj)
  - Tail RX plays some roles?

RX at Jovian magnetosphere



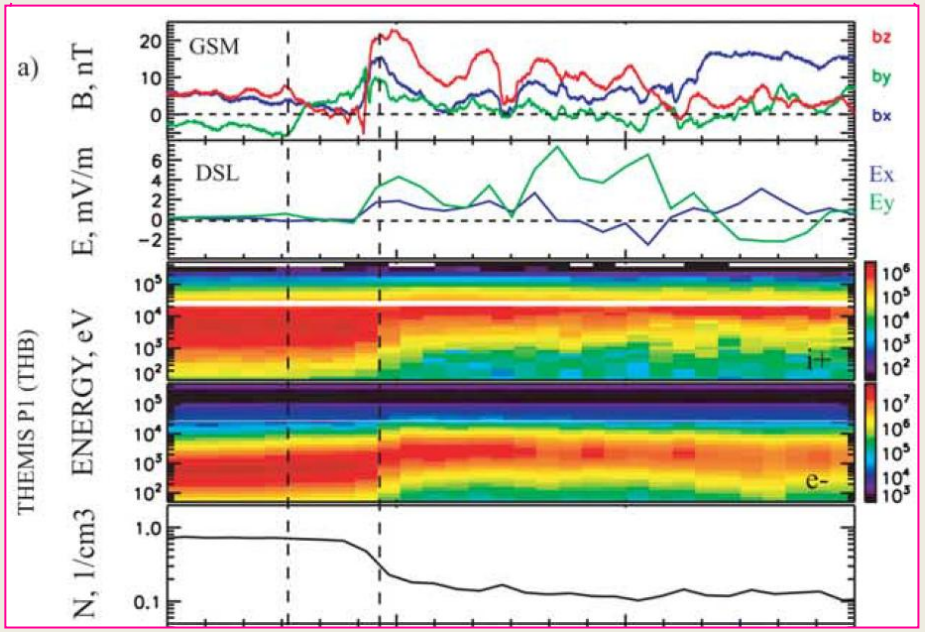
- First concept has been brought by Vasyliunas [1983]
- A supportive observation followed soon [Nishida83]
- More exclusive observations were brought by Galileo spacecraft

Earth's jet fronts: macroscopic view



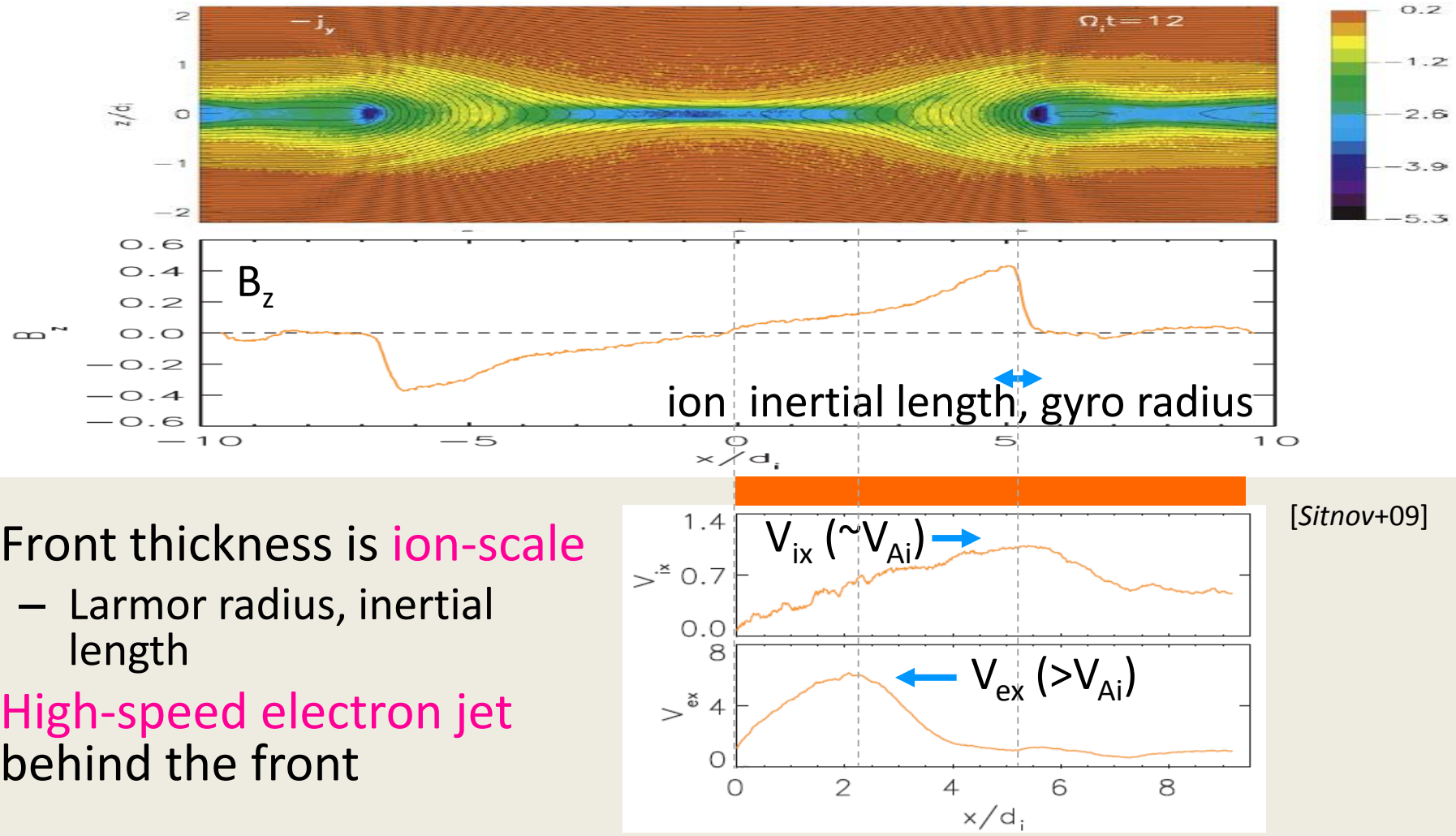
sunward ←

[*Runov*+09, 11]



- Planetward propagation of JFs (jet fronts) with the ion flow of ~V_A
- Particle energisation (although not ubiquitous)
- Density decrease

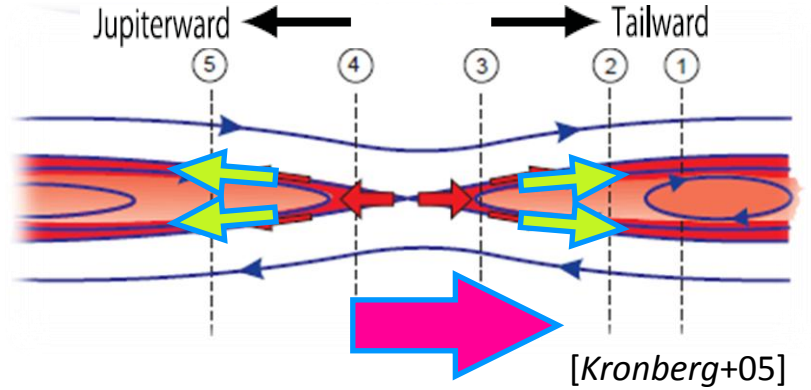
JFs in simulations: microscopic view



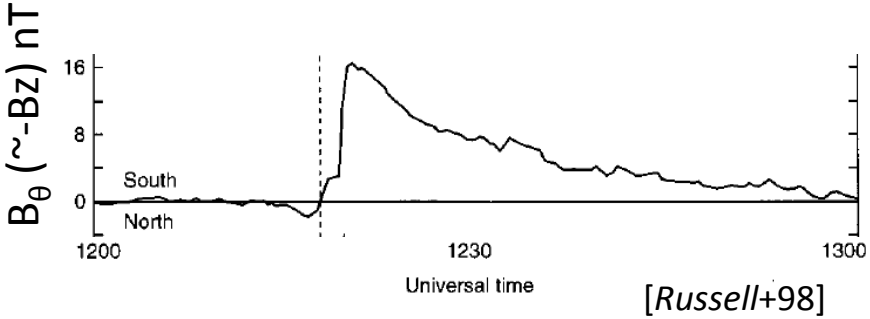
[*Sitnov*+09]

- Front thickness is ion-scale
  - Larmor radius, inertial length
- High-speed electron jet behind the front

Jovian tail RX as seen by Galileo

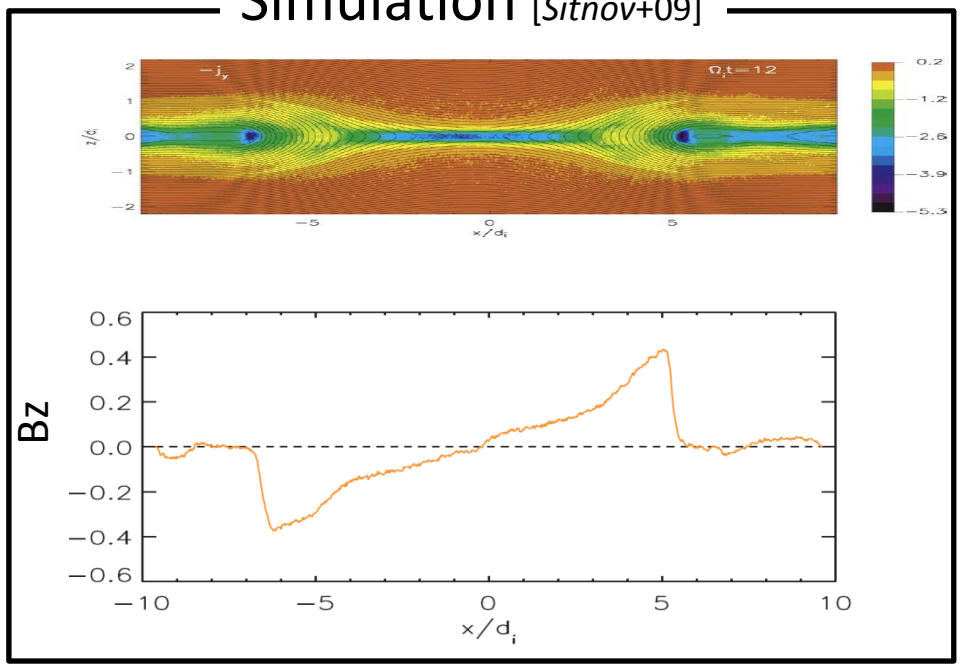


[*Kronberg*+05]



[*Russell*+98]

Simulation [*Sitnov*+09]



- RX has been argued based on energetic particle data [Woch+99,+02; Kronberg+05,11]
  - X-line at ~70 R_J on average, and tailward retreat
- Magnetic signatures of transient RX have been reported [Russell+98]
  - looks similar to Earth's jet fronts
- However, the detailed plasma sheet structure has not been clarified

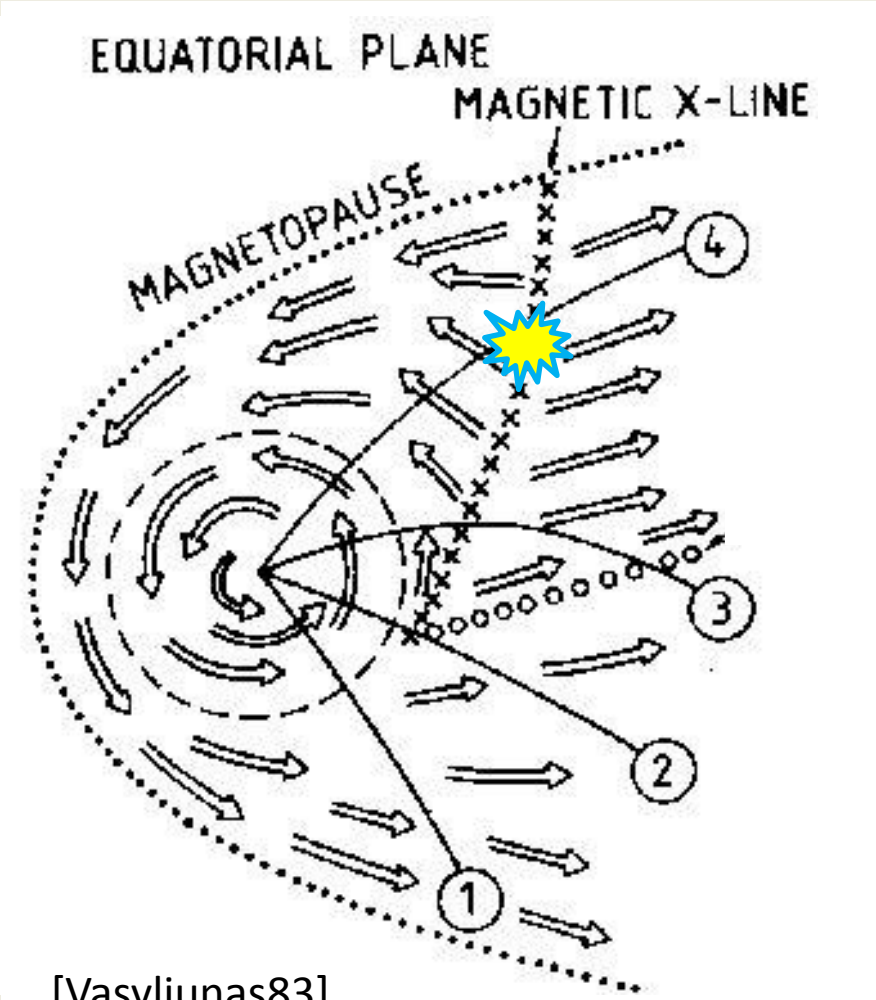
Macro-/microscopic views of RX jets

- Reconnection jet signatures in the Earth's M'sp
  - Planetward propagation with the ion flow of ~V_A
  - Density decrease
  - Particle energisation
  - Ion-scale front
  - High-speed electron jet behind the front

- ➔ How about in the Jovian magnetosphere?
  - Iogenic heavy ions: O++, S++, S+++,…
    - (cf. H+ is dominant in the Earth's case)
  - Tenuous plasma sheet
  - Rotation-driven M'sph

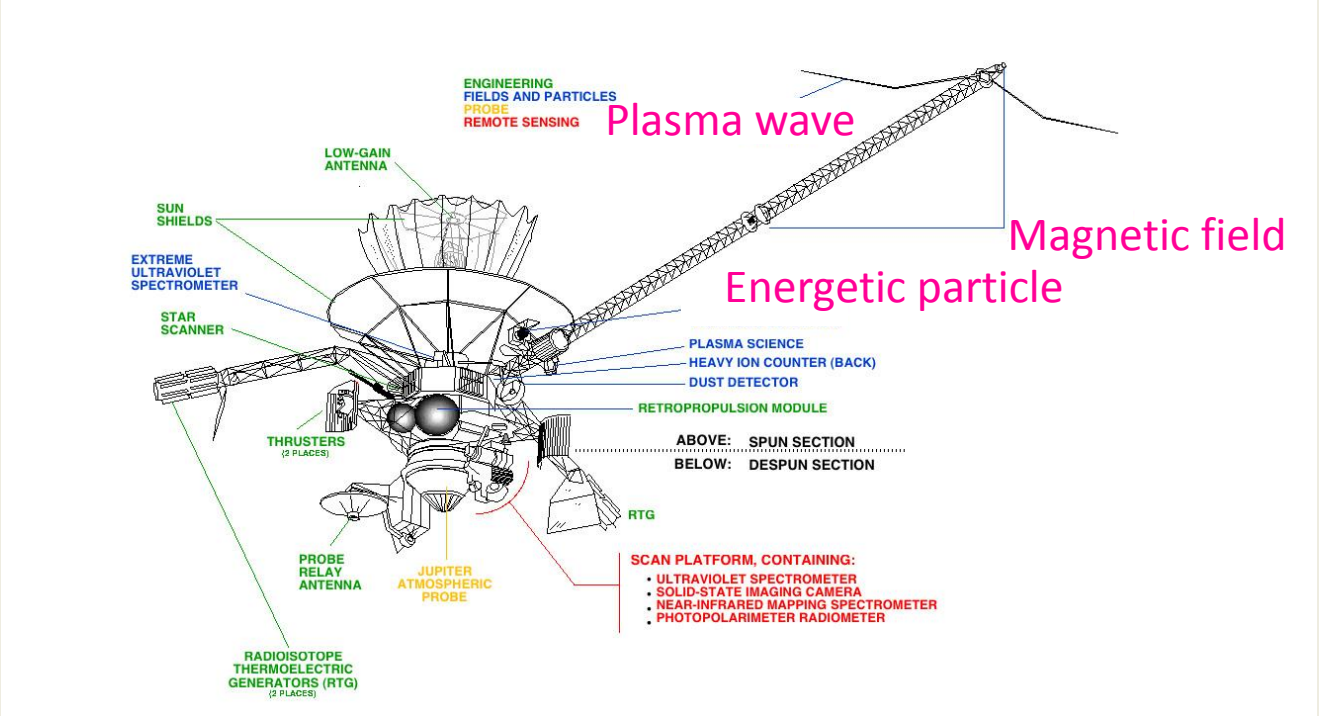
First step: case study

- Galileo spacecraft
- Location
  - 73-76 Rj
  - 2.5-3 LT
- Event
  - 17 Aug. 1997
  - Previously reported as a reconnection event by *Russell*+98 and *Kronberg*+05



[Vasyliunas83]

A problem: lack of the plasma observation



- Reliable plasma momentum data are not available
  - due to the low sensitivity of the plasma instrument
- Electron density ← radio cutoff at plasma frequency
- Plasma flow ← energetic particle anisotropies
- DC magnetic field ← magnetometer

Overview

[Kasahara+11]

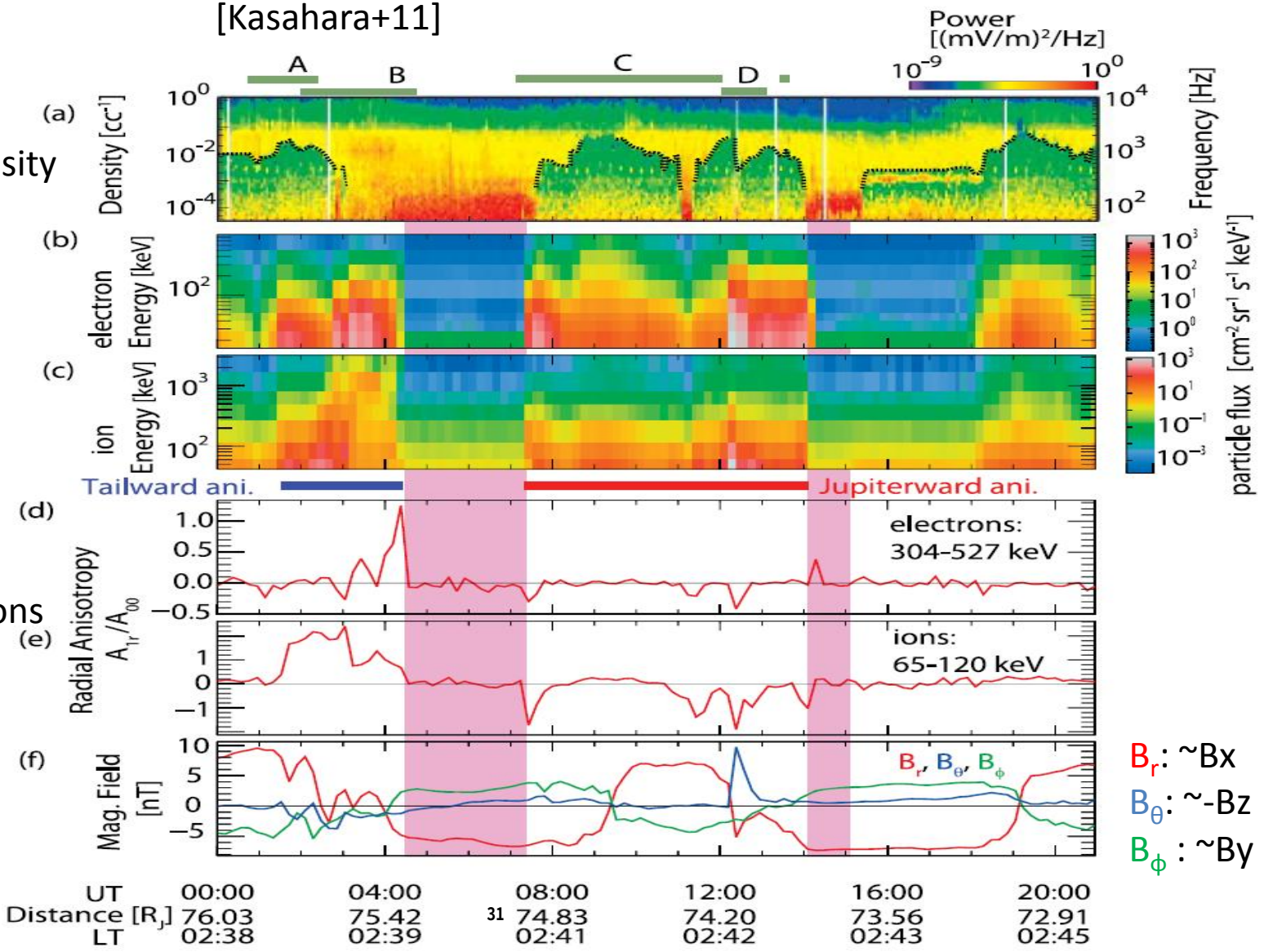
Radio wave
➔electron density

Energetic e-

Energetic i+

Anisotropies of energetic electrons and ions

Magnetic field

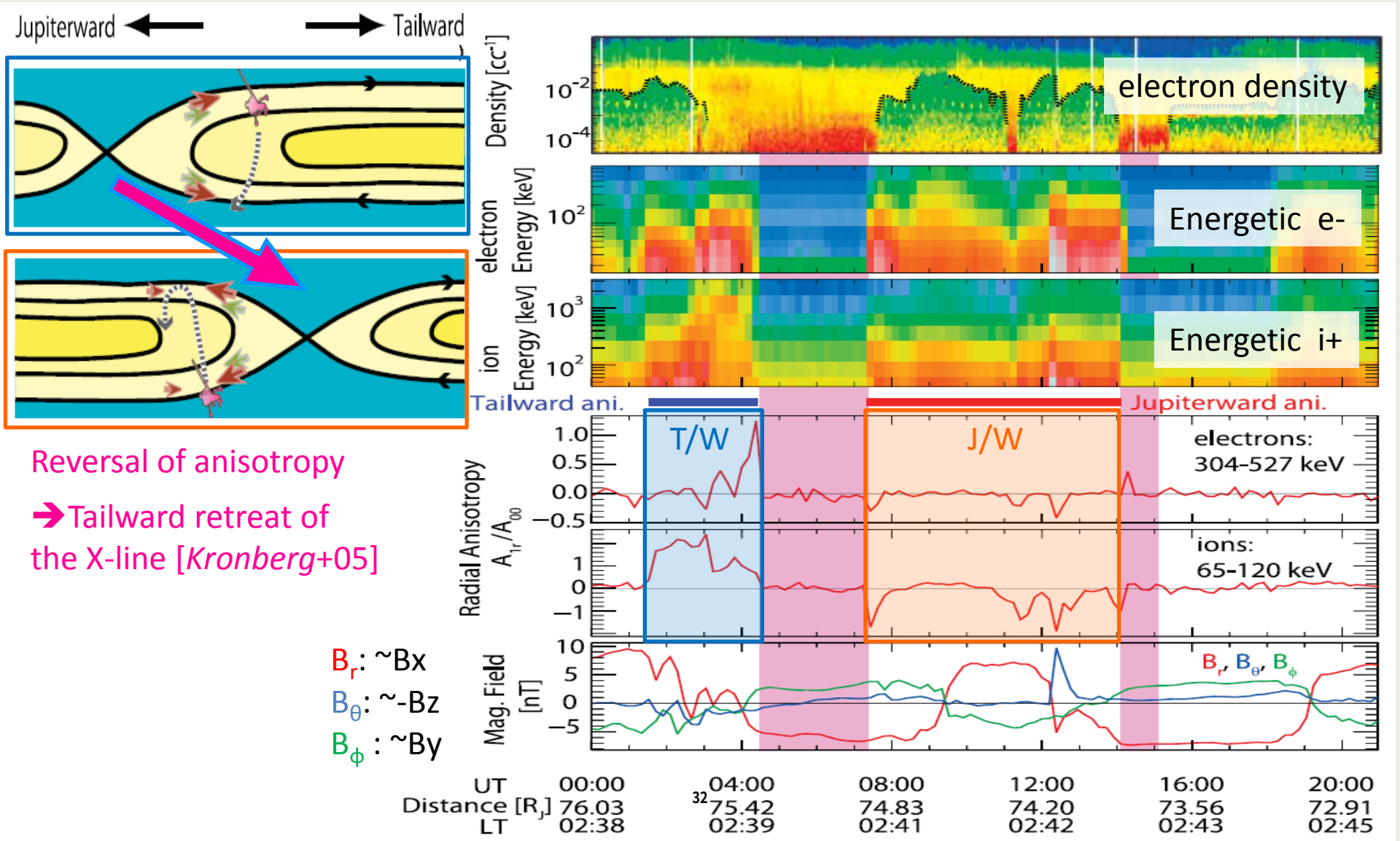


B_r: ~Bx

B_θ: ~-Bz

B_ϕ : ~By

Overview



Reversal of anisotropy

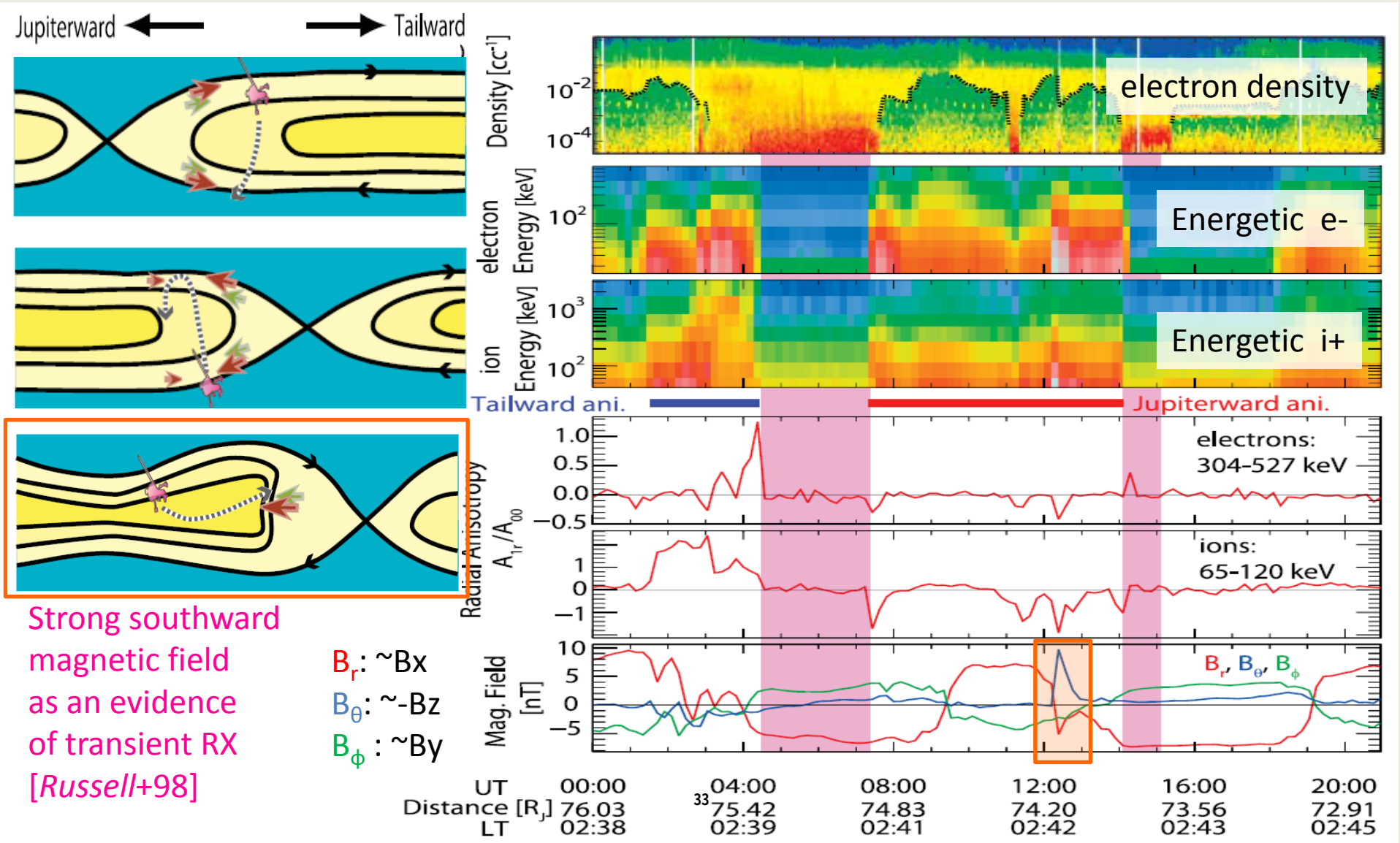
➔Tailward retreat of the X-line [*Kronberg*+05]

B_r: ~Bx

B_θ: ~-Bz

B_ϕ : ~By

Overview



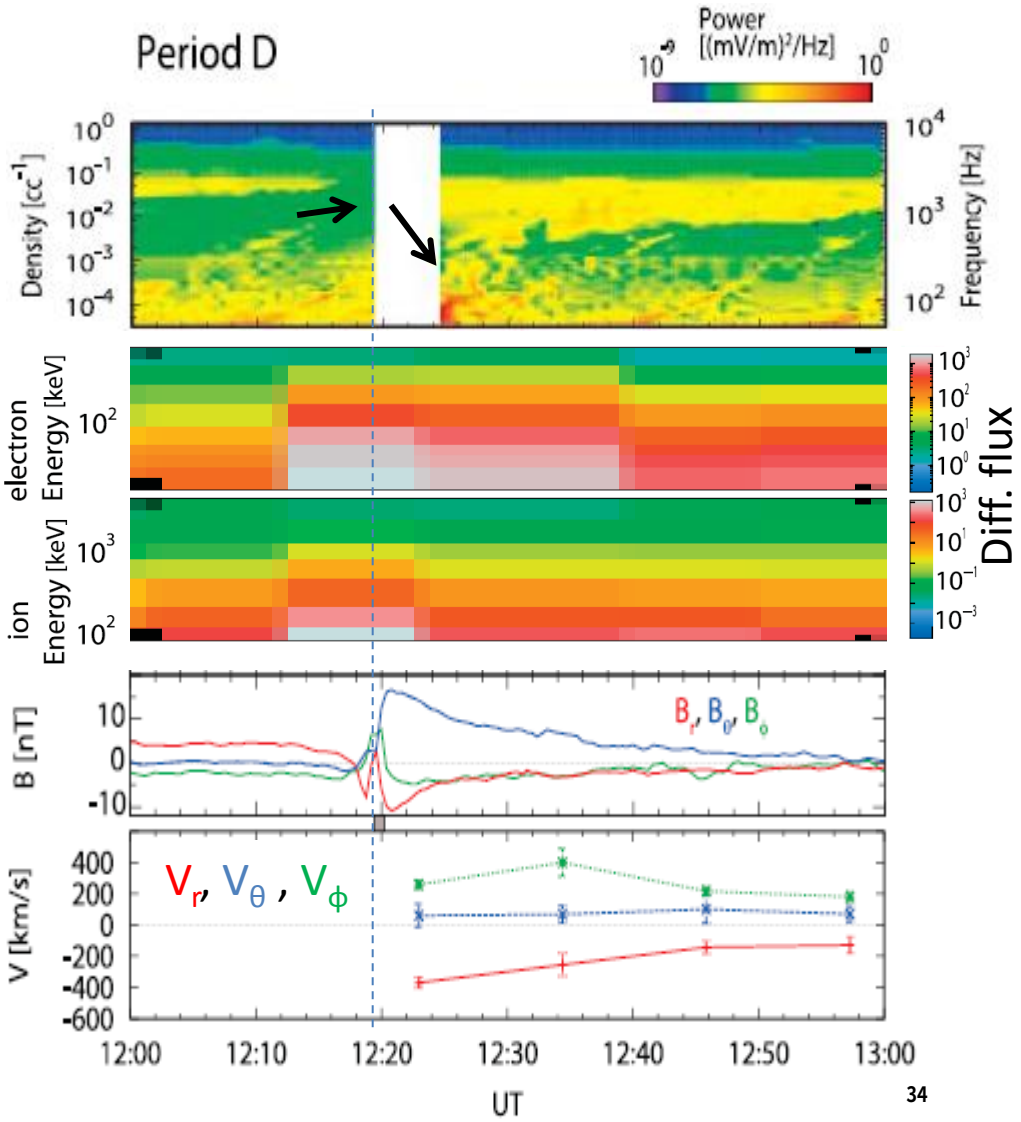
Strong southward magnetic field as an evidence of transient RX [*Russell*+98]

B_r: ~Bx

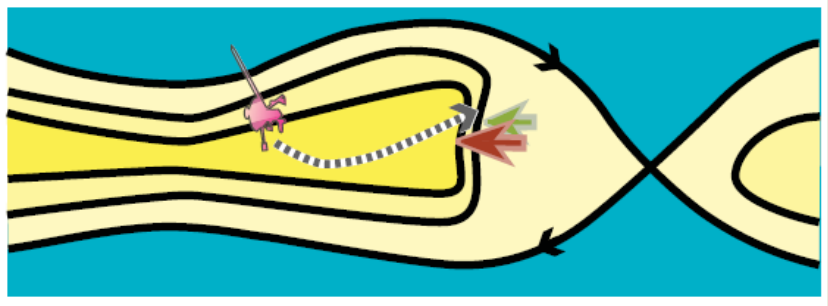
B_θ: ~-Bz

B_ϕ : ~By

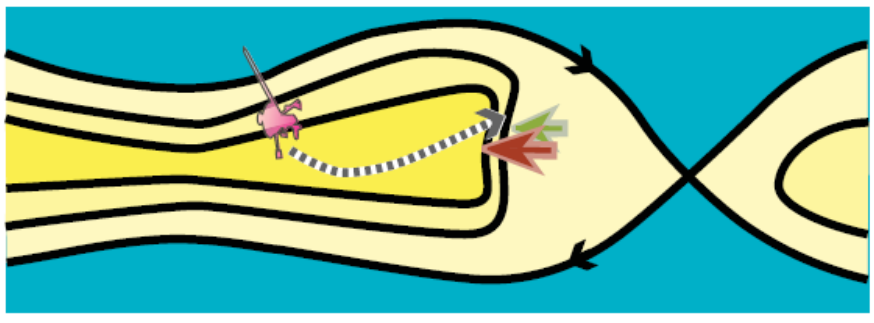
JF-like strong magnetic field



- Strong southward magnetic field with
  - Density depletion
  - Energetic particle flux enhancement
- Jupiterward ion flow ~450 km/s
  - cf. V_{Ai}~650 km/s for m/q=10
- Front thickness : ~10,000-20,000 km



Comparison to the Earth's case

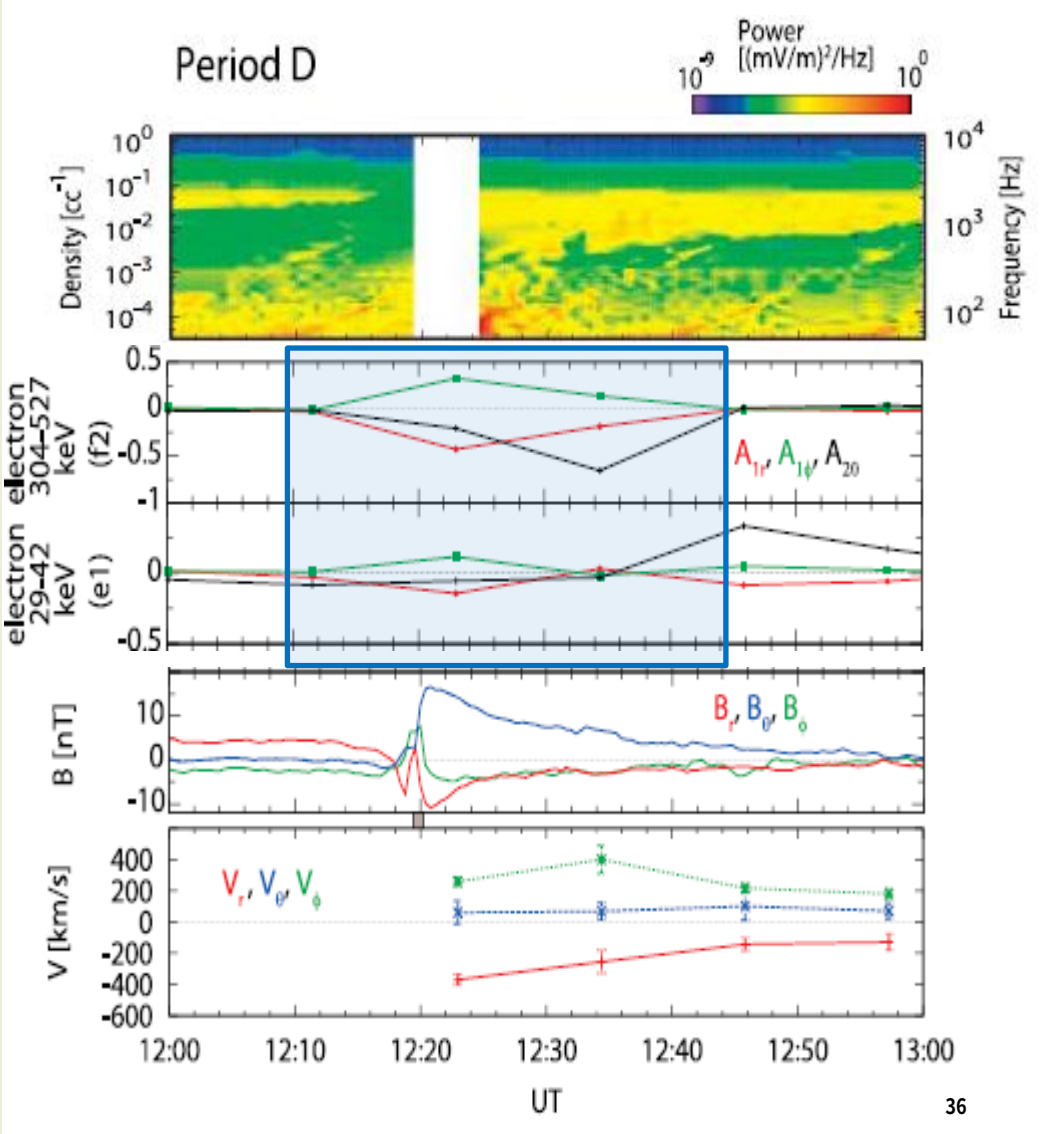


	Jupiter	Earth
Jet Front thickness	10000-20000 km	300-1000 km

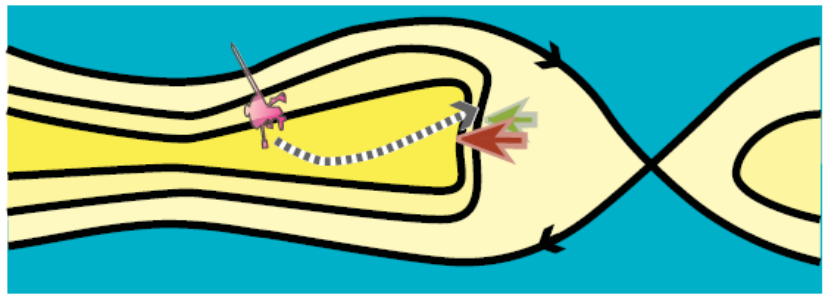
- An apparently larger spatial scale was observed
  - However, the jet front has an ion scale, similarly to the Earth's case
- The large ion scale is attributed to the large mass and the low density
  - O++, S++, S+++,…
  - $n_e<10^{-2}$ cm^{-3}

$$\rho_i = \frac{mV}{qB}, \qquad d_i = c\sqrt{\frac{m/q}{4\pi n_e e}}$$

One more thing…



- Surprisingly, field-perpendicular anisotropies of the electrons are seen, too
  - Electron jet ~10,000-20,000 km/s
  - much faster than the ion flow

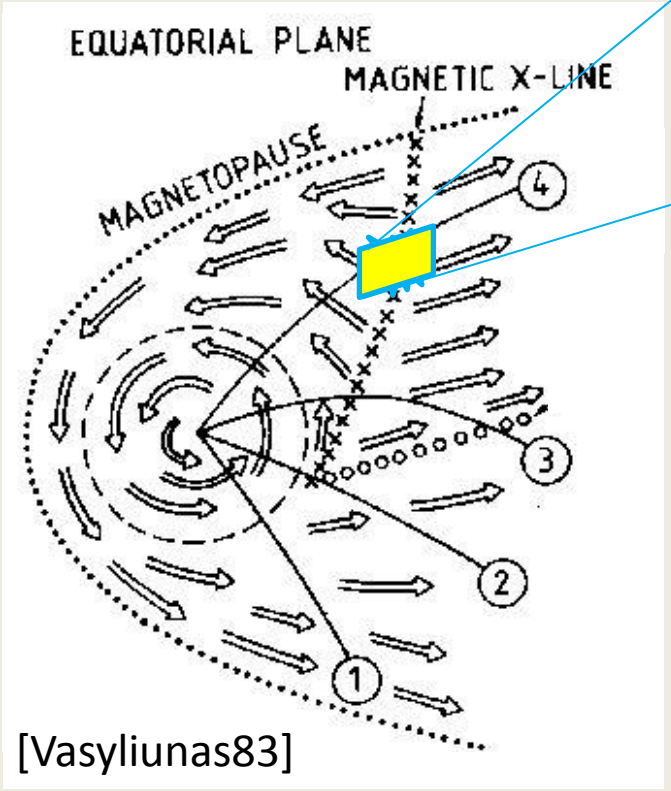


Summary of the observation

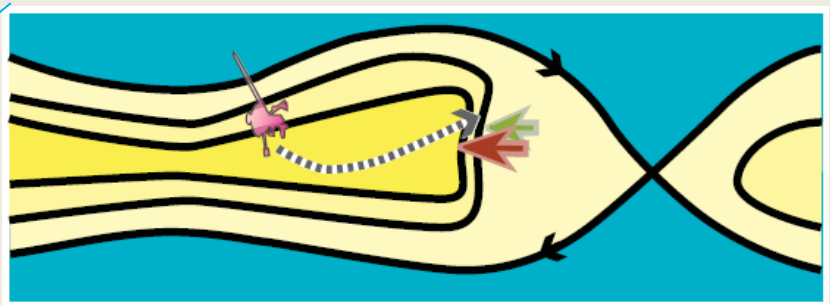
- Planetward propagation with the ion flow of ~V_A ?
  - The ion flow of ~V_A was observed
- Density decrease ?
  - Significant decrease of the electron was observed at the front
- Particle energisation ?
  - Energetic electron and ion fluxes significantly enhanced
- Ion-scale front ?
  - The estimated front thickness was close to the Larmor radius and inertial length of the ion
- High-speed electron jet behind the front (i-e decoupling) ?
  - Electron jet exceeding ion Alfvén velocity was observed

➔A jet front structure was found to be similar to the Earth's case

Further questions

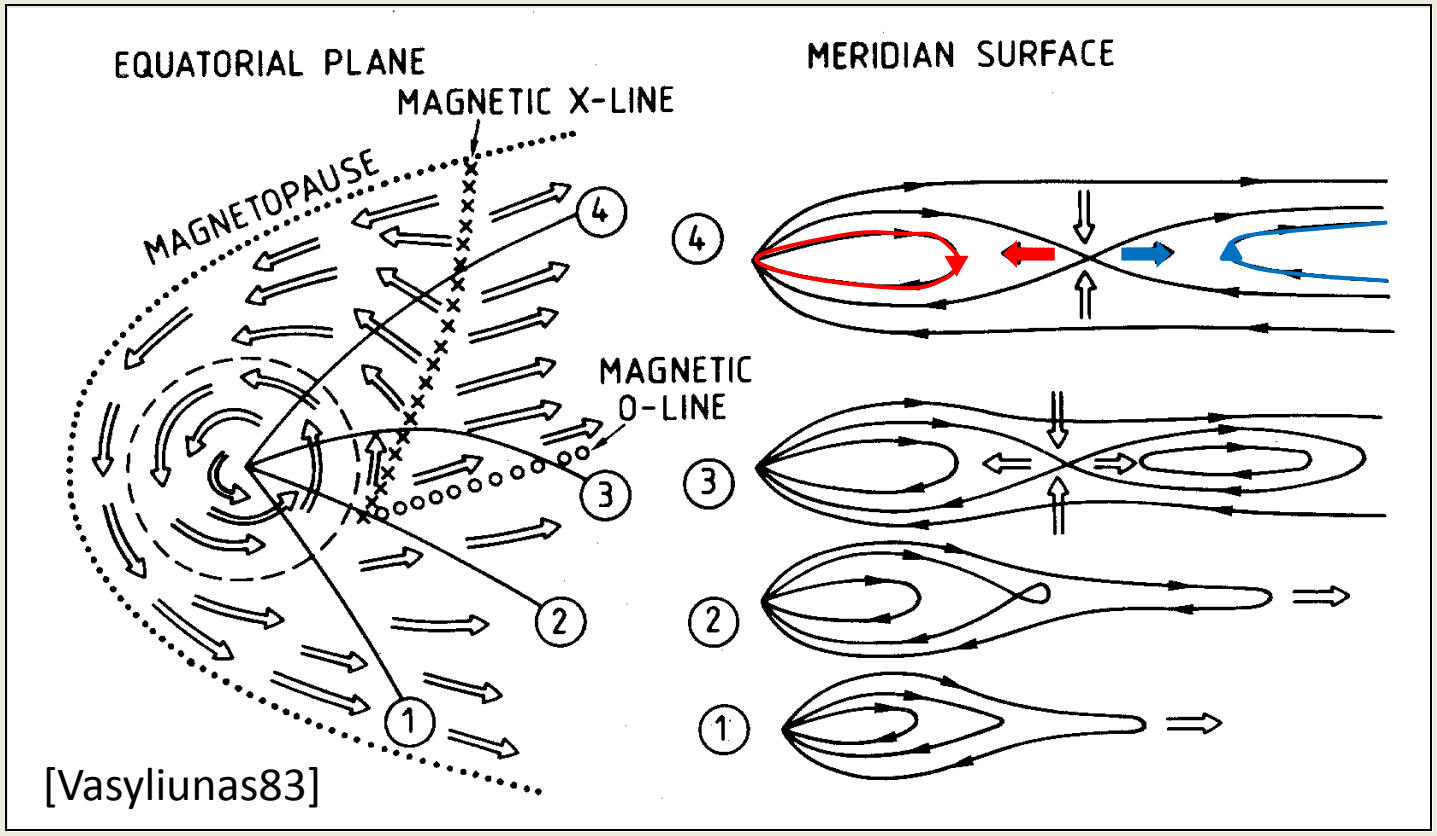


[Vasyliunas83]


[Kasahara+11]

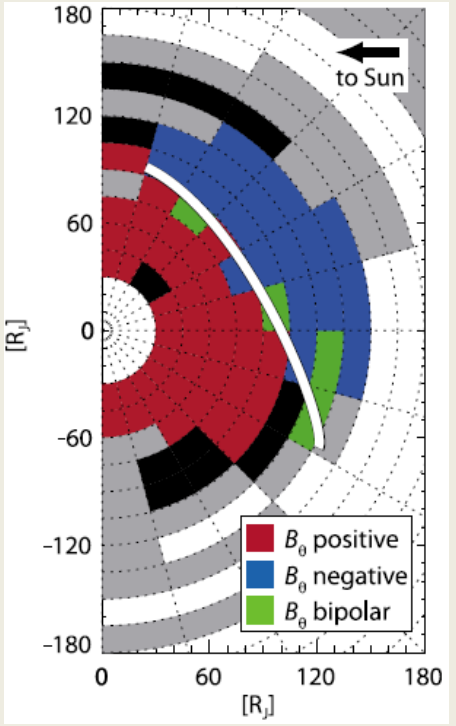
- How ubiquitous RX jets are?
- Are RX jets consistent with field-aligned currents to generate transient auroral arcs?
- ➔ We investigate multiple events to deduce an average picture

Typical X-line location in Jovian tail?



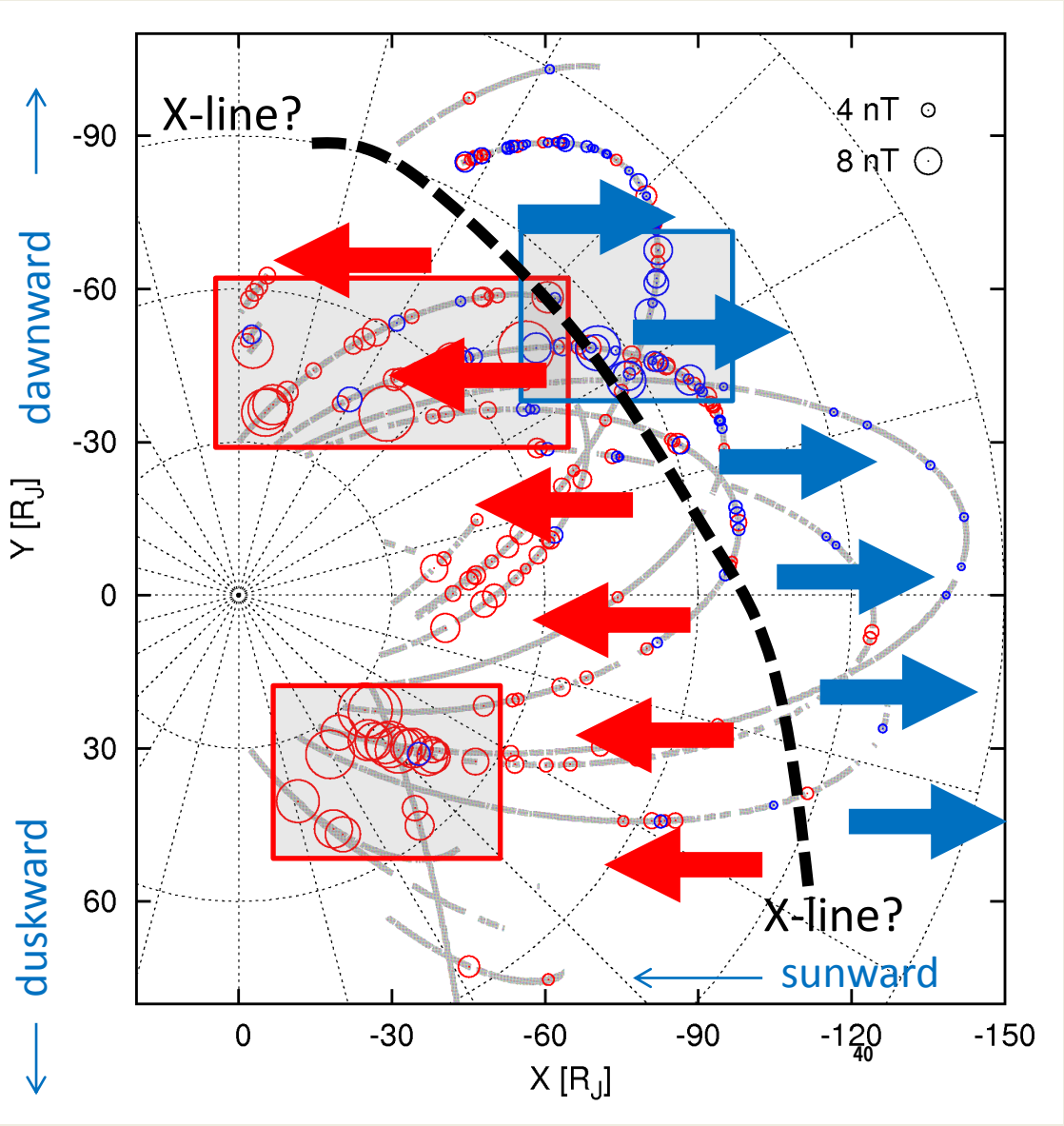
[Vasyliunas83]

[Vogt+10]



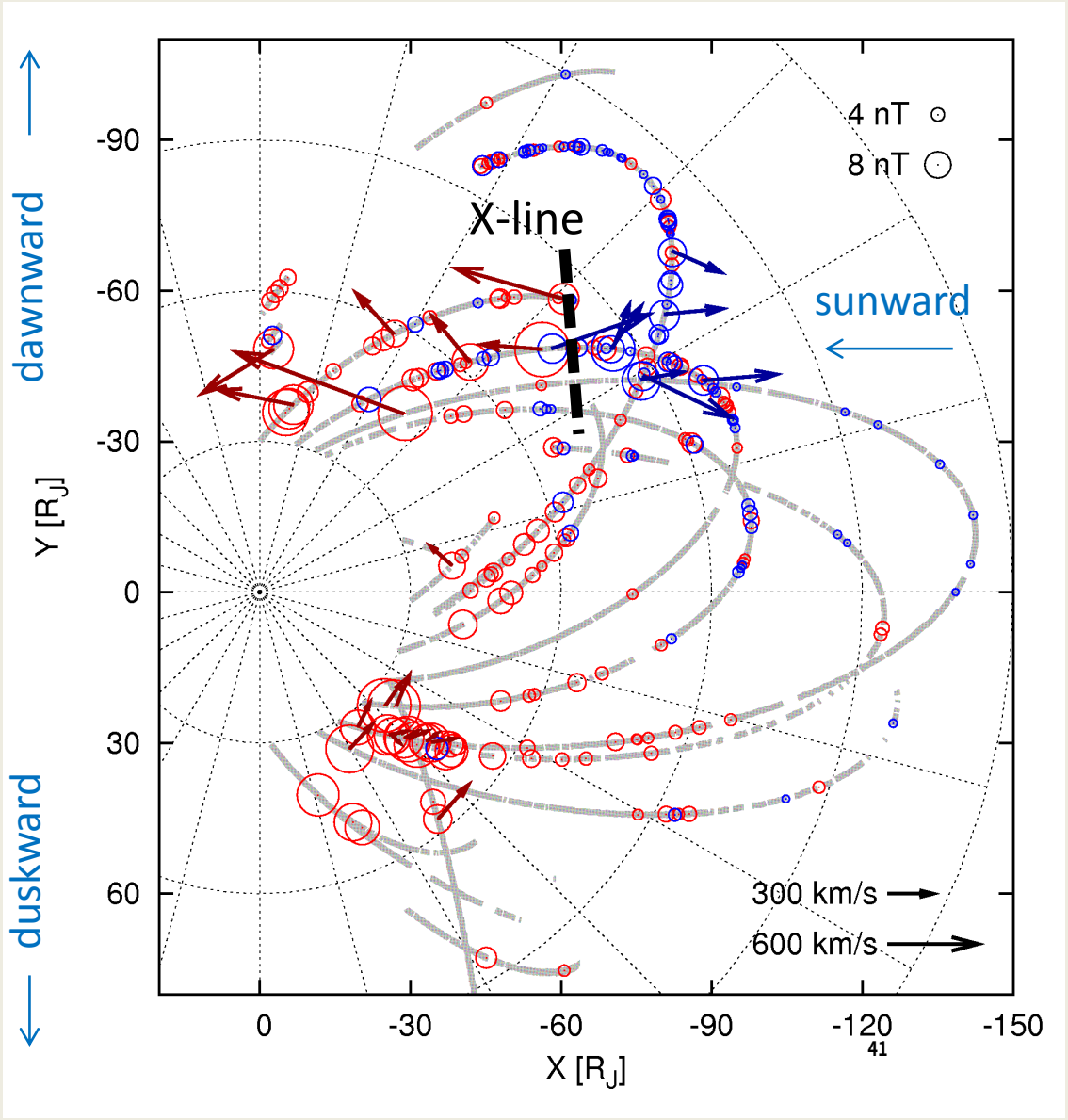
- A recent work determined the typical X-line location based on magnetic field directions [Vogt+10]
  - 80-100 R_J
- Do plasma behave consistently?

B_θ map revisited



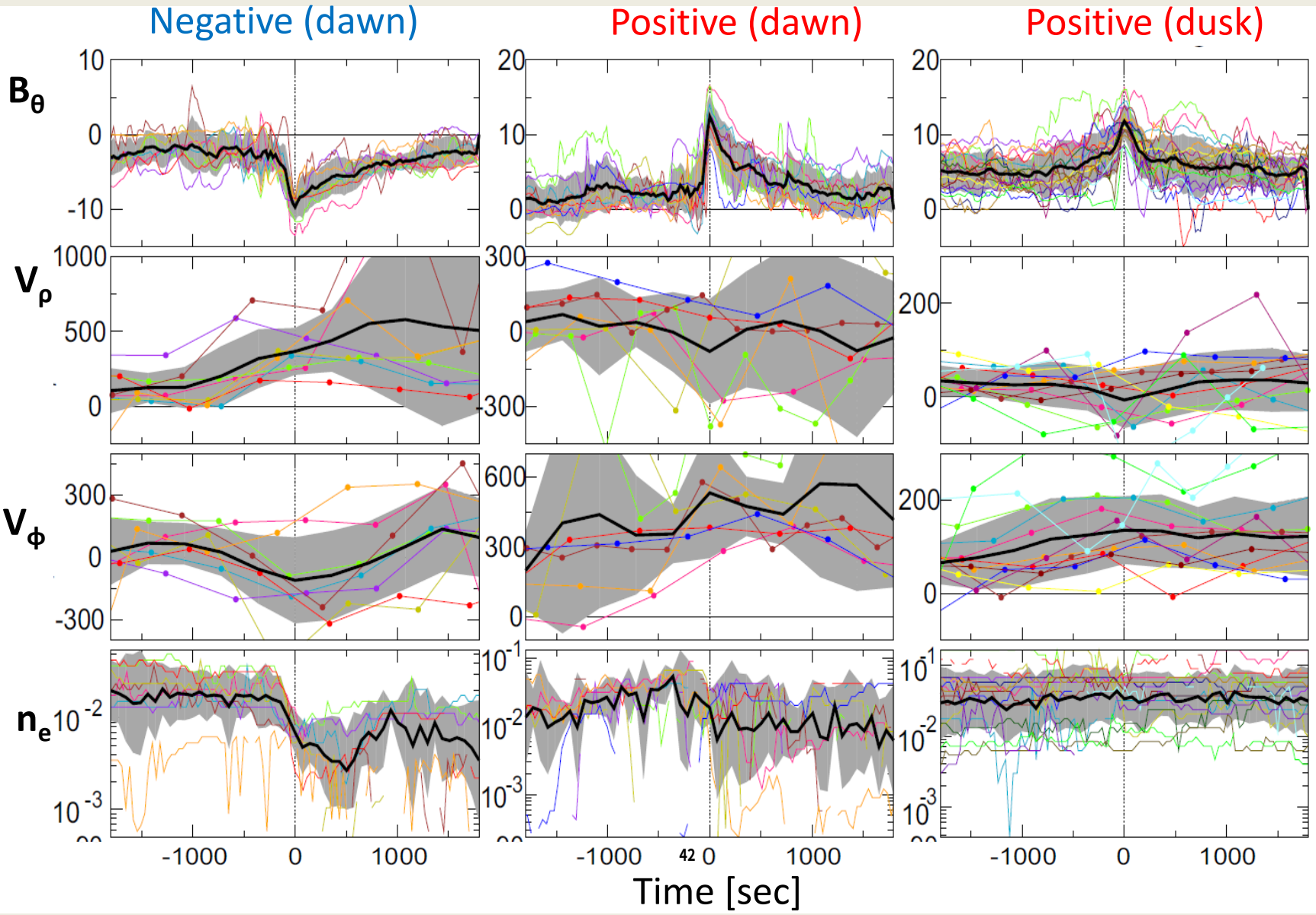
- Size of circle indicates B_θ strength at peaks
  - Red: positive
  - Blue: negative
- Focus on strong events (>8nT) for more analyses
- Strong events are clustered in three regions
  - dawnside tailward (Negative events)
  - dawn side Jupiterward (Positive events)
  - Duskside (Positive events)

EPD flows ($V_{\perp}$)

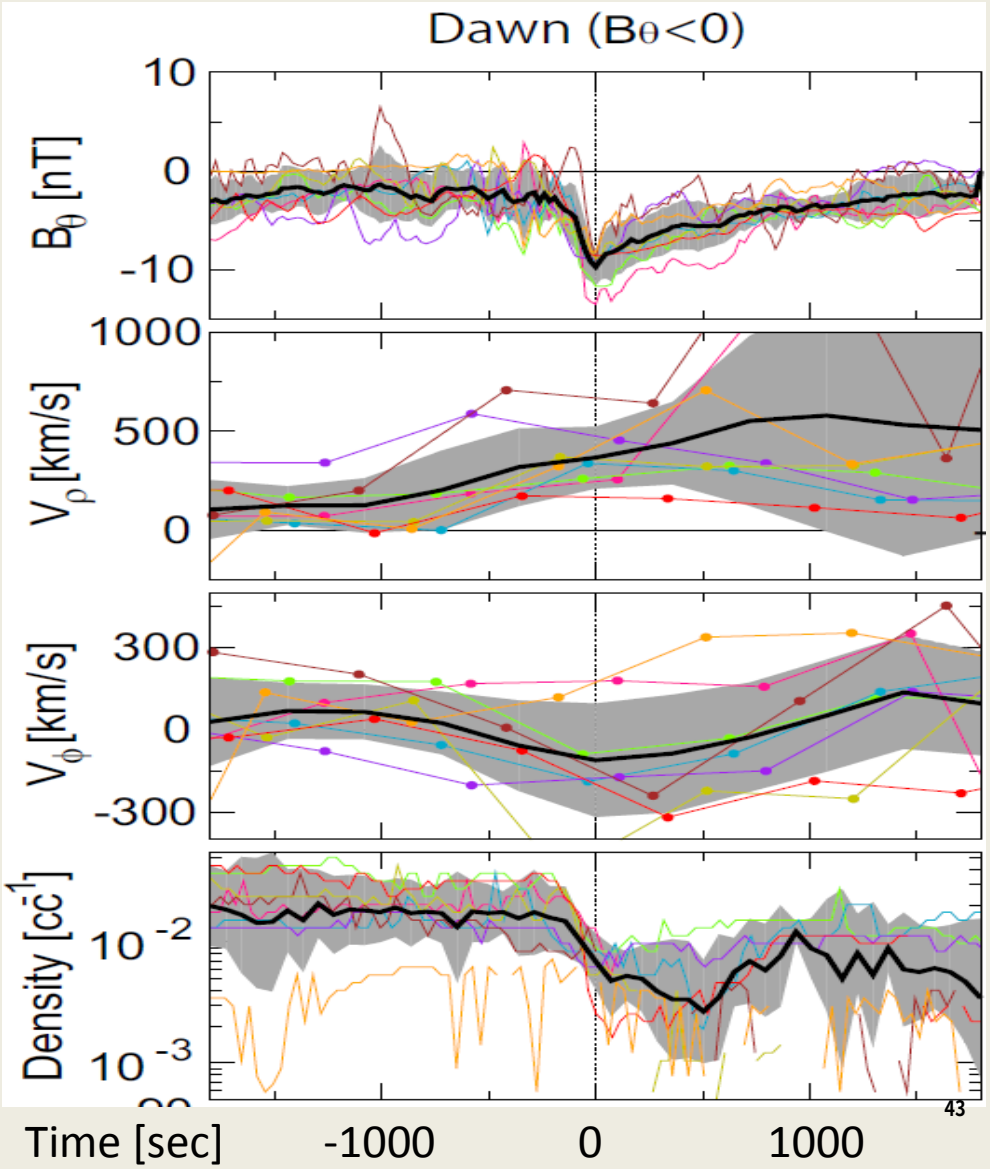


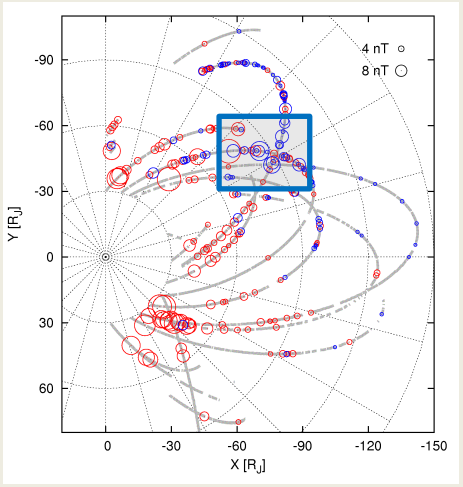
- Duskside flow cannot be interpreted as outflow of tail reconnection
- Dawn negative events and dawn positive events are consistent with tail reconnection

Time history analyses (T=0 is the magnetic peak)



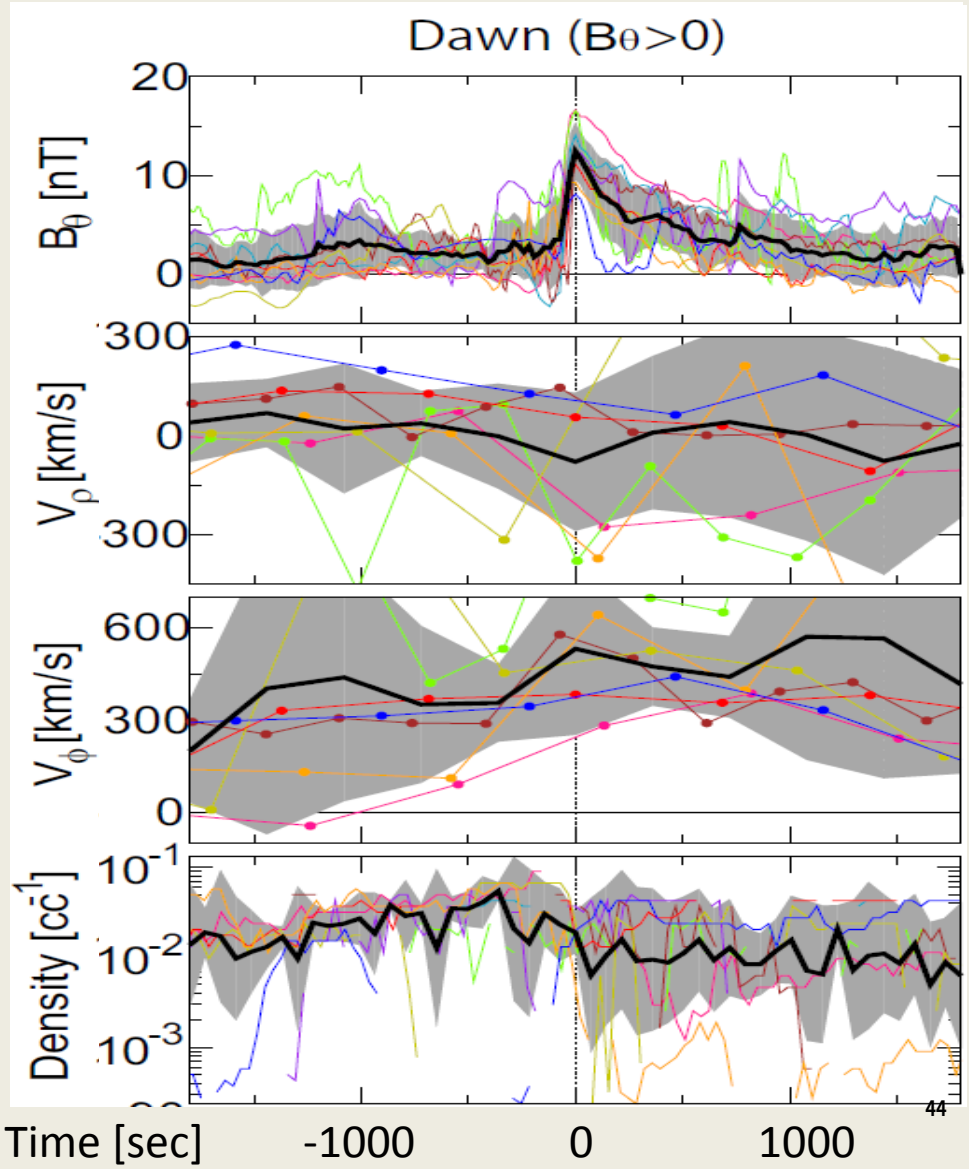
Dawnside negative events

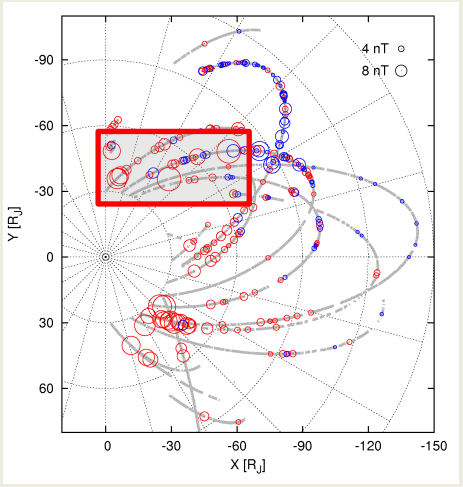




- Consistent with tailward propagating jets
  - B_θ: steep fall, gradual decay
  - Outward velocity increases
  - Density decreases at the front

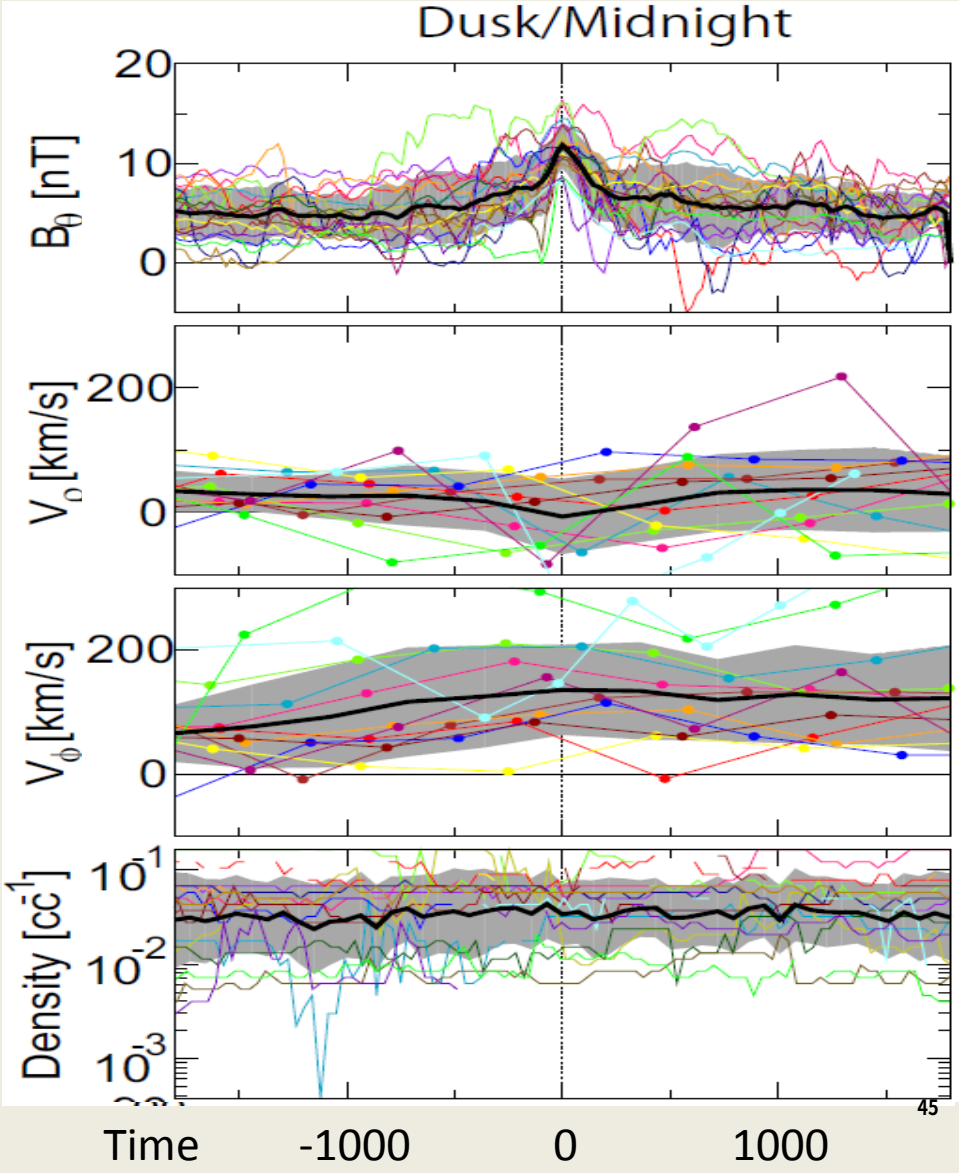
Dawnside positive events

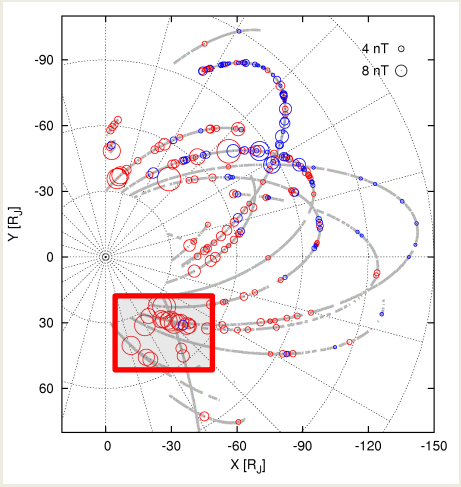




- Consistent with jets planetward of X-line
  - B_θ: steep rise, gradual decay
  - Radial velocity becomes more inward, with enhanced azimuthal component
  - Density decreases at the front

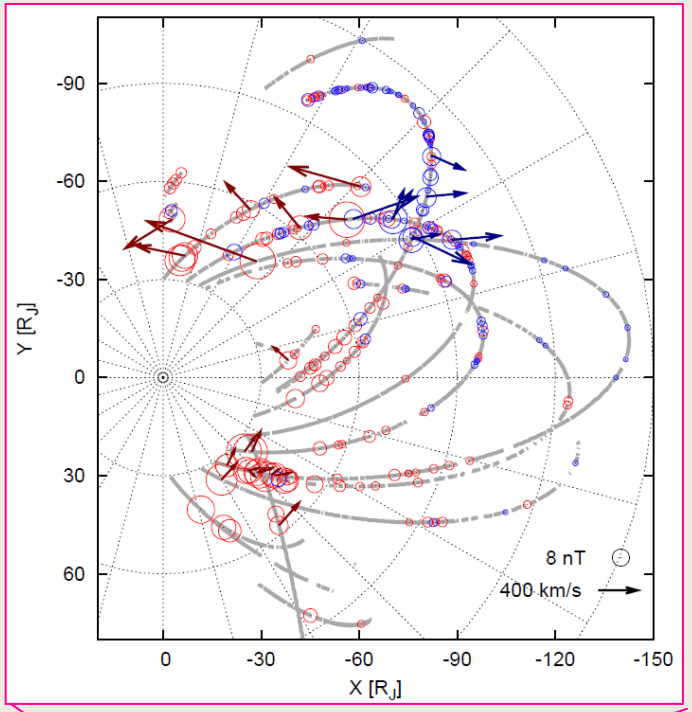
Duskside positive events



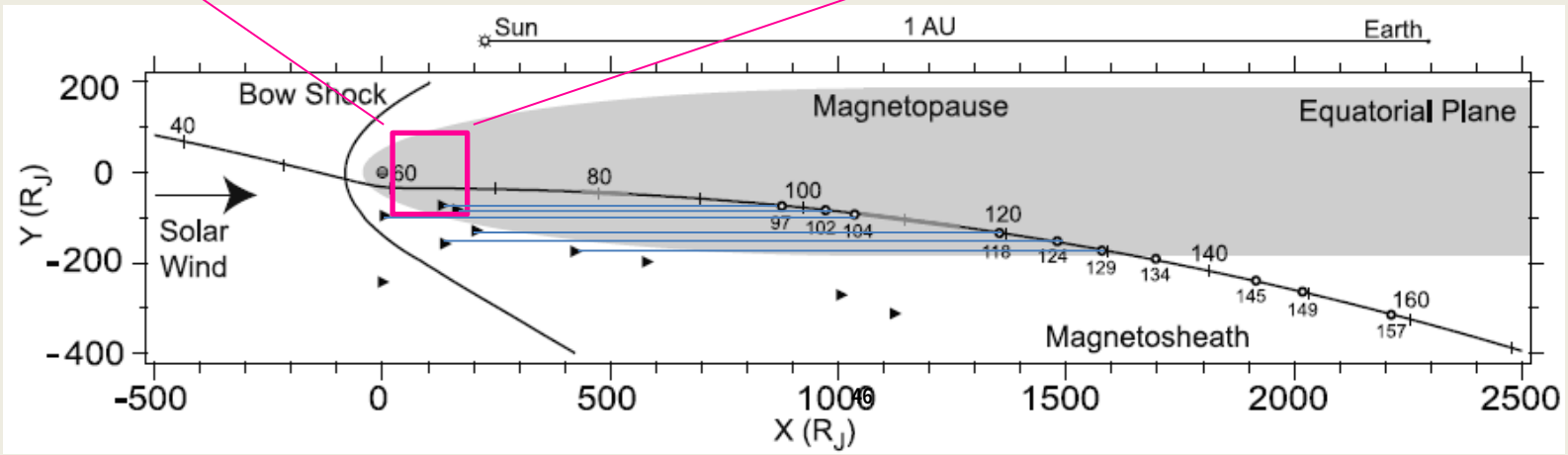


- B_θ profile different to previous two types
  - Gradual rise and fall
- Plasma signatures are not the typical of jets
  - Only a slight enhancement of the azimuthal flow at the front
  - Density does not change

Discussion (1/2): RX jets

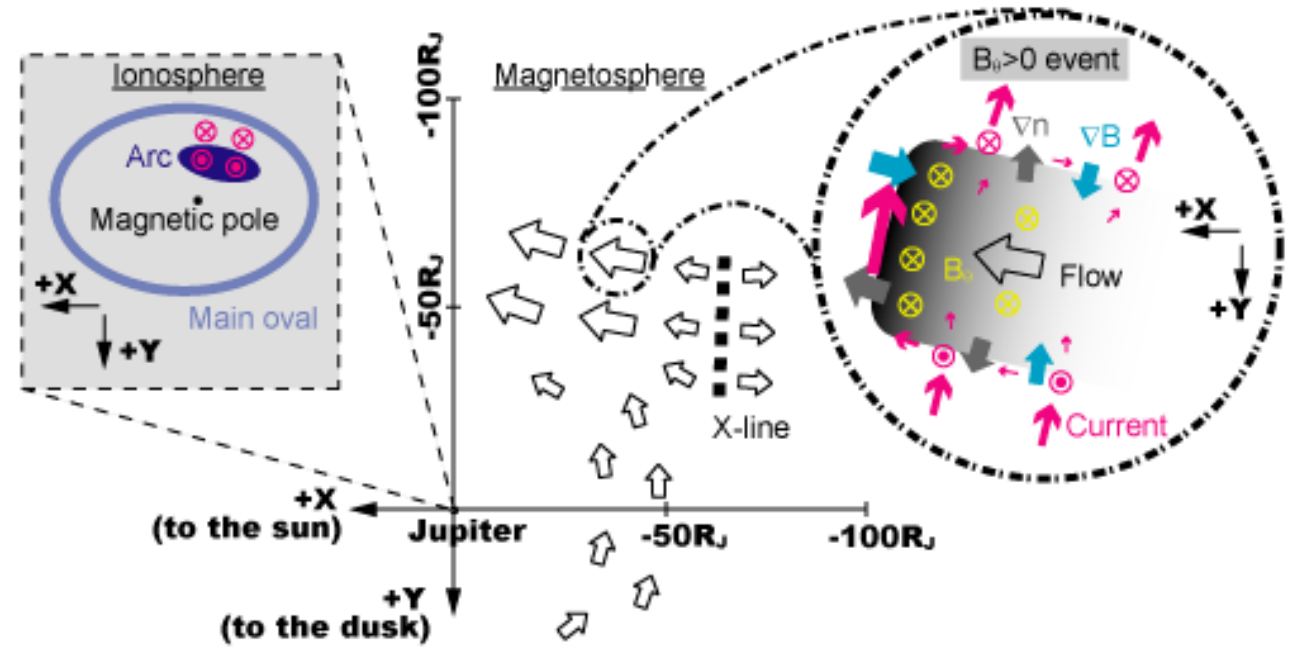


- Dawnside RX jets are ubiquitous
- Duskside events are not RX jets
  - Does duskside X-line exist?
  - New Horizons suggested duskside X-line at x~-150 Rj (left end of blue horizontal lines)
  - worth more investigation



[Hill+08]

Discussion (2/2): FAC and aurora



$$\mathbf{j}_{\parallel} \sim B \int \left[\frac{2\nabla B \cdot \mathbf{j}_{\perp}}{B^2} + \frac{n m_i}{Z B} \frac{d}{dt}\left(\frac{\Omega}{B}\right) - \frac{\nabla n \cdot \mathbf{j_{in}}}{nB} \right] dl_{\parallel}$$

[Hasegawa&Sato80]

- Plasma/magnetic structure in the dawnside events are similar to those in the Earth's cases ➔auroral arc poleward of the main oval
- $j_{||}$~ 0.3 nA/m^2 at the outer edge of the current sheet
- If 1% of this FAC reaches the ionosphere, it is sufficient to illuminate significant aurora ($j_{||}$~ 0.4 uA/m^2 at the I'sp)

Summary

- Multi-instrumental data analysis on reconnection jets in the Jovian tail
- Case study: microscopic views of a jet front event were examined
  - Structure of fronts are similar to the Earth's case
- Multi-event study: global view of RX jet events
  - RX jets are ubiquitous at least in the dawnside
  - Plausible for generating transient auroral arcs