Auroral Acceleration – What to Expect at Jupiter

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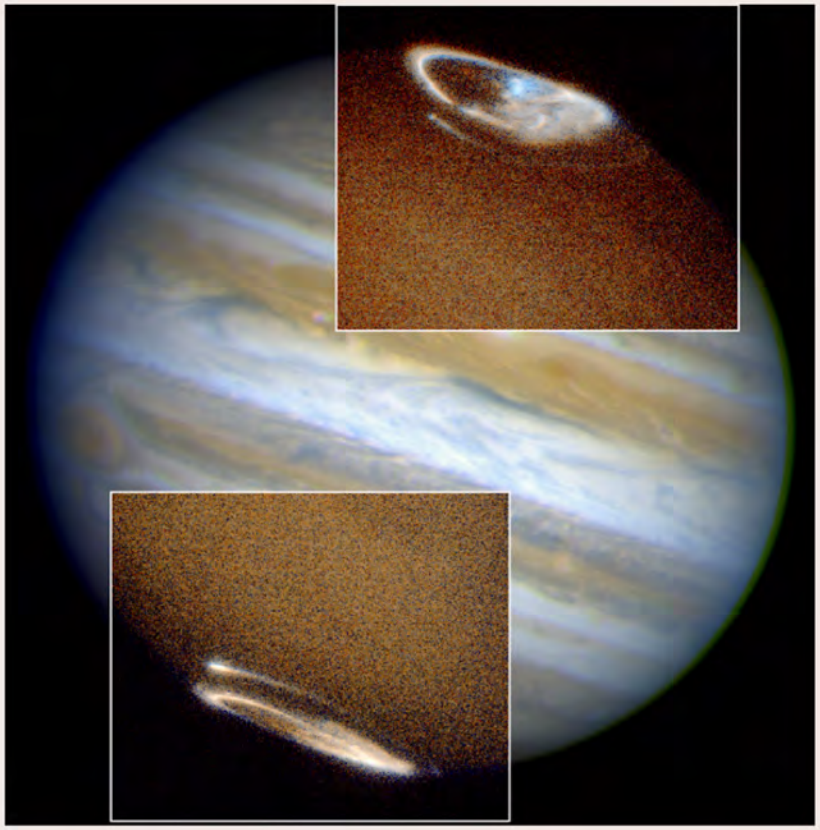
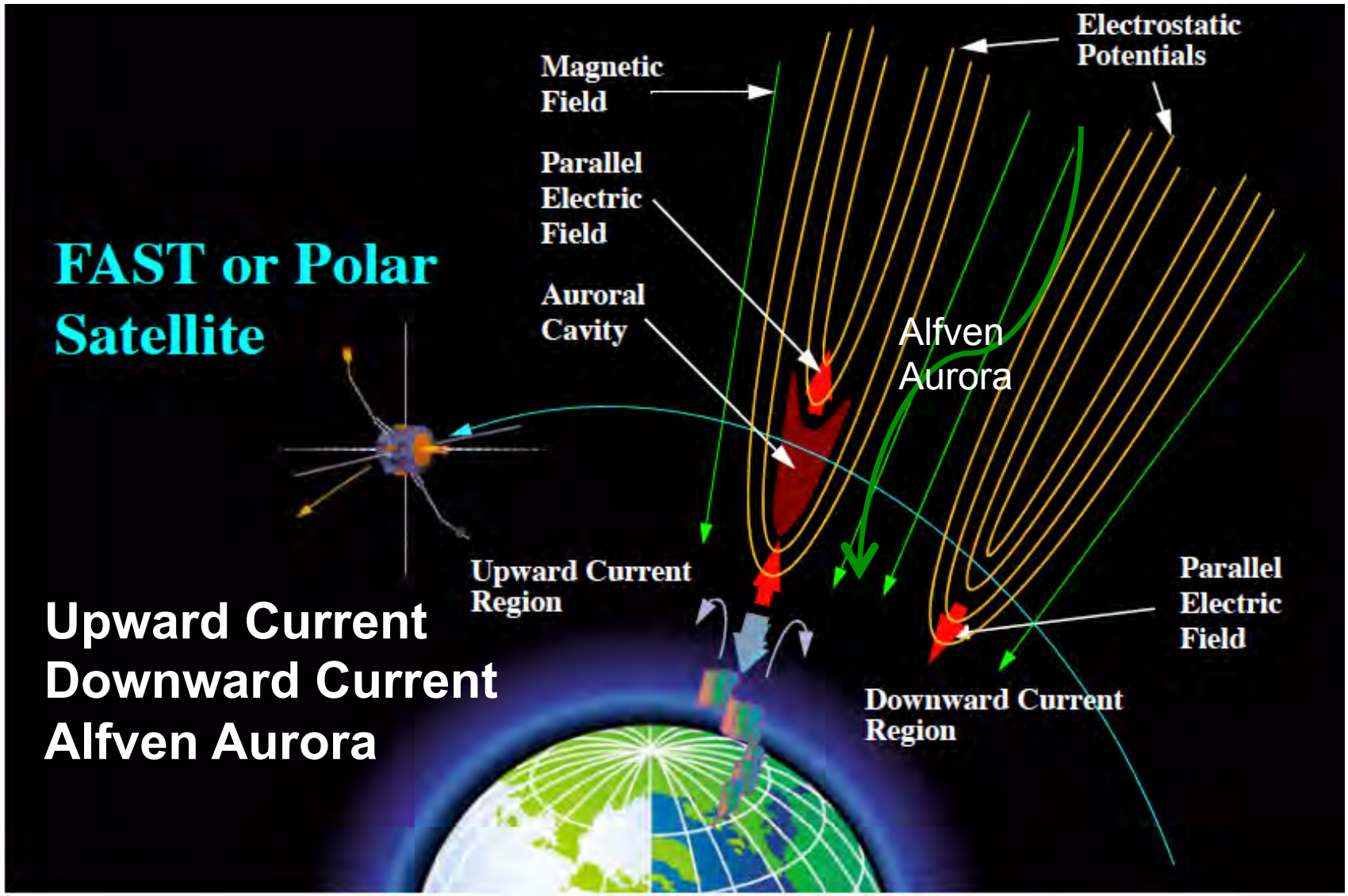


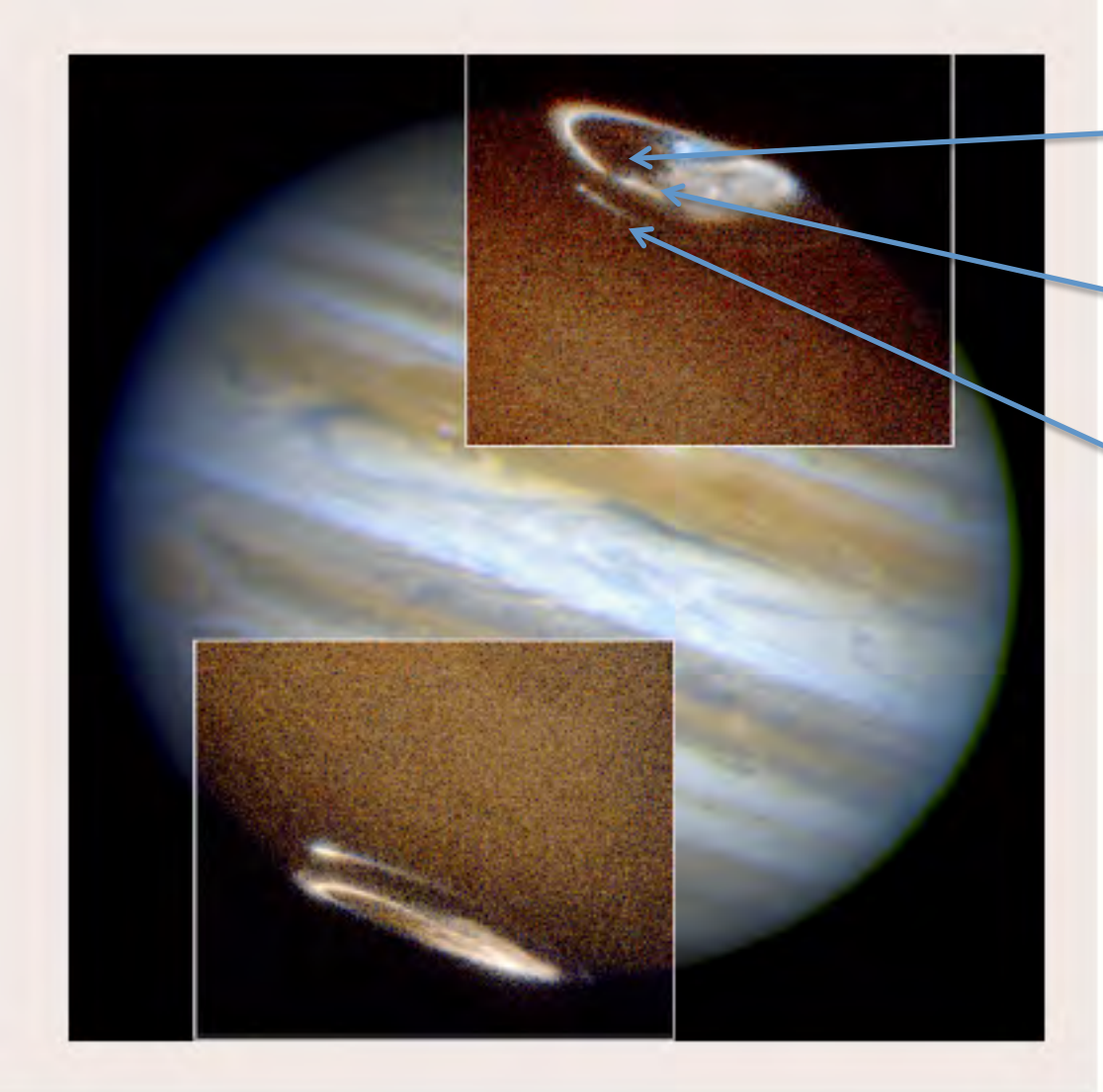
Point of this Talk

- The driving forces of Jupiter's aurora (Io and strong rotation) are quite distinct from those at Earth.
- None-the-less, auroral acceleration processes at Jupiter should be similar to those at Earth. But we expect surprises!
- We observe three types of acceleration processes at Earth: upward current region, downward current region, and Alfvenic acceleration.
- Jupiter's three types of aurora is expected to have a mixture of these acceleration processes, but may have unique characteristics.
- One needs to carefully scale the Earth and Juno observations to make comparisons. Juno orbits at higher speeds than do Earth satellites and Jupiter's magnetic field is significantly stronger than Earth's. These differences result in different observational time scales.
- Studying acceleration processes with Juno observations will be very, very interesting. Universal processes can be identified.

Acceleration Processes at Earth

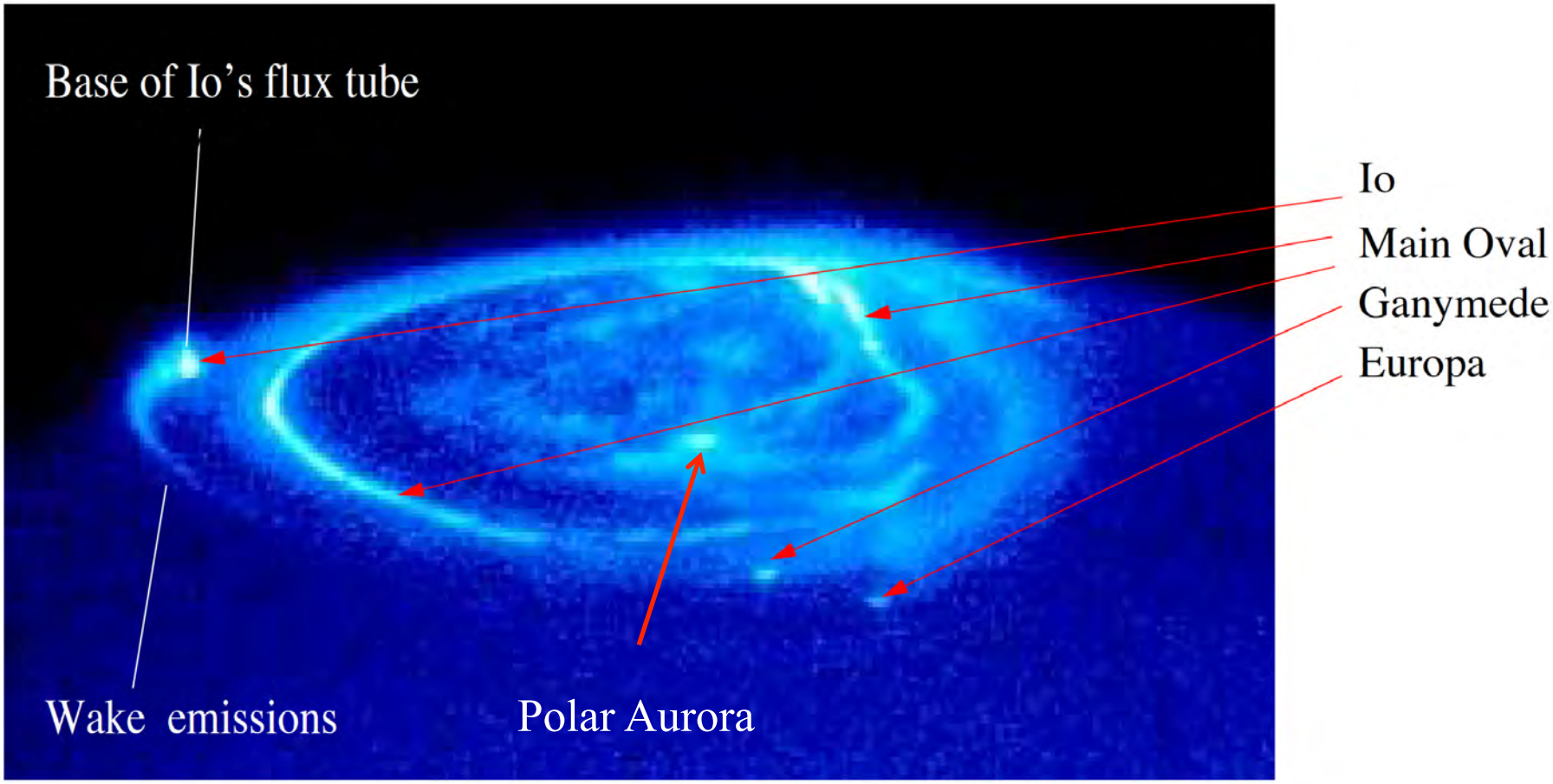


Jupiter's Aurora

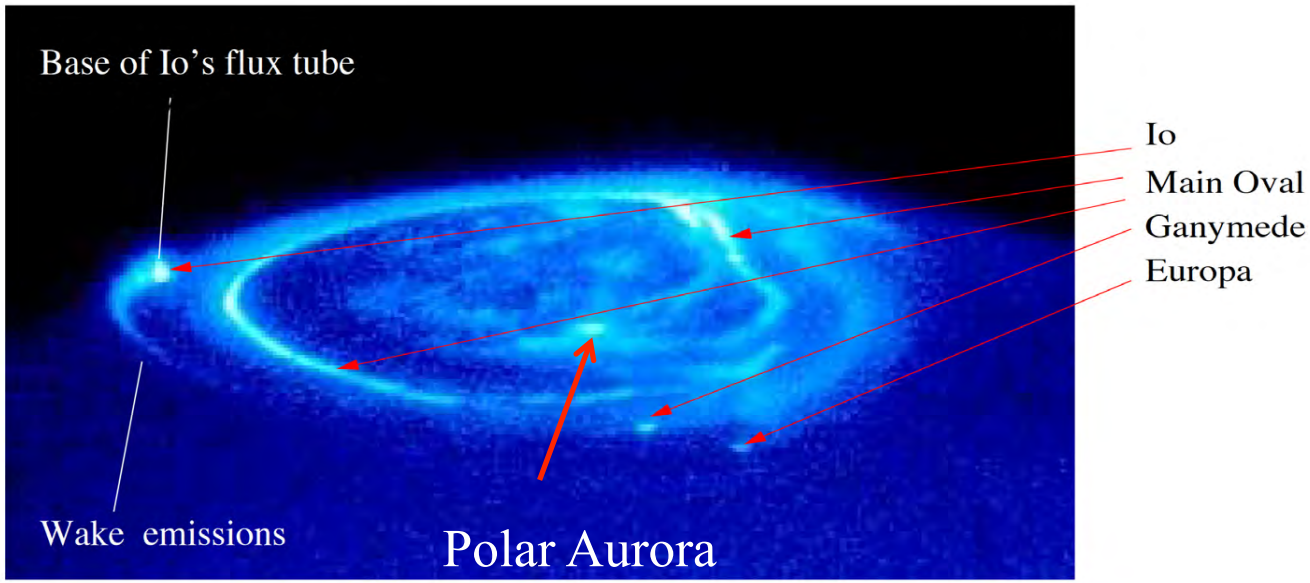


λ_i: O(100's km) same as at Earth.
ρ_i: O(1 km)
λ_e: O(10's km) same as at Earth.

Jupiter's Aurora



Acceleration Processes and Jupiter's Aurora

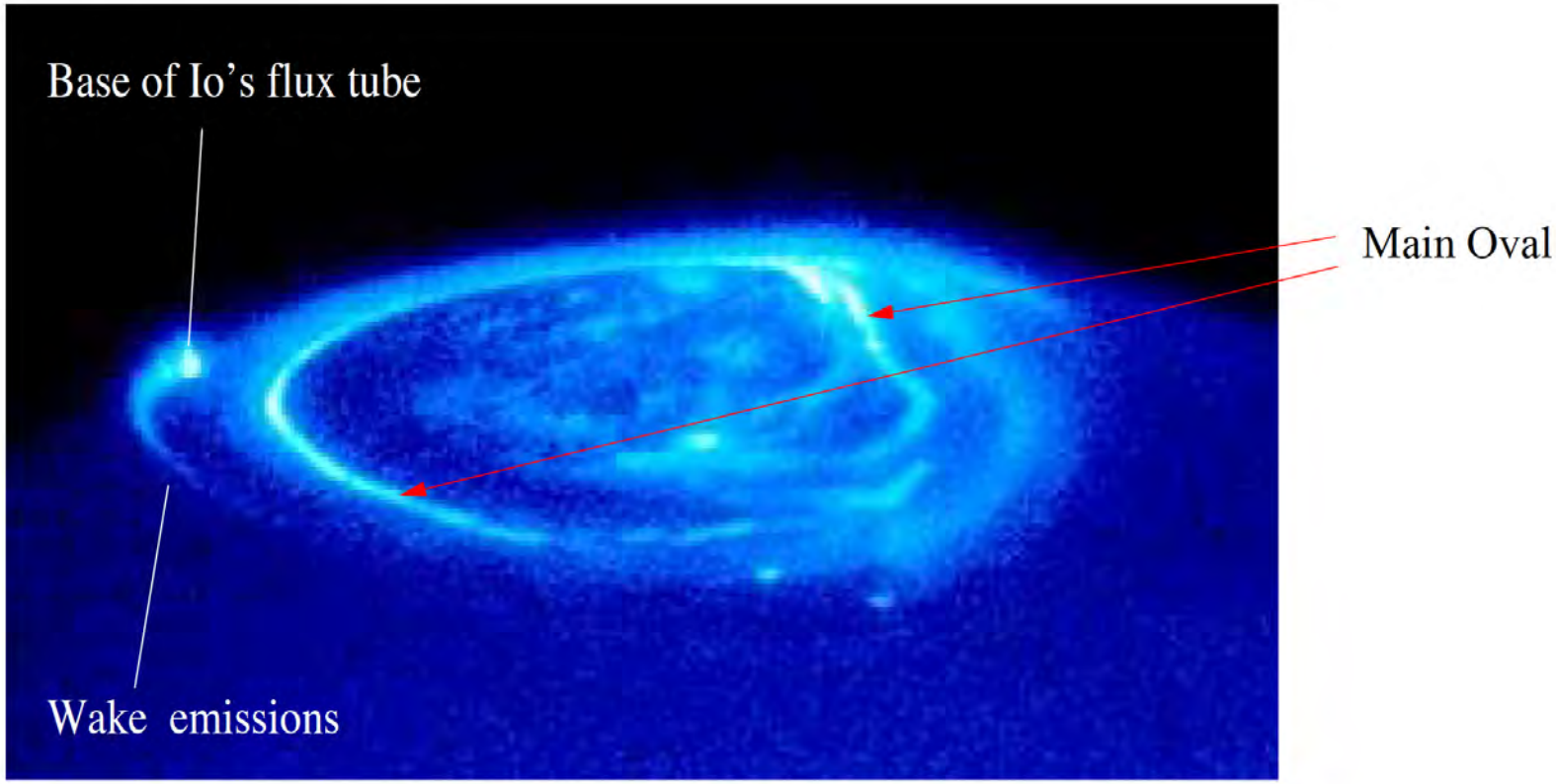


Upward Current Region: Main Oval; Io Wake Region: Most Polar Aurora

Alfven Aurora: Io Spot; Polar Aurora Boundaries; Dark Region?

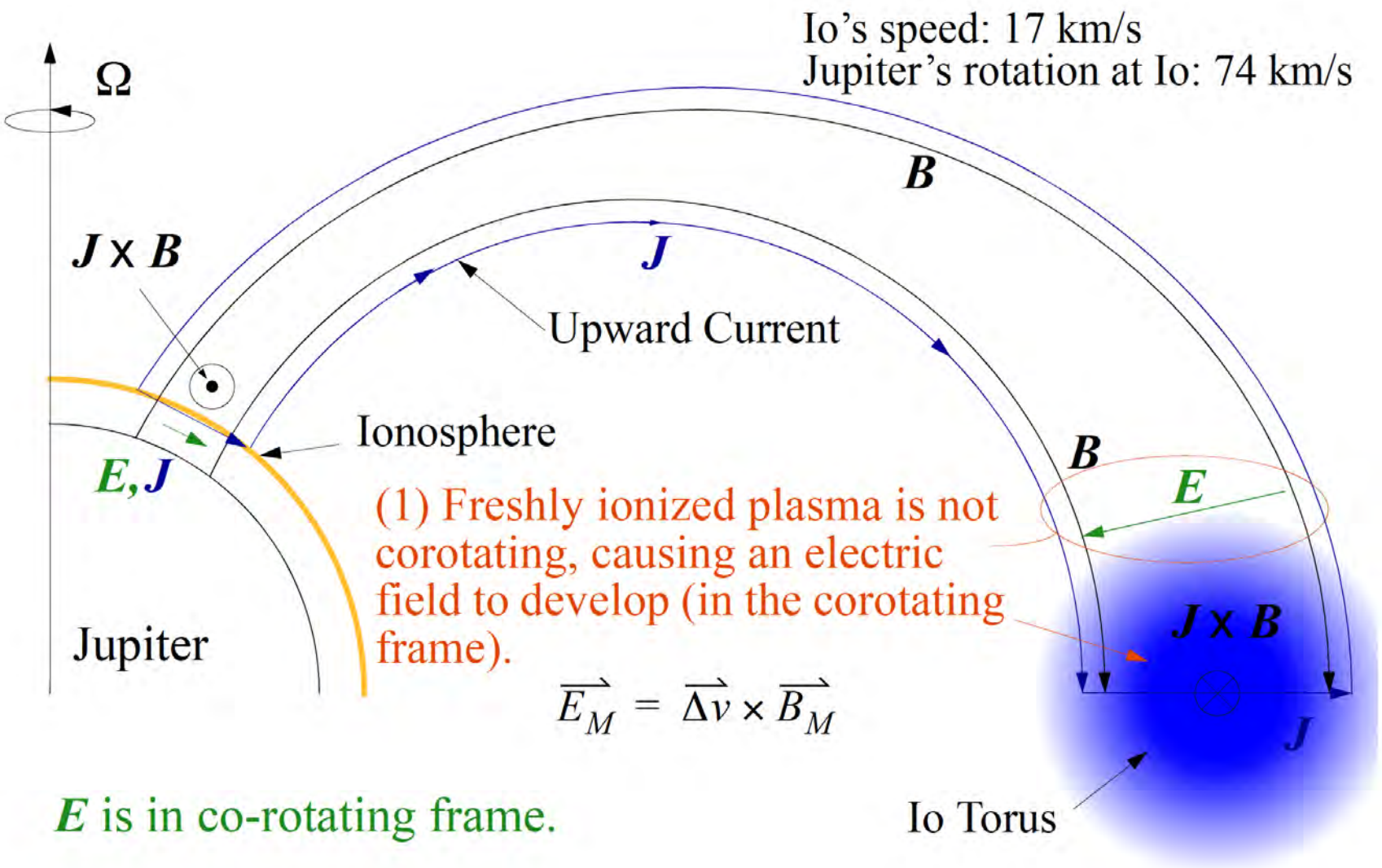
Downward Current Region: Dark Region?

Jupiter's Main Oval: An Upward Current Region



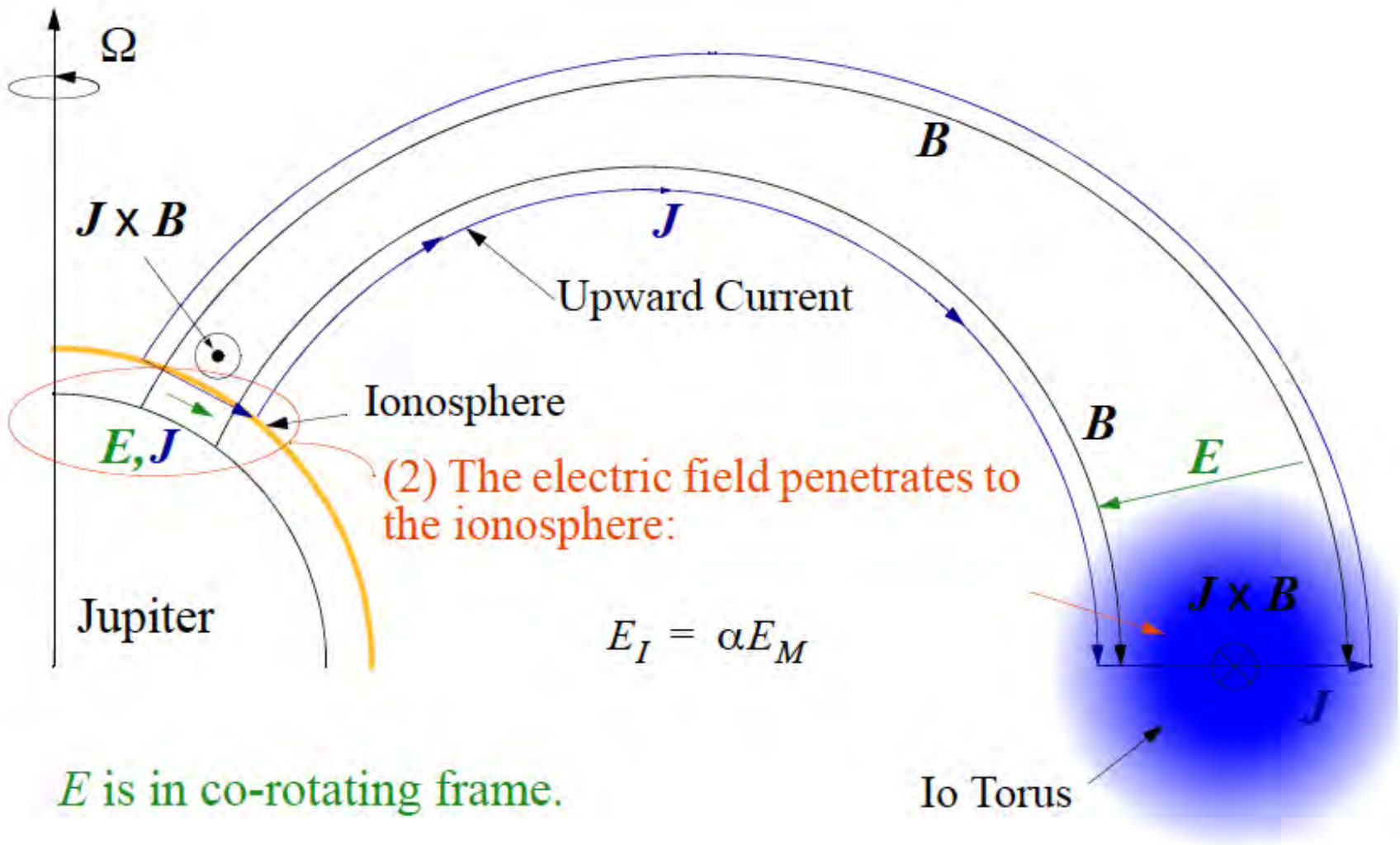
- The main oval, ~83° magnetic latitude, magnetically connects to the equatorial plasma at ~30 R_J.
- UV emissions indicate ~100 kV electrons,~20 mW/m^2; they do not significantly vary with changes in the solar wind
- The aurora is thought to come the rotational energy of Jupiter. It is associated with co-rotation breakdown.

Jupiter's Main Oval: Angular Momentum Transfer

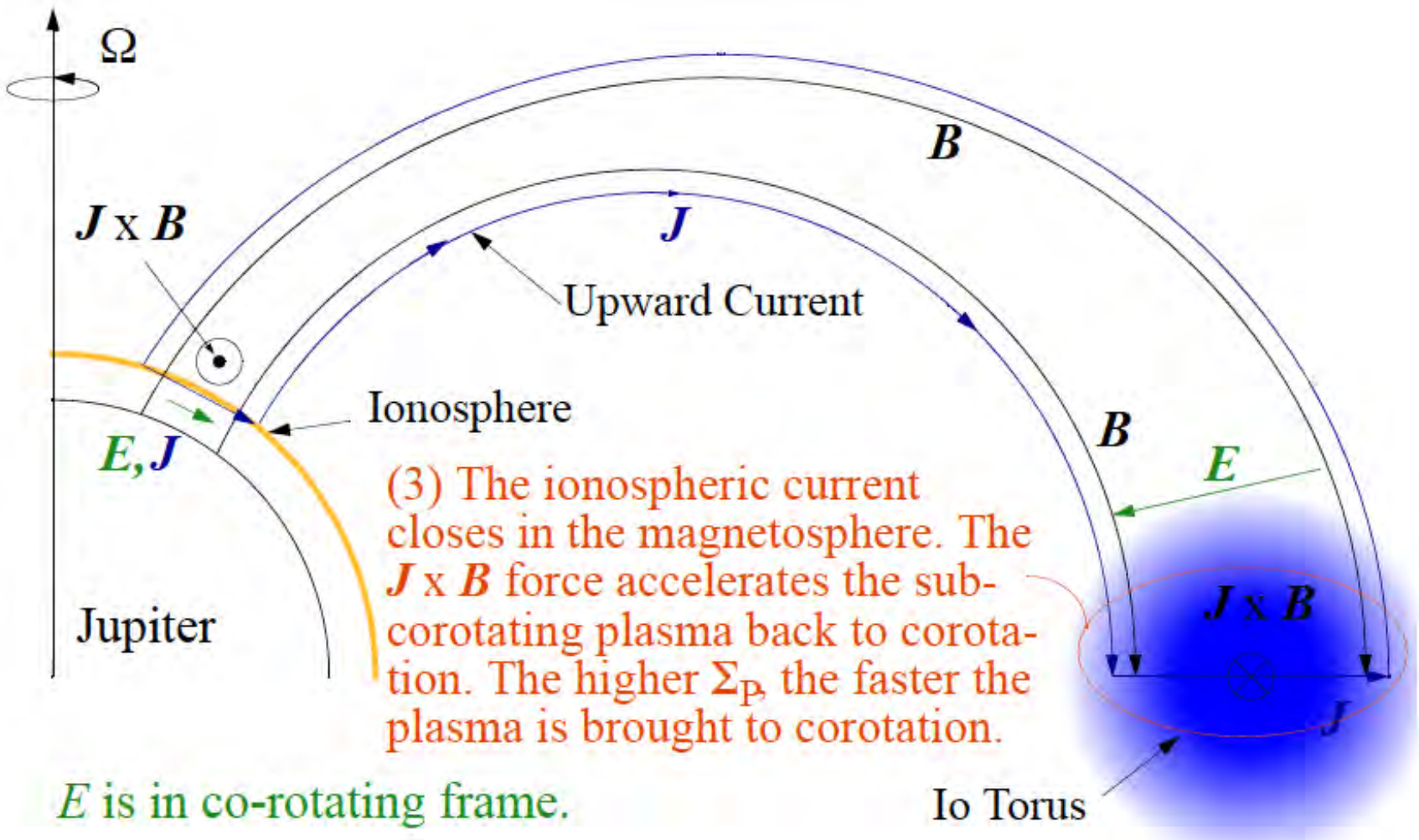


E is in co-rotating frame.

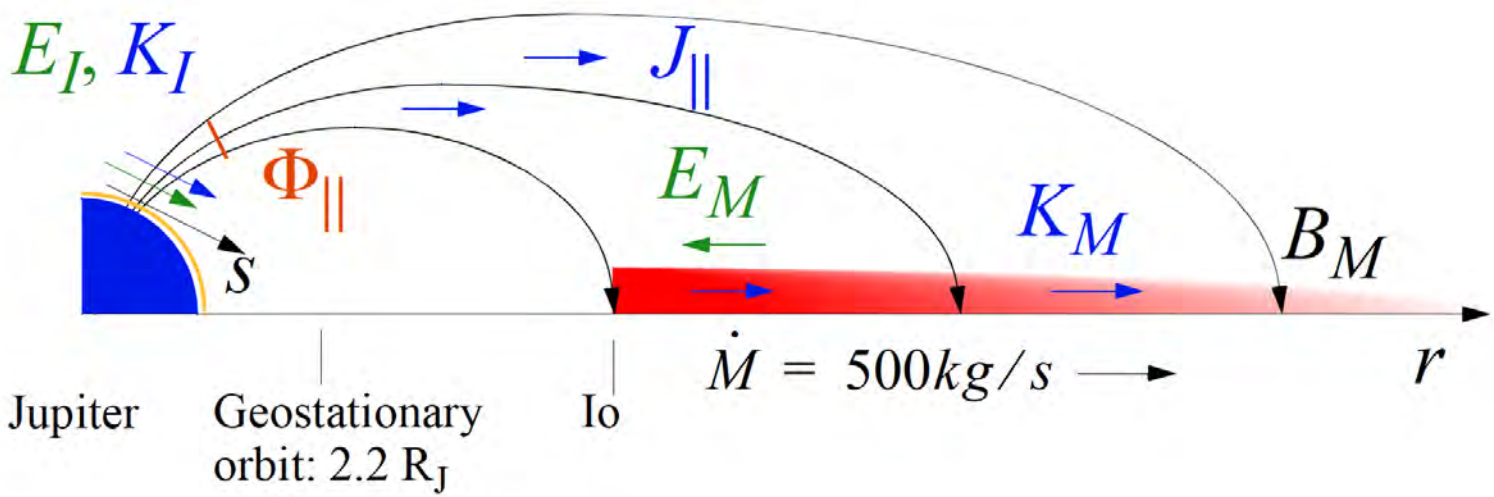
Jupiter's Main Oval: Angular Momentum Transfer



Jupiter's Main Oval: Angular Momentum Transfer



Jupiter's Main Oval: Angular Momentum Transfer



- Jupiter's stationary orbit is ~2.2 RJ. The rigid rotation outward of this point is faster than the orbital speed.
- The centrifugal force from Jupiter's rapid rotation forces Io's 500 kg/s plasma out via an interchange instability.
- To maintain rigid rotation, Jupiter must accelerate the plasma, in other words, transfer angular momentum.
- The corotation lag felt in Jupiter's ionosphere generates a current to accelerate Io's plasma.
- A large *r*, the process must break down.

Jupiter's Main Oval: Angular Momentum Transfer

$$\dot{M}\frac{d}{dr}(\Omega r^2) = 2\pi r^2 K_M B_M$$

Angular momentum.

Ray et al. alters conductance with energy fluxes.

$$E_M = (\Omega - \Omega_J) r B_M$$

Generalized Ohm's law (magnetosphere).

$$K_I = \Sigma_P E_I$$

Ohm's law (ionosphere).

$$K_M = -2\left(\frac{s}{r}K_I\right)$$

Current continuity.

$$J_{\parallel}^{I} = j_x + j_x(R_x - 1)\left(1 - e^{-\left(\frac{e\Phi_{\parallel}}{T_x(R_x - 1)}\right)}\right)$$

Mirror resistance.

Hill et al. in Black

Ray et al. in red.

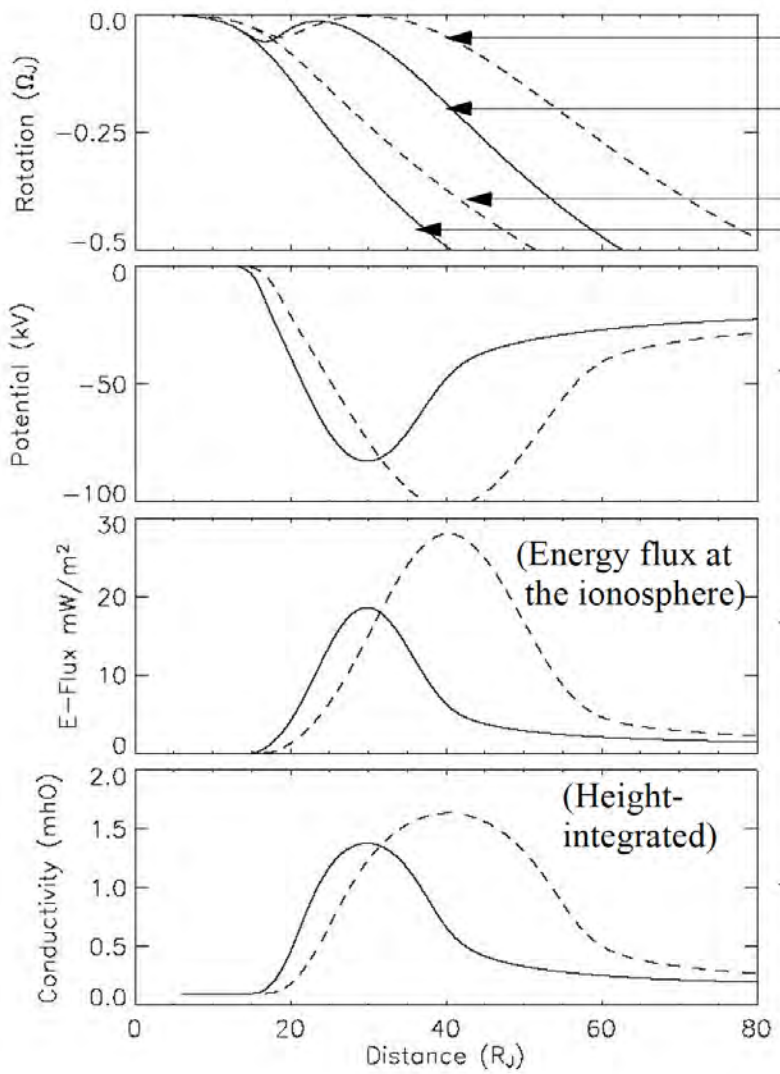
$$J_{\parallel} = \frac{1}{r}d(rK_M)/dr$$

Current continuity.

$$E_I = \alpha\left(E_M + \frac{d\Phi_{\parallel}}{dr}\right)$$

Faraday's law.

Jupiter's Main Oval: Angular Momentum Transfer



$\dot{M} = 500 kg/s$: Dashed Lines

$\dot{M} = 1000 kg/s$: Solid Lines

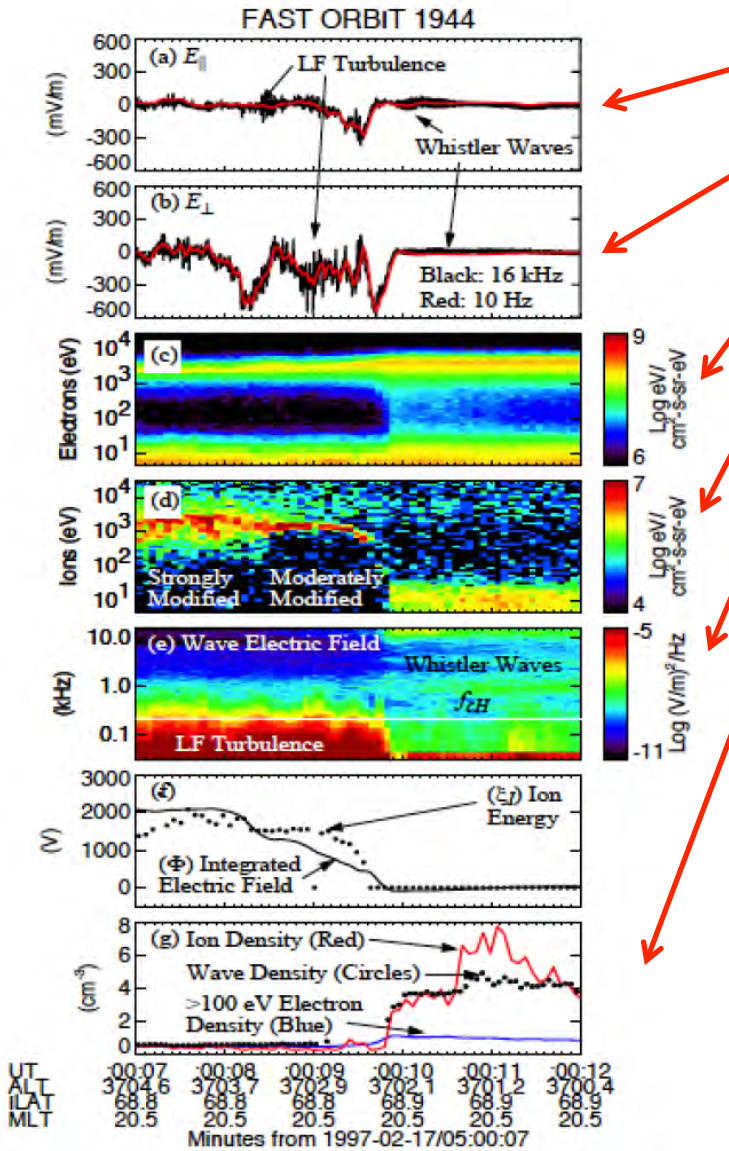
$\Phi_{||} = 0$. Angular momentum transfer is weaker than if $|\Phi_{||}| > 0$.

$|\Phi_{||}|$ reaches ~50-100 kV as observed by HST [*Clarke et al.*, 1992].

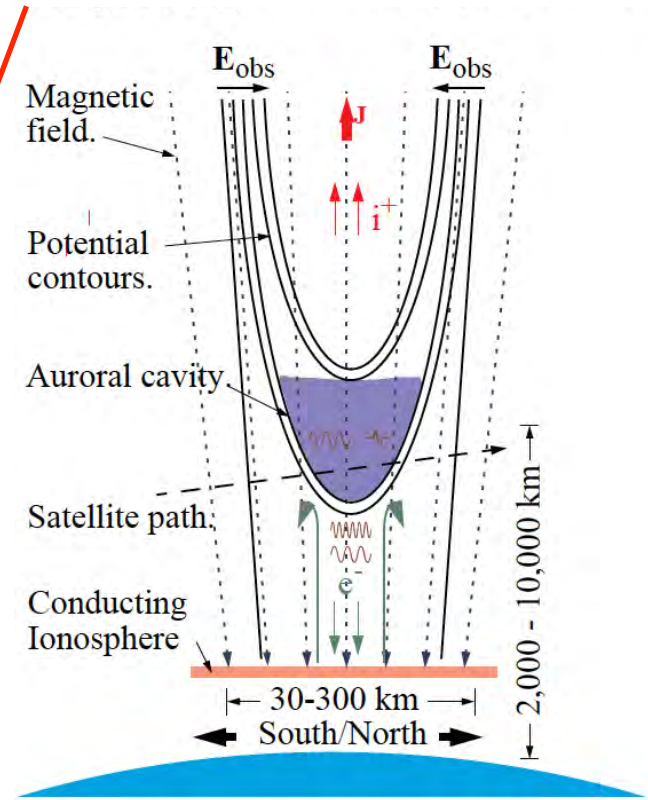
The energy flux into the ionosphere reaches ~20 mW/m^2 in accordance to HST observations [*Clarke et al.*, 1992].

The increase in ionospheric conductivity (Σ_P) is a is due to electron impact ionization. The higher conductivity dramatically increases angular momentum transfer.

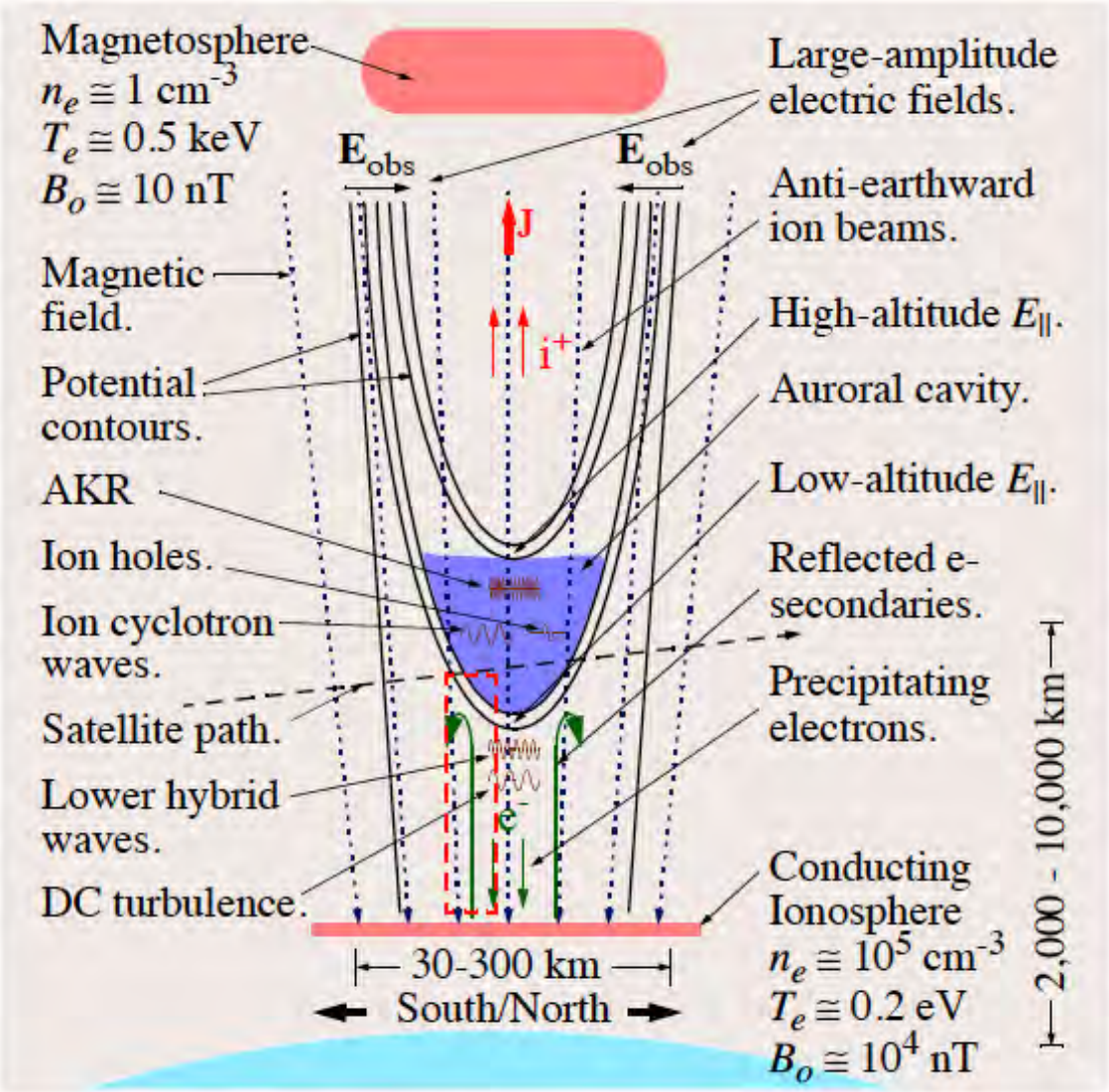
Jupiter's Main Oval: Upward Current Region



(1) Parallel electric fields (double layers).
(2) Perpendicular electrostatic shocks.
(3) Accelerated electrons.
(4) Anti-Earthward ion beam.
(5) Strong wave activity.
(6) Deep density cavity.

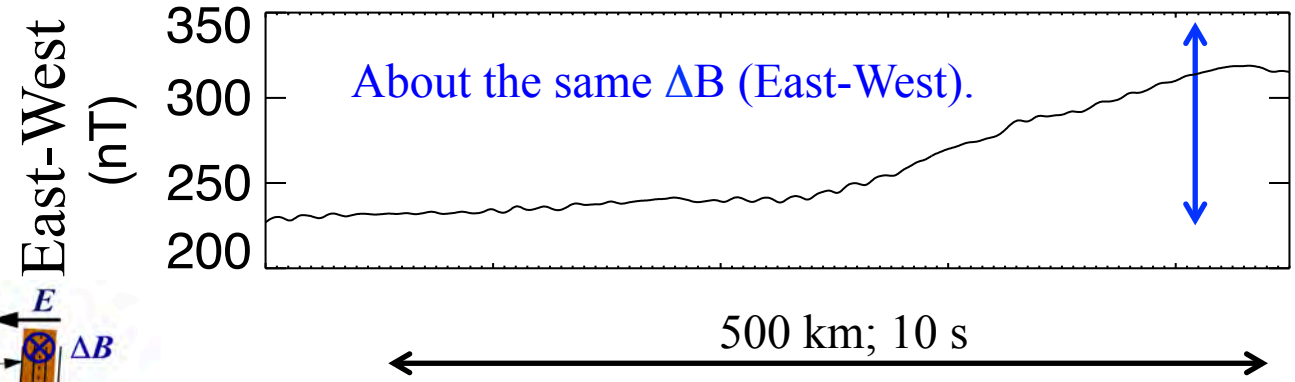


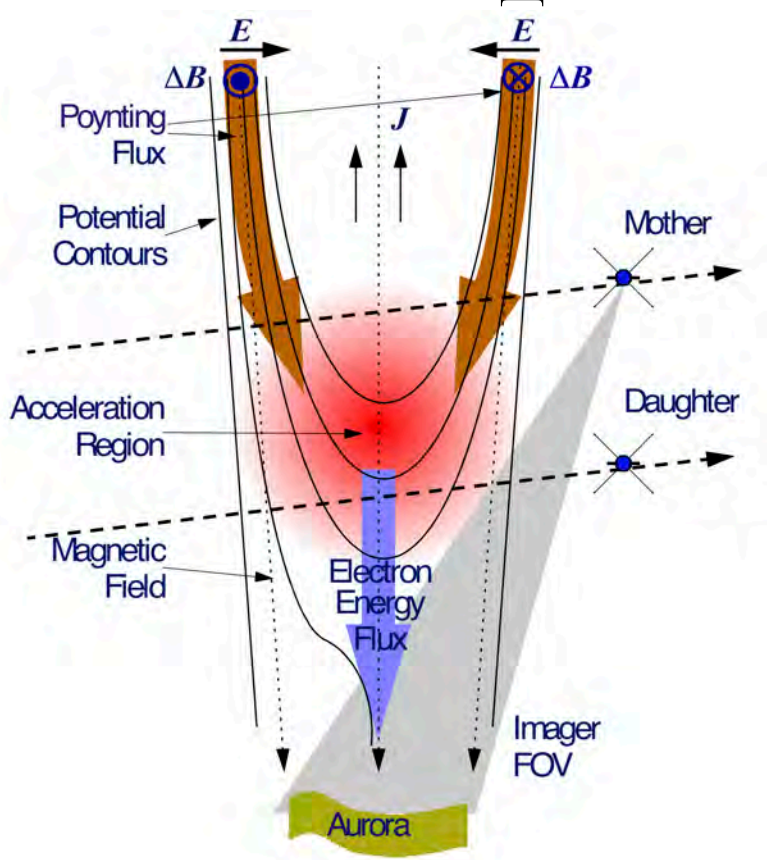
Upward Current Region



- Observations suggest that the parallel electric fields are confined to two transition layers.
- The low-altitude transition layer separates the ionosphere from the auroral cavity.
- The high altitude transition layer separates the auroral cavity from the magnetosphere.
- We define the auroral cavity as the region between the parallel electric fields.

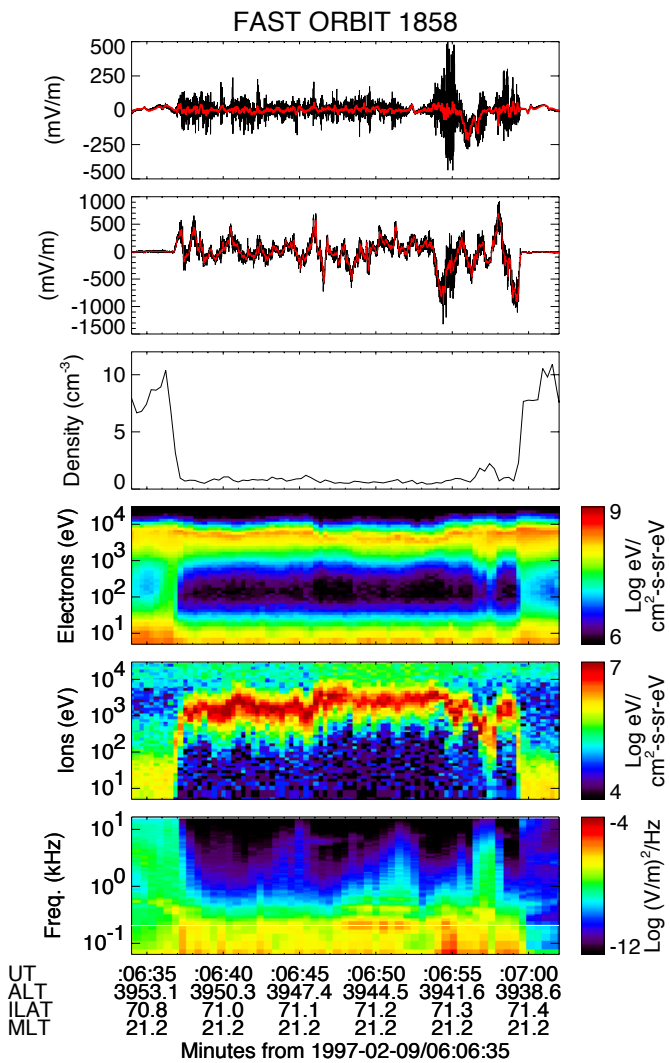
Upward Current Region: Magnetic Fields

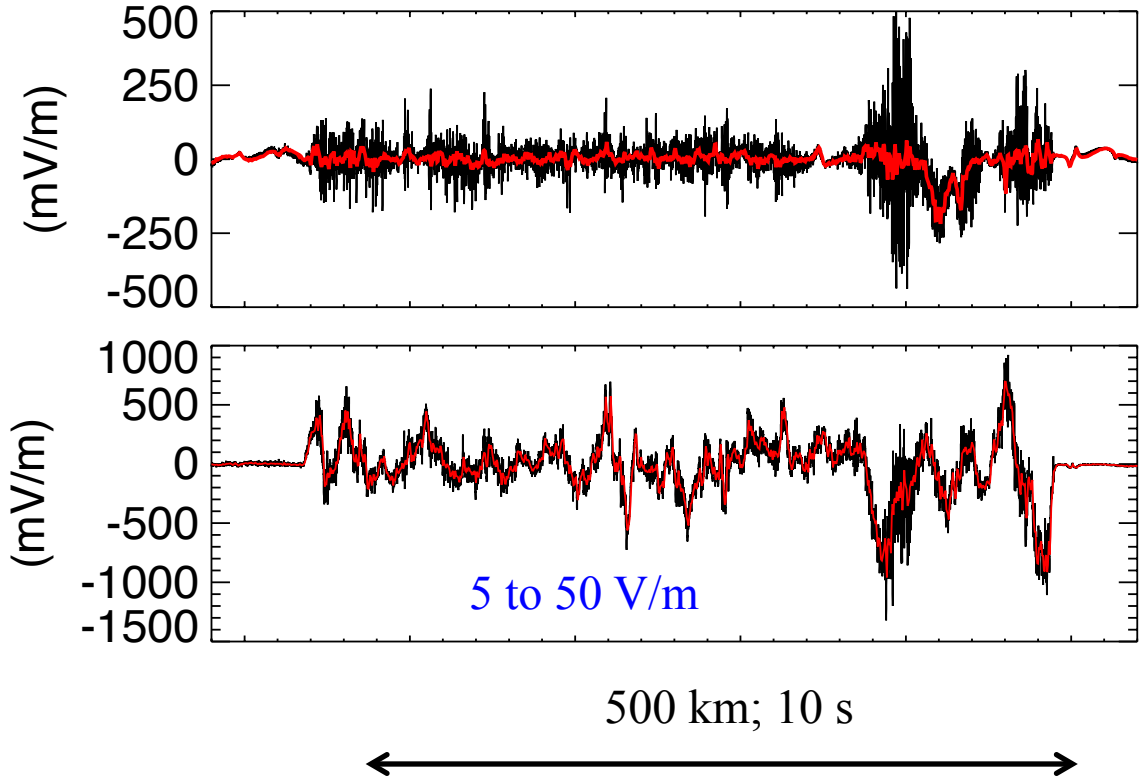




Magnetic field deflections are expected to be the same as at Earth. The time scale will be faster.

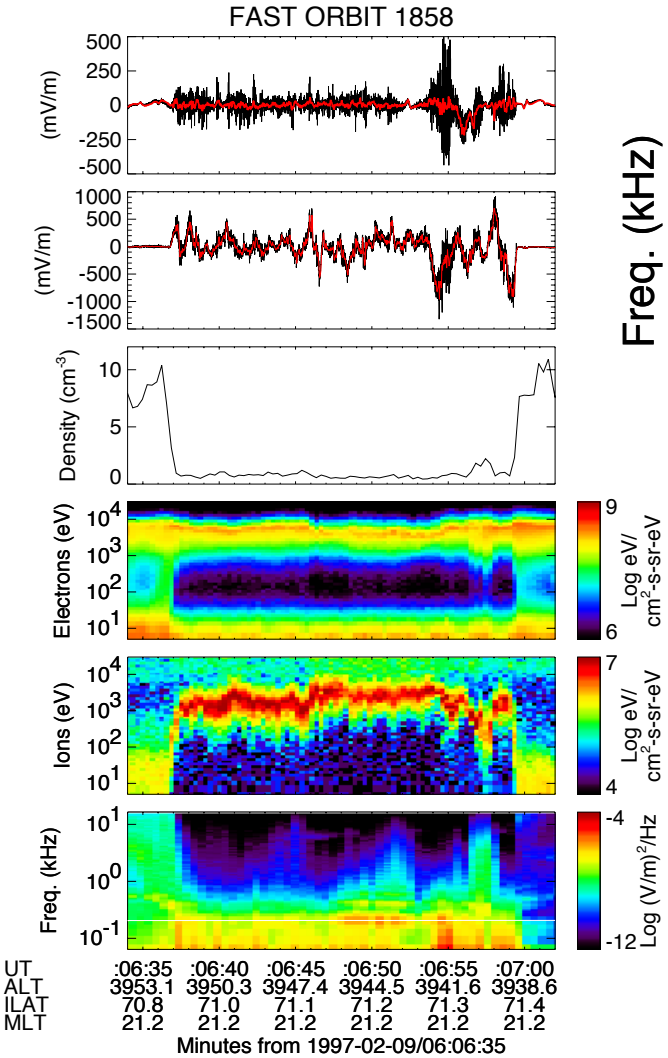
Upward Current Region: Electric Fields

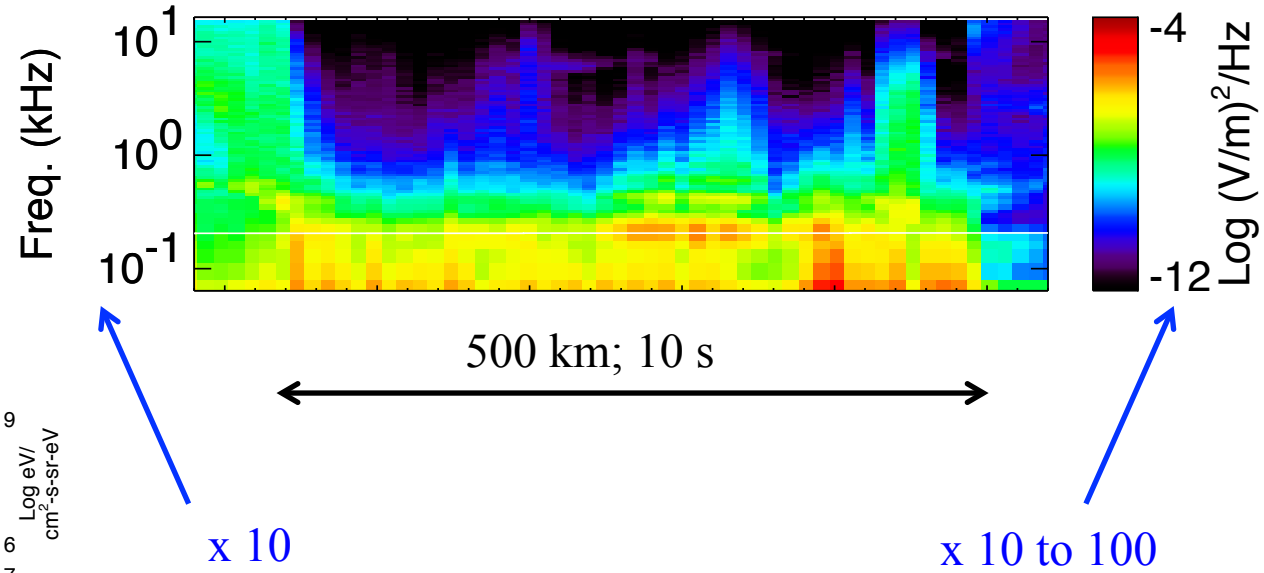




Electric field amplitudes should be considerably larger and, depending on boundary layer thickness, much faster time scale.

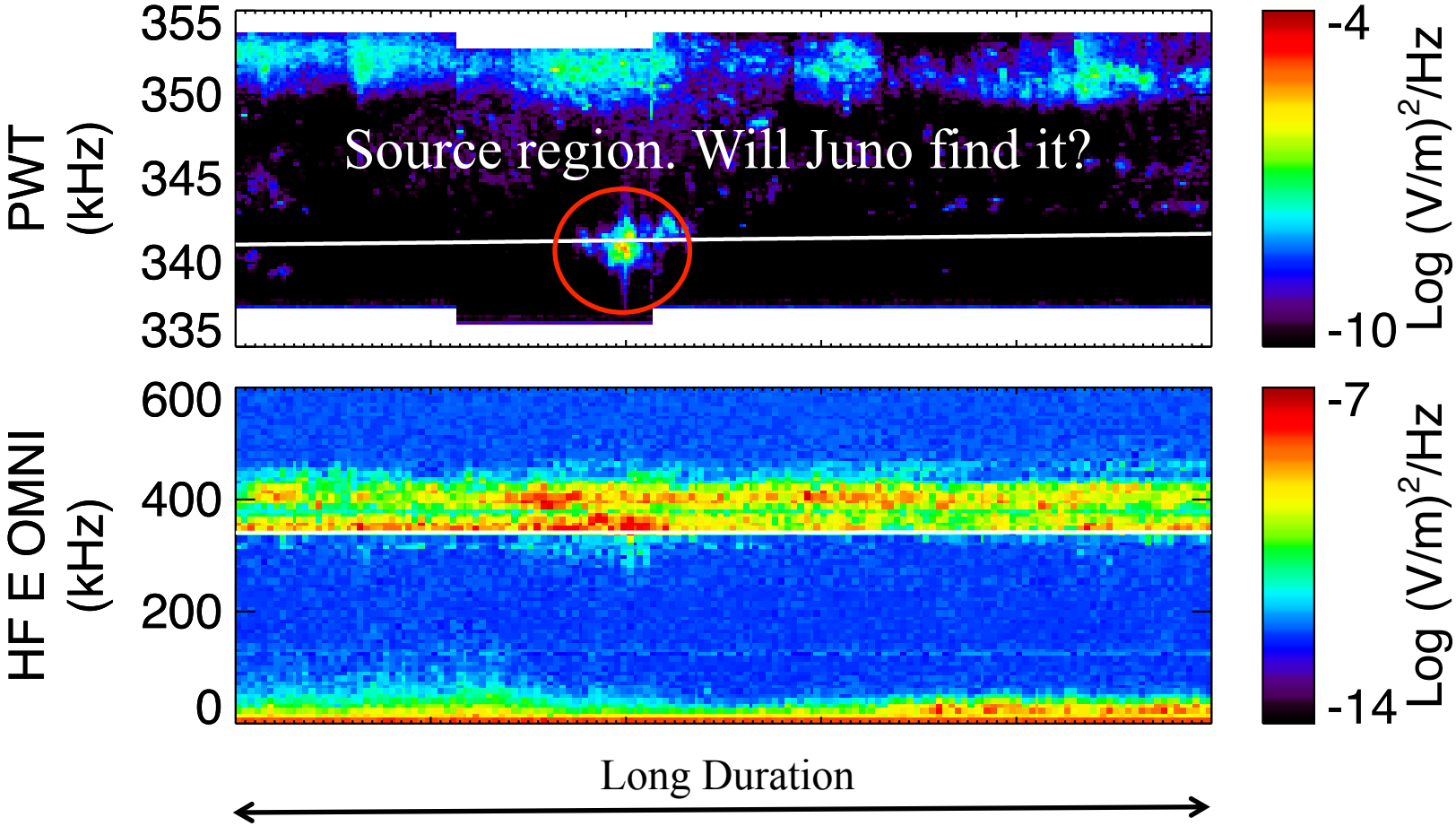
Upward Current Region: Waves





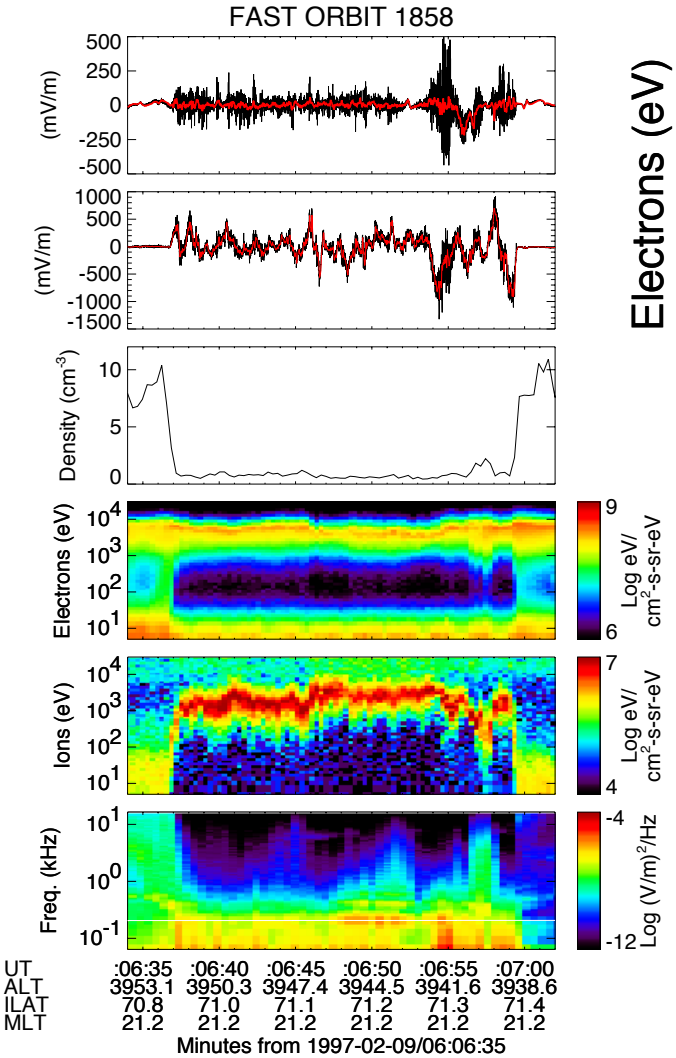
Ion-cyclotron waves should have higher frequencies and amplitudes may be much more intense.

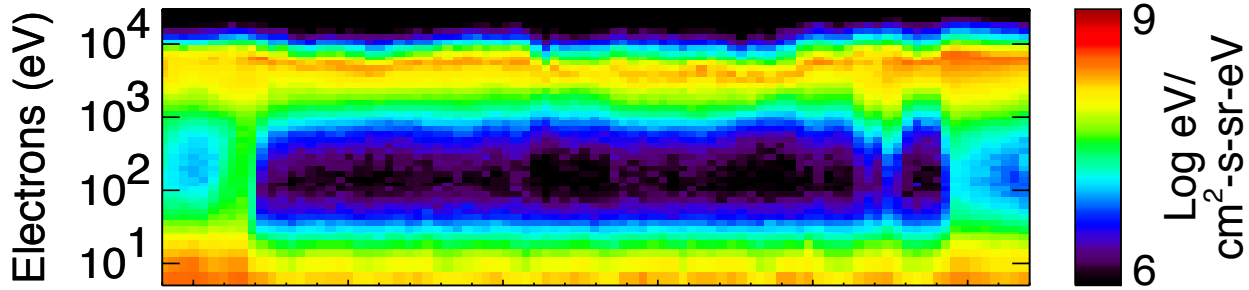
Upward Current Region: Waves



Radio frequency emissions have considerably higher frequencies

Upward Current Region: Electrons





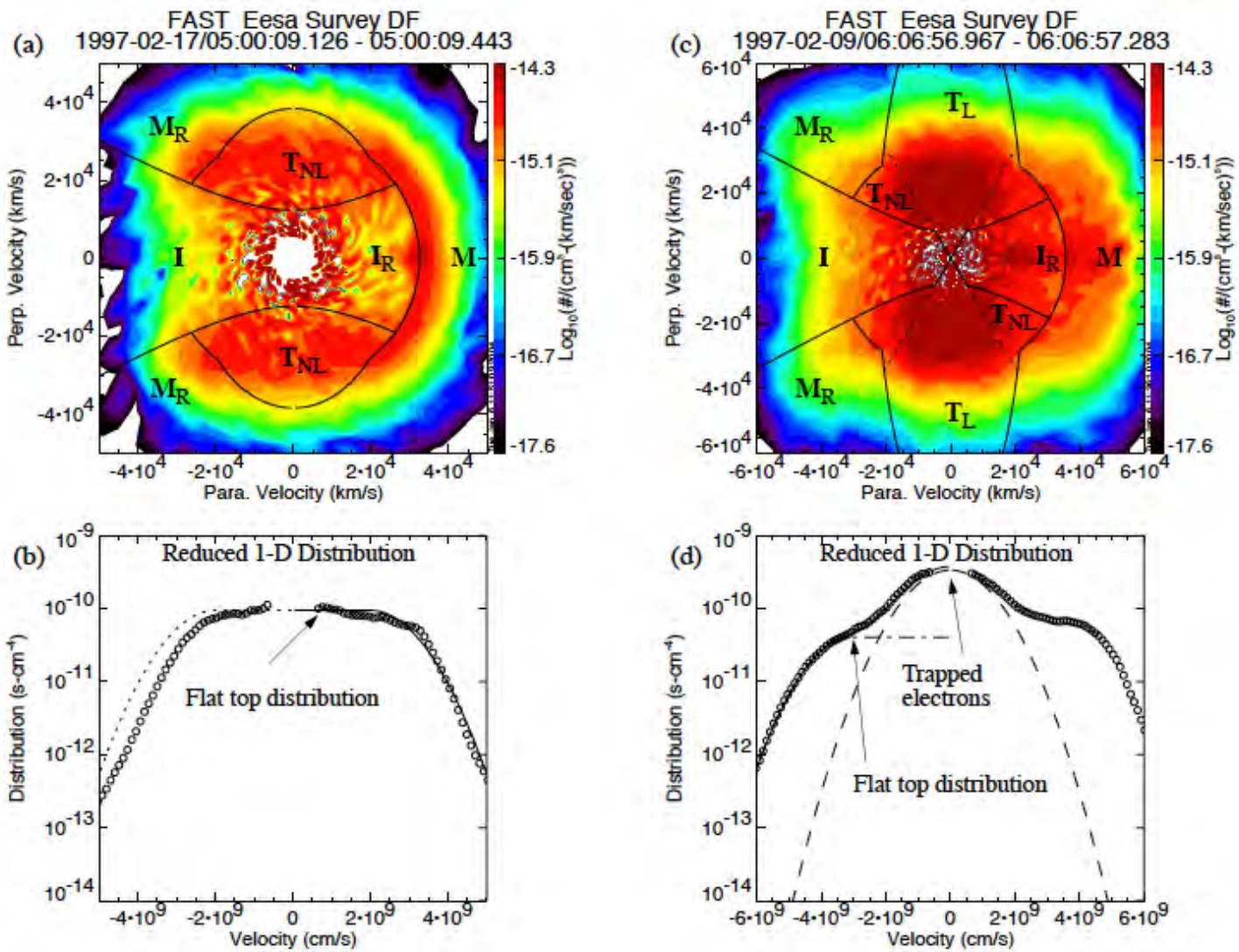
500 km; 10 s

x 5 to 10

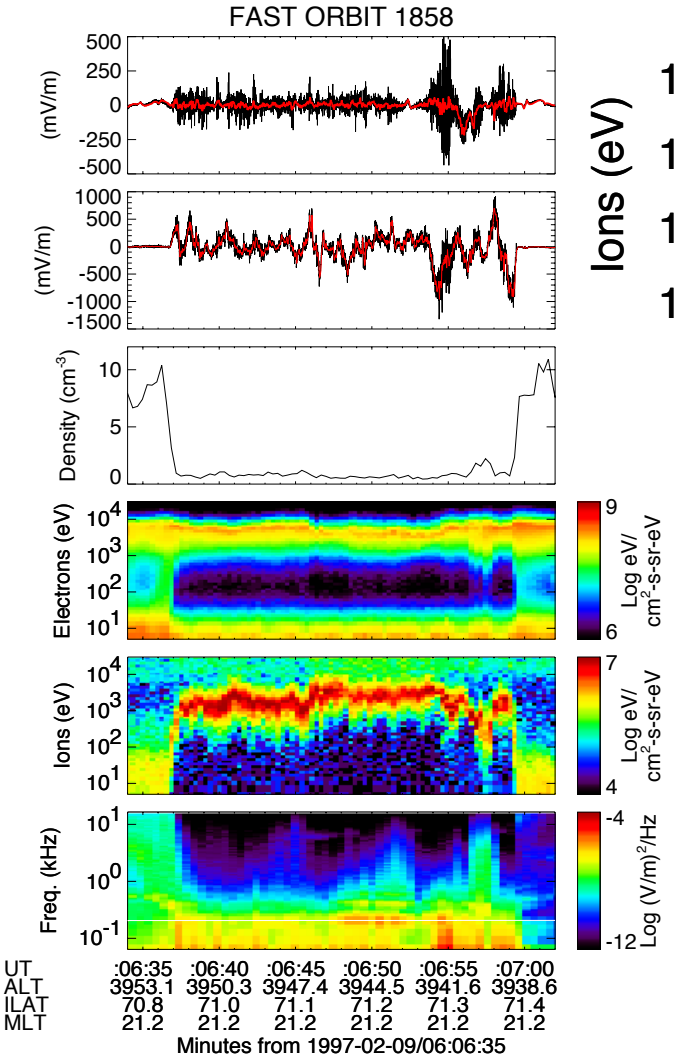
About the same

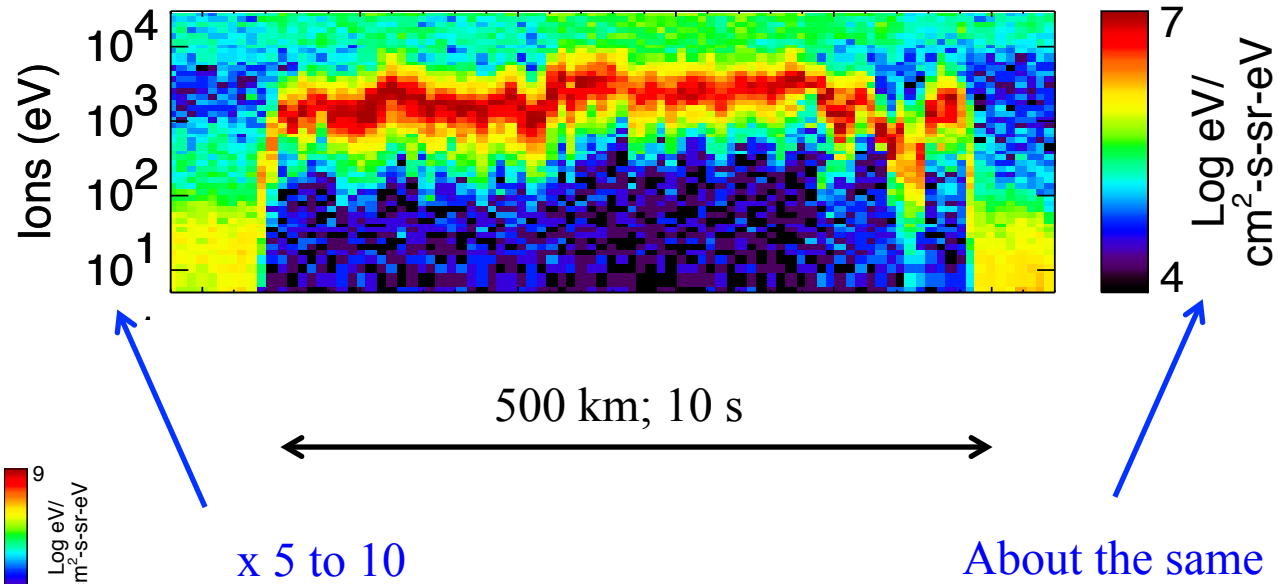
Electrons should have higher energies.

Upward Current Region: Electrons



Upward Current Region: Ions





Anti-Jovian ion beams should have higher energies.

Integrated Electric Field and Ion Beam

- DC Electric Fields

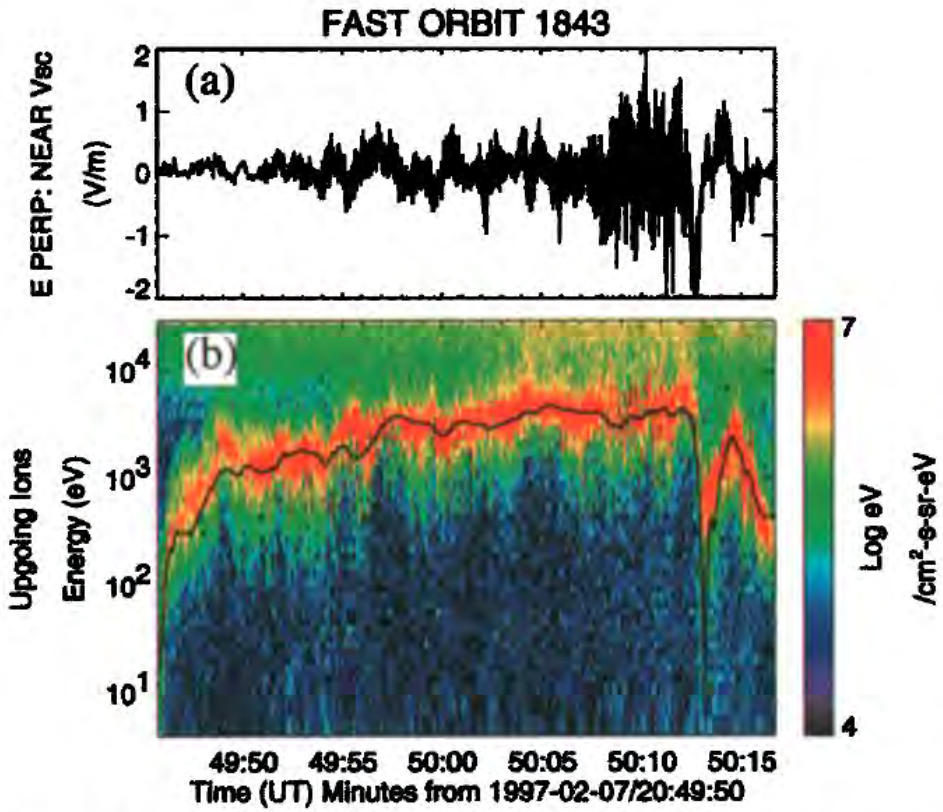
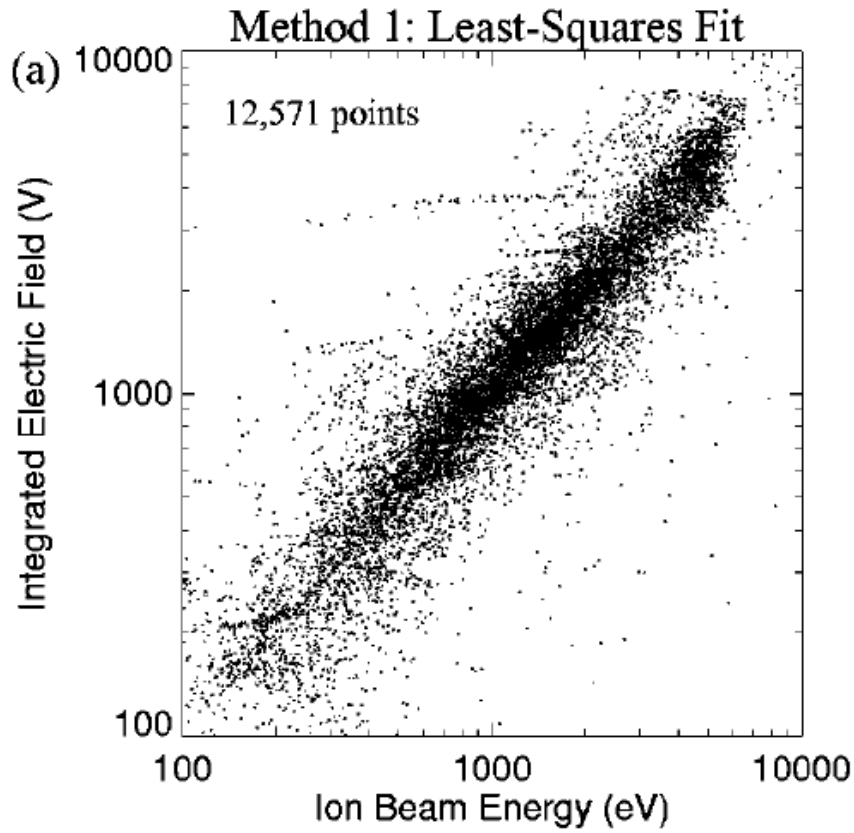
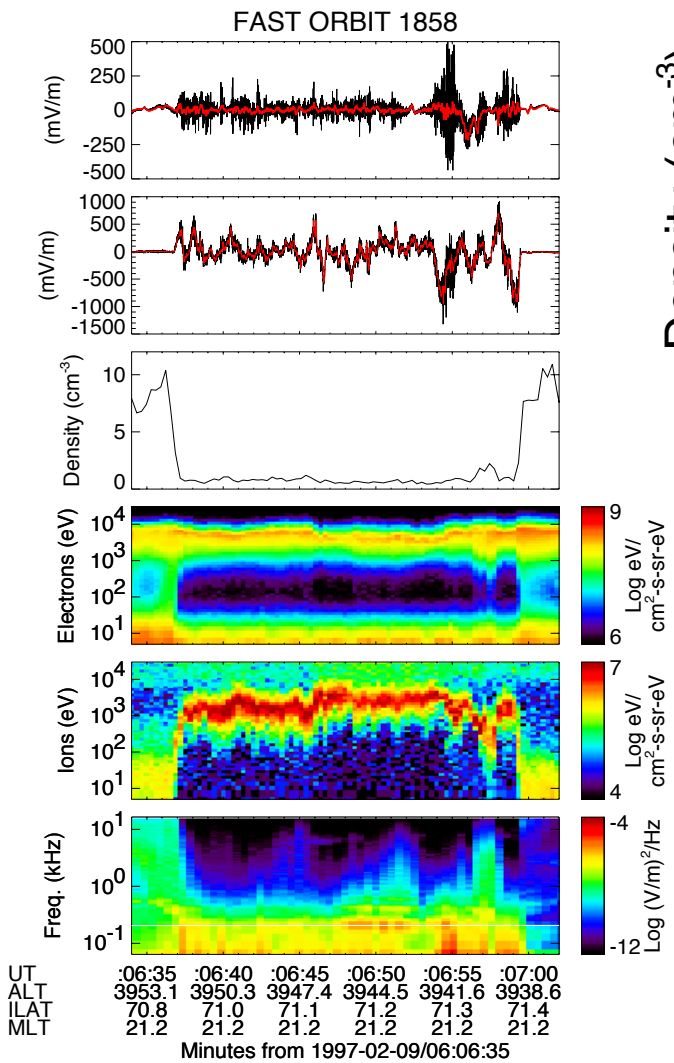
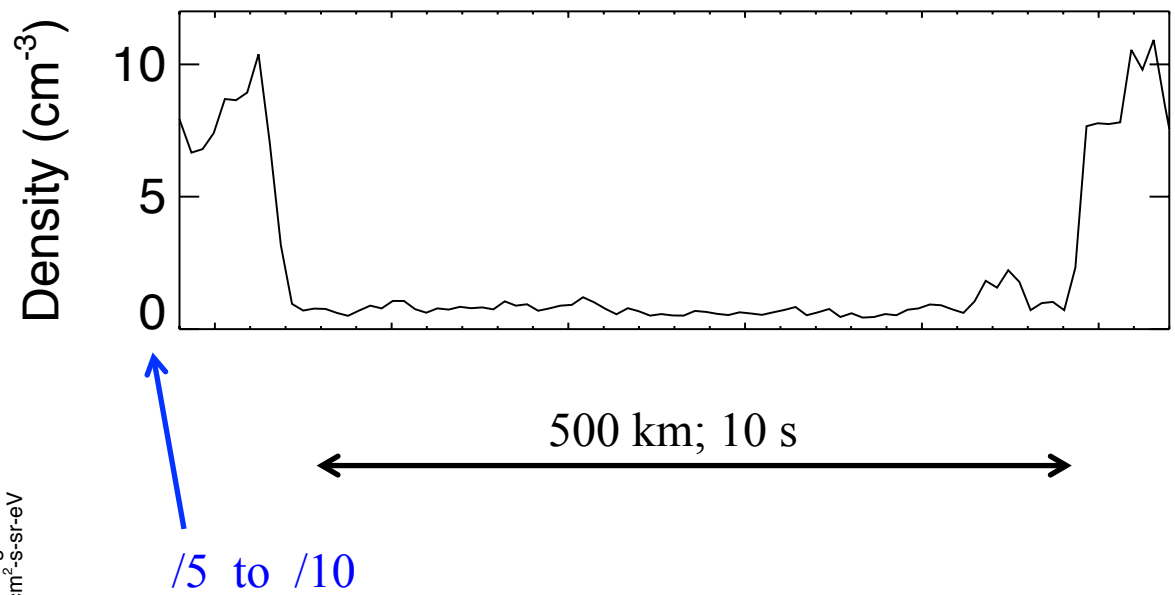


Figure 2. (a) The D.C. electric field perpendicular to $\mathbf{B}_0$ and nearly along to the velocity of the satellite. (b) Up-going ion energy flux versus energy with the inferred parallel potential from the observed electric field superimposed.



Upward Current Region: Density

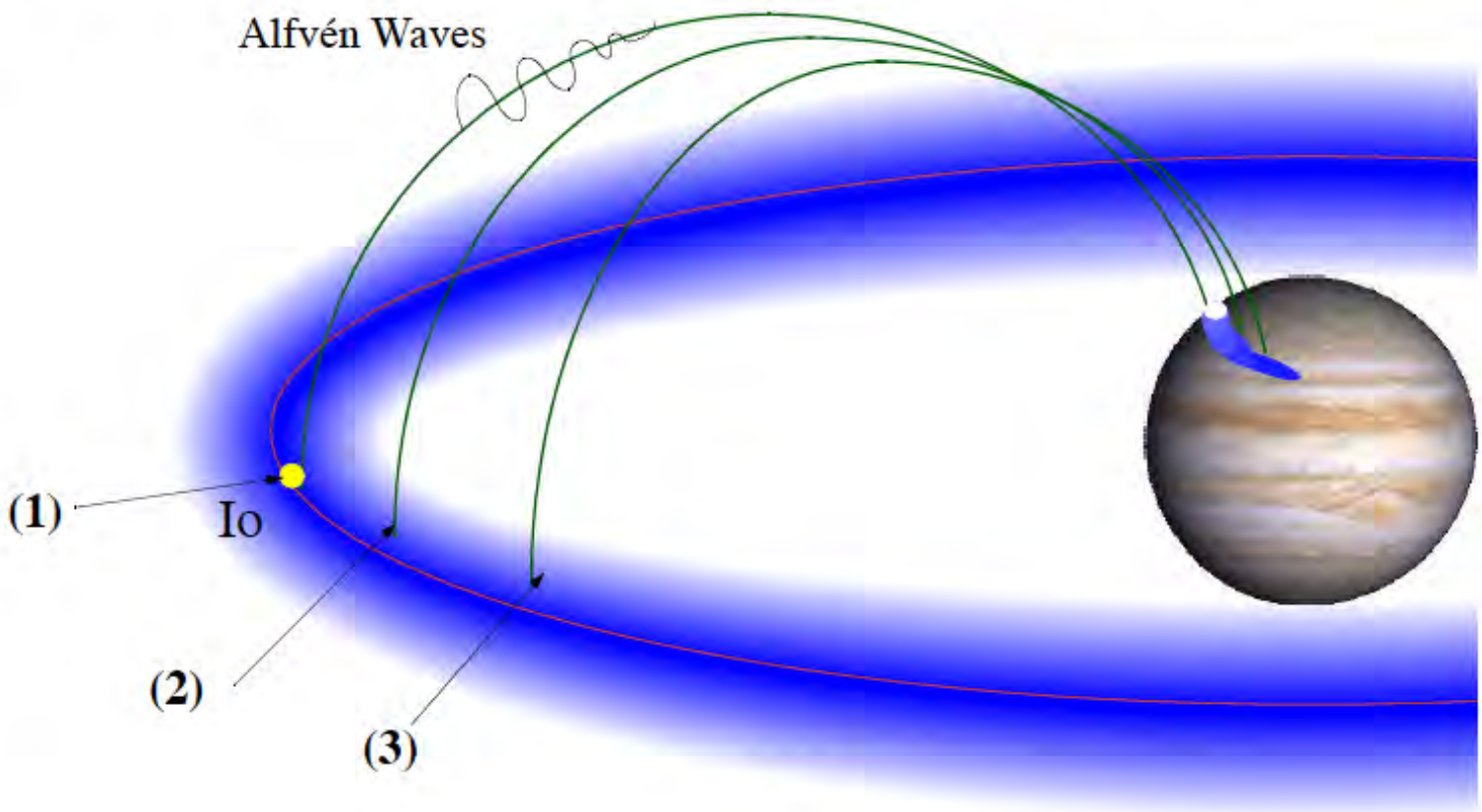




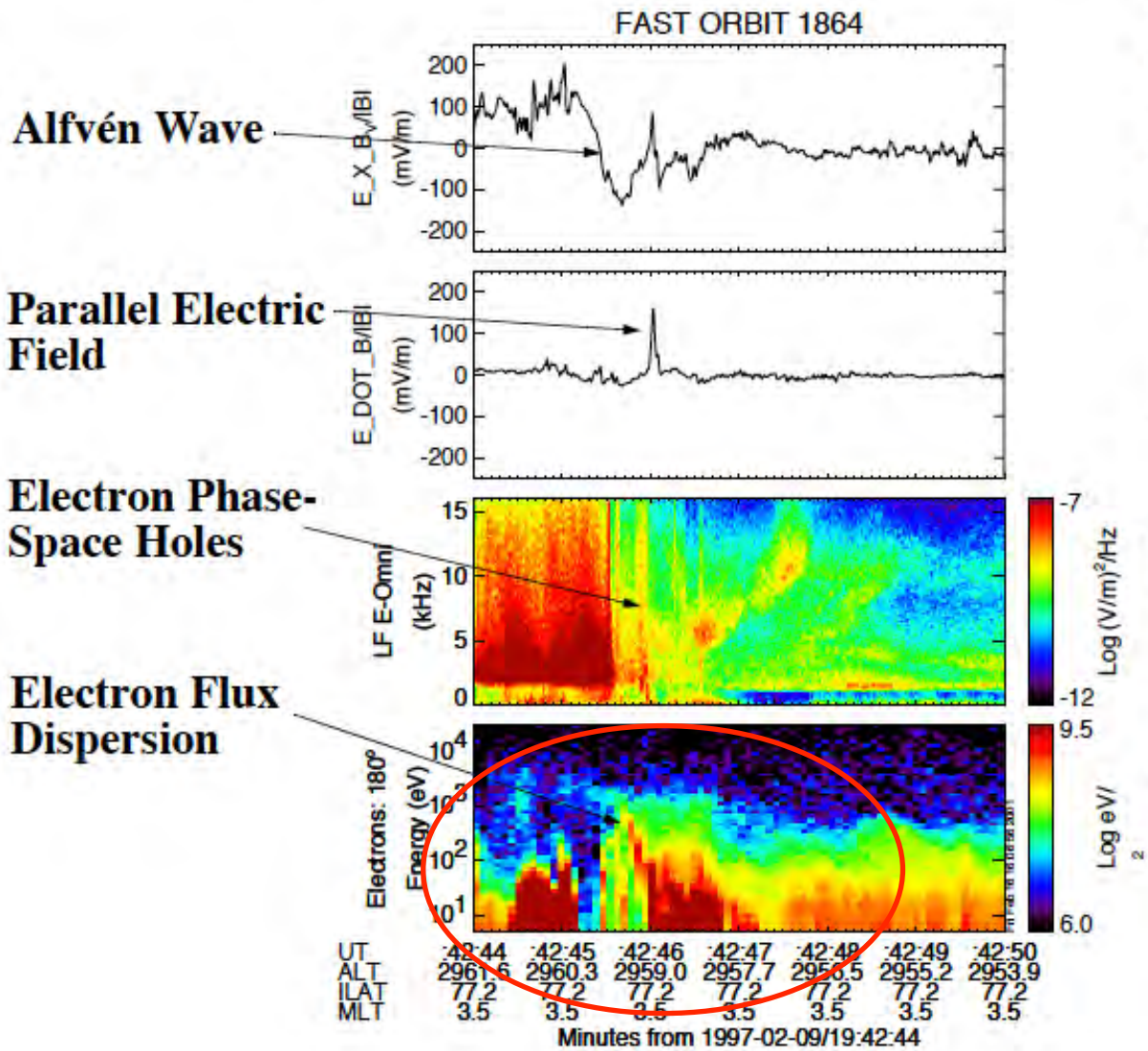
Density cavity may not be as deep – the densities at ~2 R_J are low to begin with.

Alfven Aurora

(1) Alfvén wave from inductive current ["Unipolar inductor", *Goldreich and Lynden-Bell*, 1969] and/or pick-up ions [e. g. *Combi et al.*, 1998].
(2) Pick-up ions exchange momentum with torus plasma resulting a few km/s sub-corotation. The torus momentum exchange takes ~8 minutes and extends for roughly 20 R_I (1/2 R_J).
(3) A large-scale current system extending for ~180° in Io's wake couples the torus plasma to Jupiter.



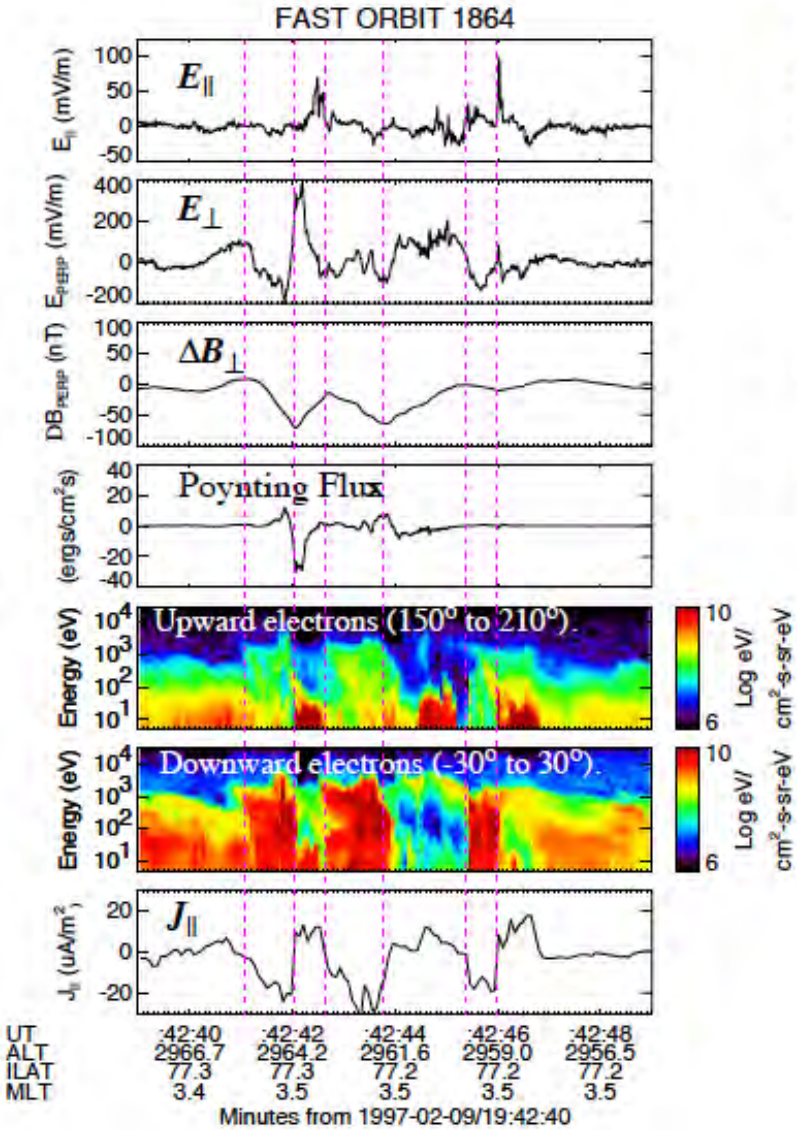
Alfven Aurora



The Alfvén-dominated region has some of the same features of the upward and downward current regions including:

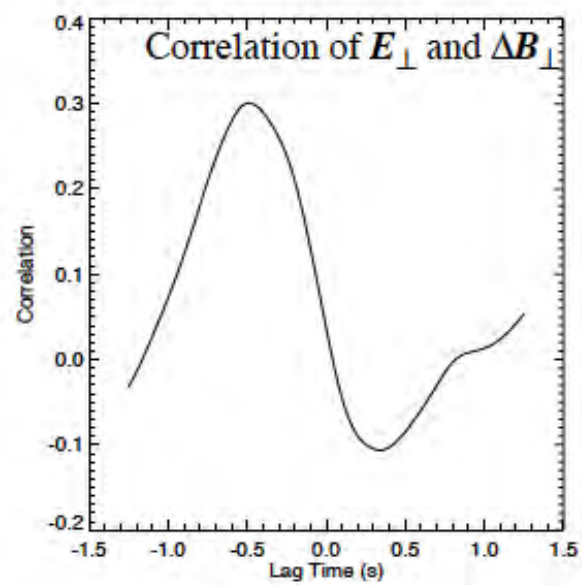
- Strong field-aligned electron fluxes in both directions (can result in very bright aurora).
- Highly filamented currents.
- Intense ion outflow.
- Strong whistler emissions, ion cyclotron waves, and electron phase-space holes.
- Parallel electric fields (not static).

Alfven Aurora

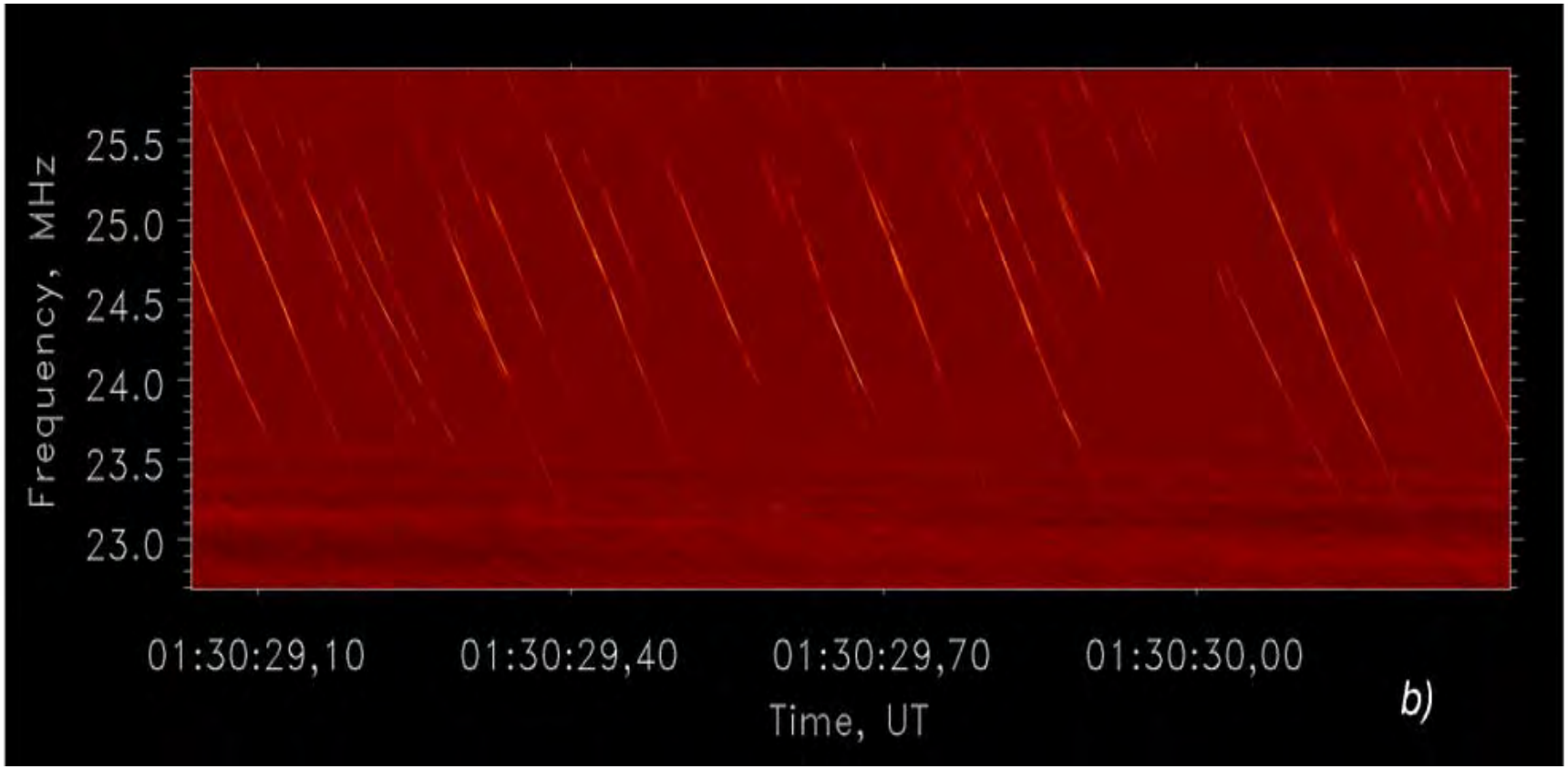


Alfvén Wave

- Electrons are organized by the slope of $\boldsymbol{B}_{\perp}$.
- The cross-correlation of $\boldsymbol{E}_{\perp}$ and $\boldsymbol{B}_{\perp}$ indicate a wave period of ~2 s.
- $\boldsymbol{E}_{\perp}$ and $\boldsymbol{B}_{\perp}$ are nearly out of phase indicating a possible standing wave (ionospheric resonator).
- Net Poynting flux is ~0 even though there are strong fluctuations.
- $\boldsymbol{B}_{\perp}$ is 'triangular' in shape resulting in a 'square wave' in $\boldsymbol{J}_{\parallel}$.
- $\boldsymbol{E}_{\parallel}$ is associated with high shear in the parallel current.

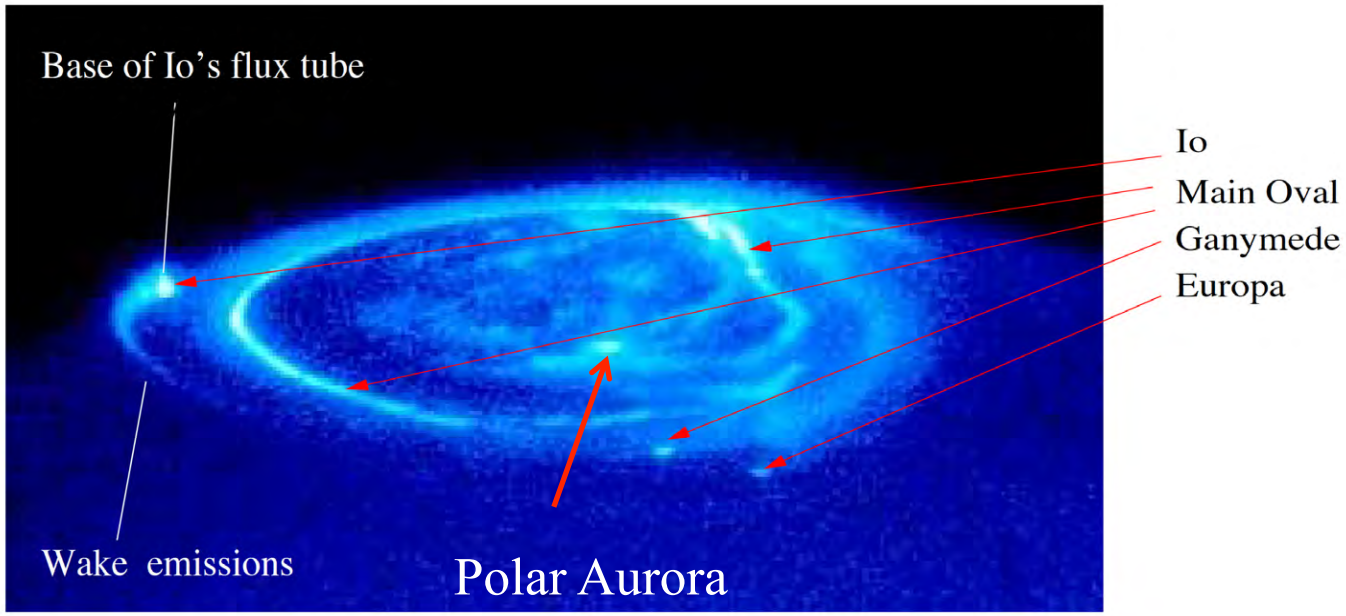


Alfven Aurora



The ionospheric resonator at Jupiter has a frequency of roughly 20 Hz (Earth is <1 Hz). The Doppler shift could be roughly the same order.

Acceleration Processes and Jupiter's Aurora

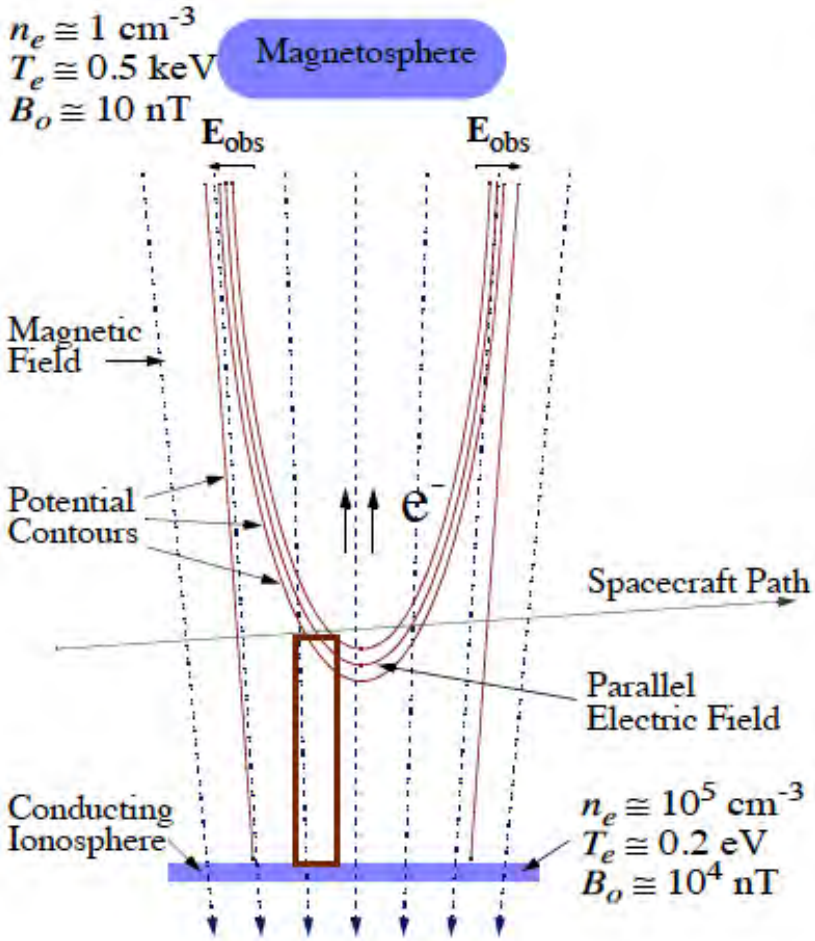


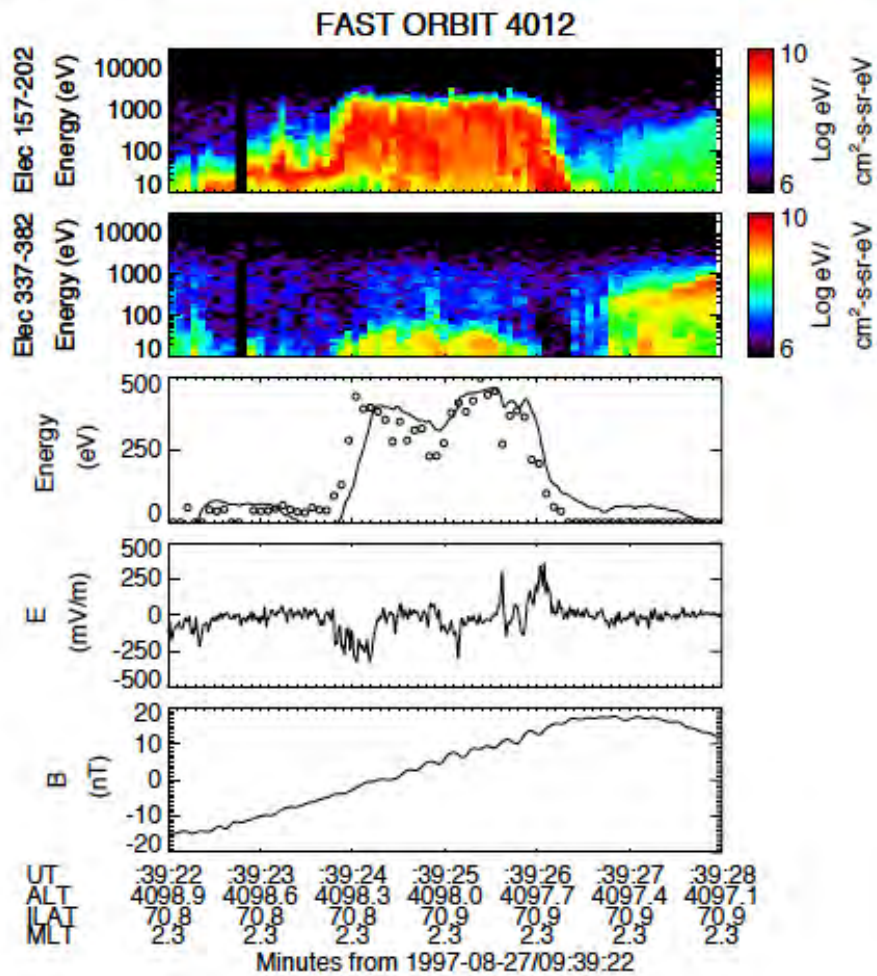
Upward Current Region: Main Oval; Io Wake Region: Most Polar Aurora

Alfven Aurora: Io Spot; Polar Aurora Boundaries; Dark Region?

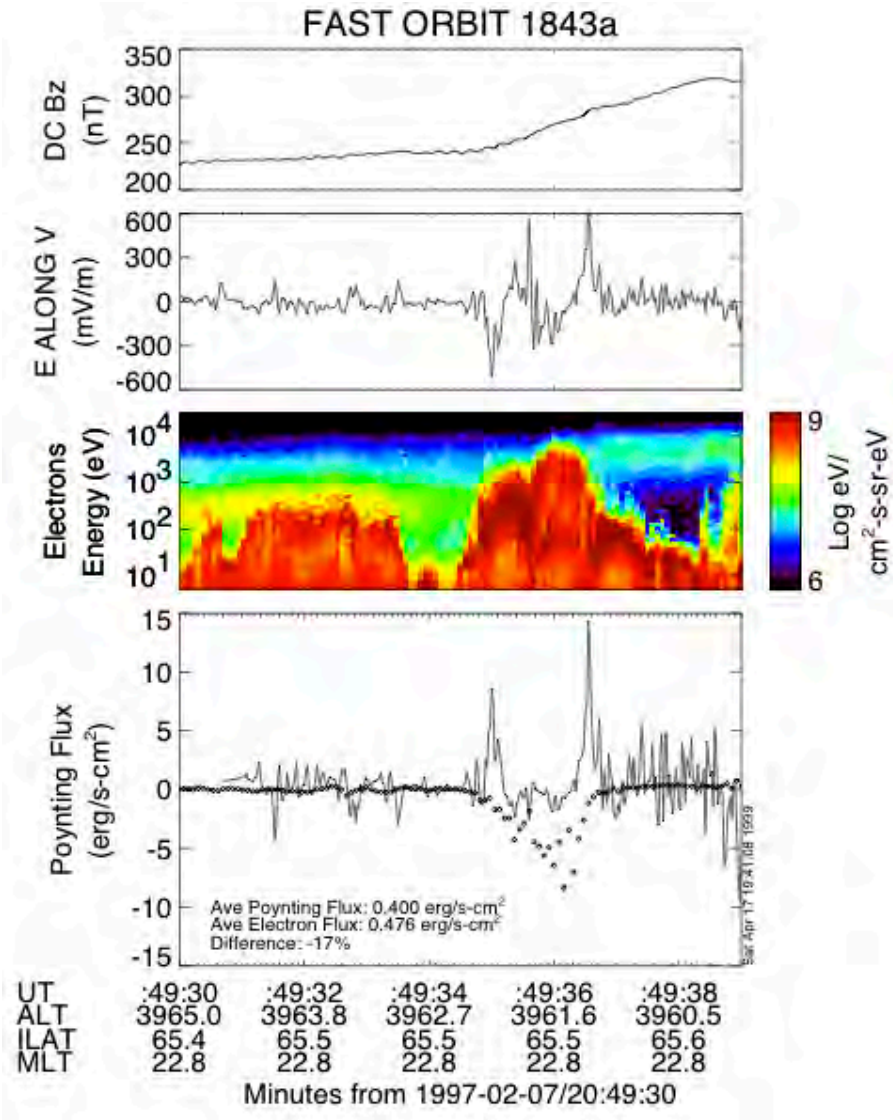
Downward Current Region: Dark Region?

Downward Current Region: Where is it?



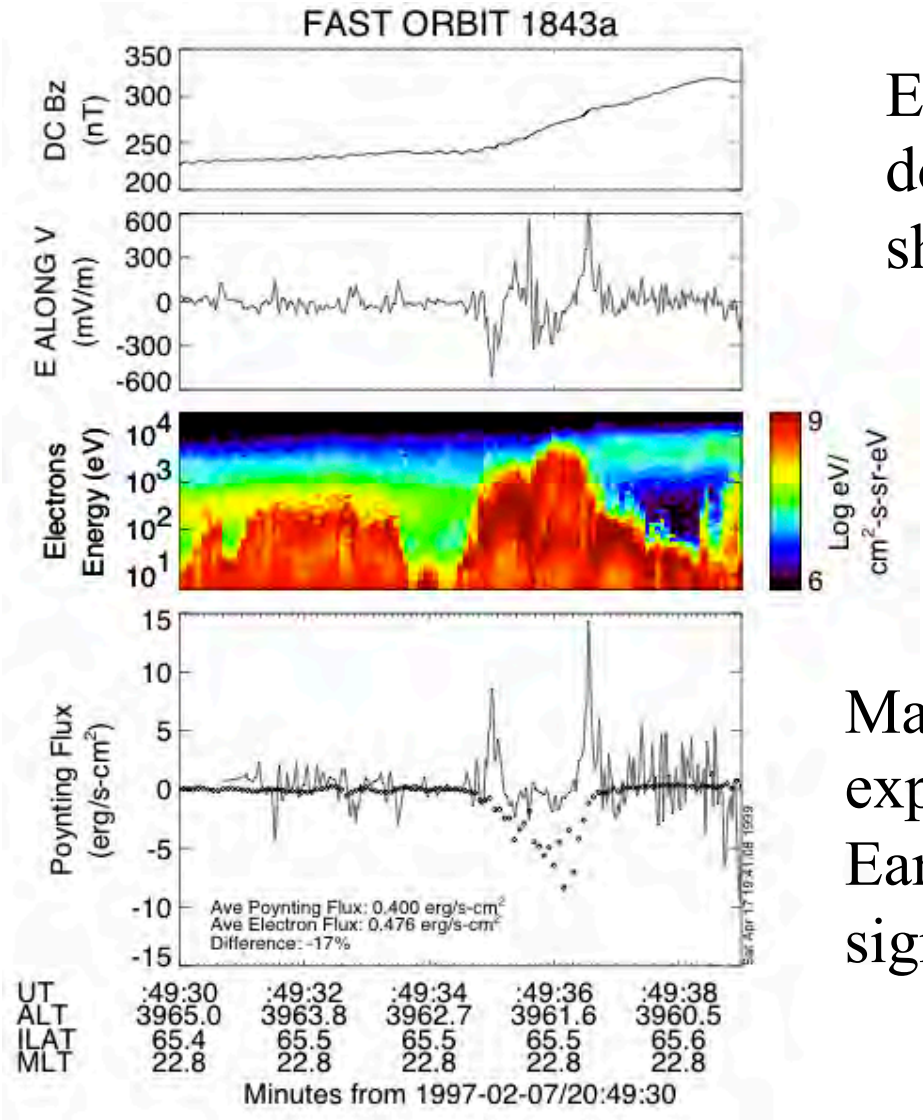


Downward Current Region: What to Look For



(1) Anti-Jovian accelerated electrons: field-aligned and broader energy.
(2) Strong wave activity
(3) Parallel electric fields (double layers).
(4) Perpendicular electrostatic shocks (diverging).
(5) Ion conics.

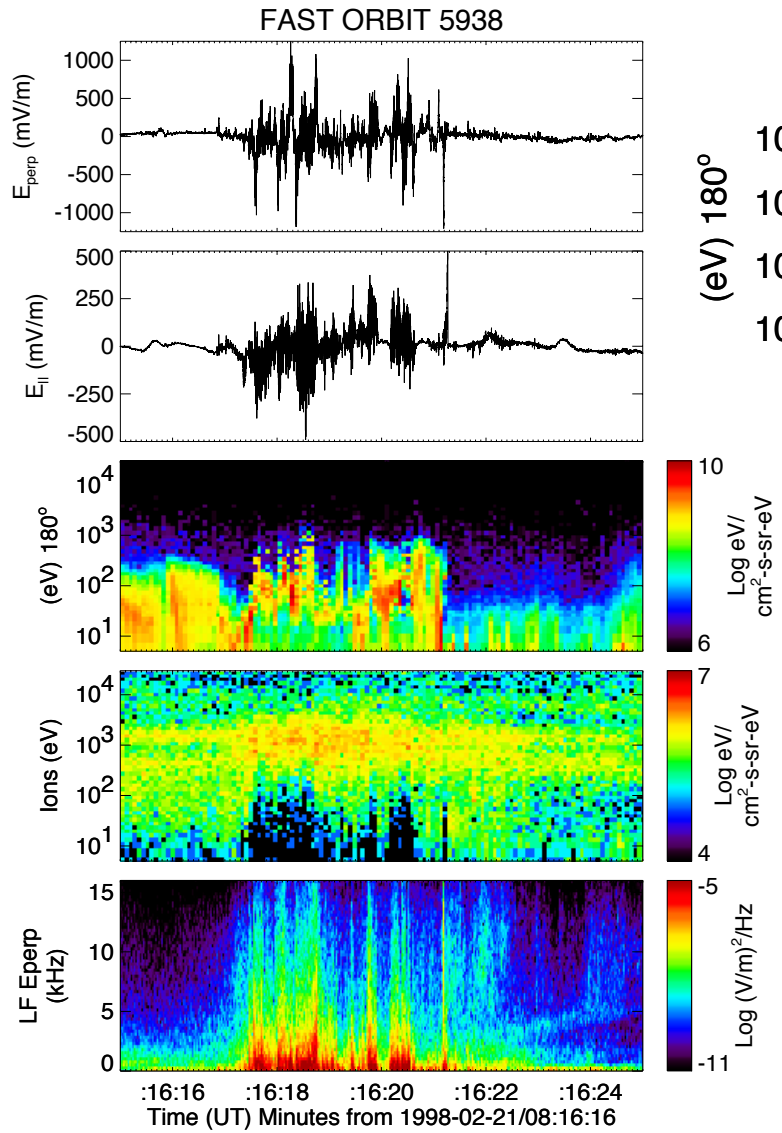
Downward Current Region: Magnetic Field

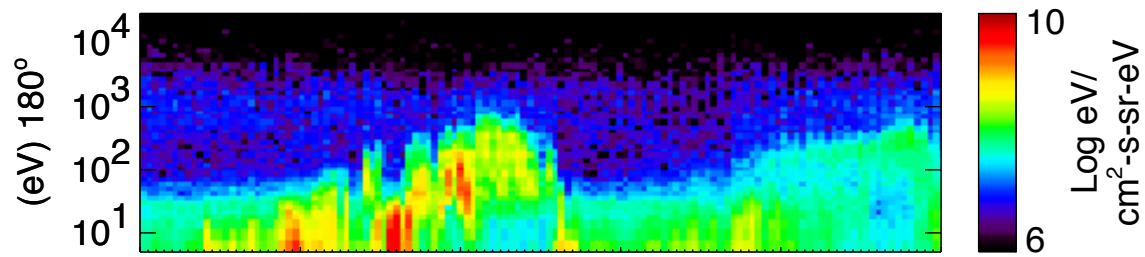


East –West DB indicates downward current. Amplitudes should be similar.

Magnetic field deflections are expected to be the same as at Earth. The time scale will be significantly faster.

Downward Current Region: Electrons





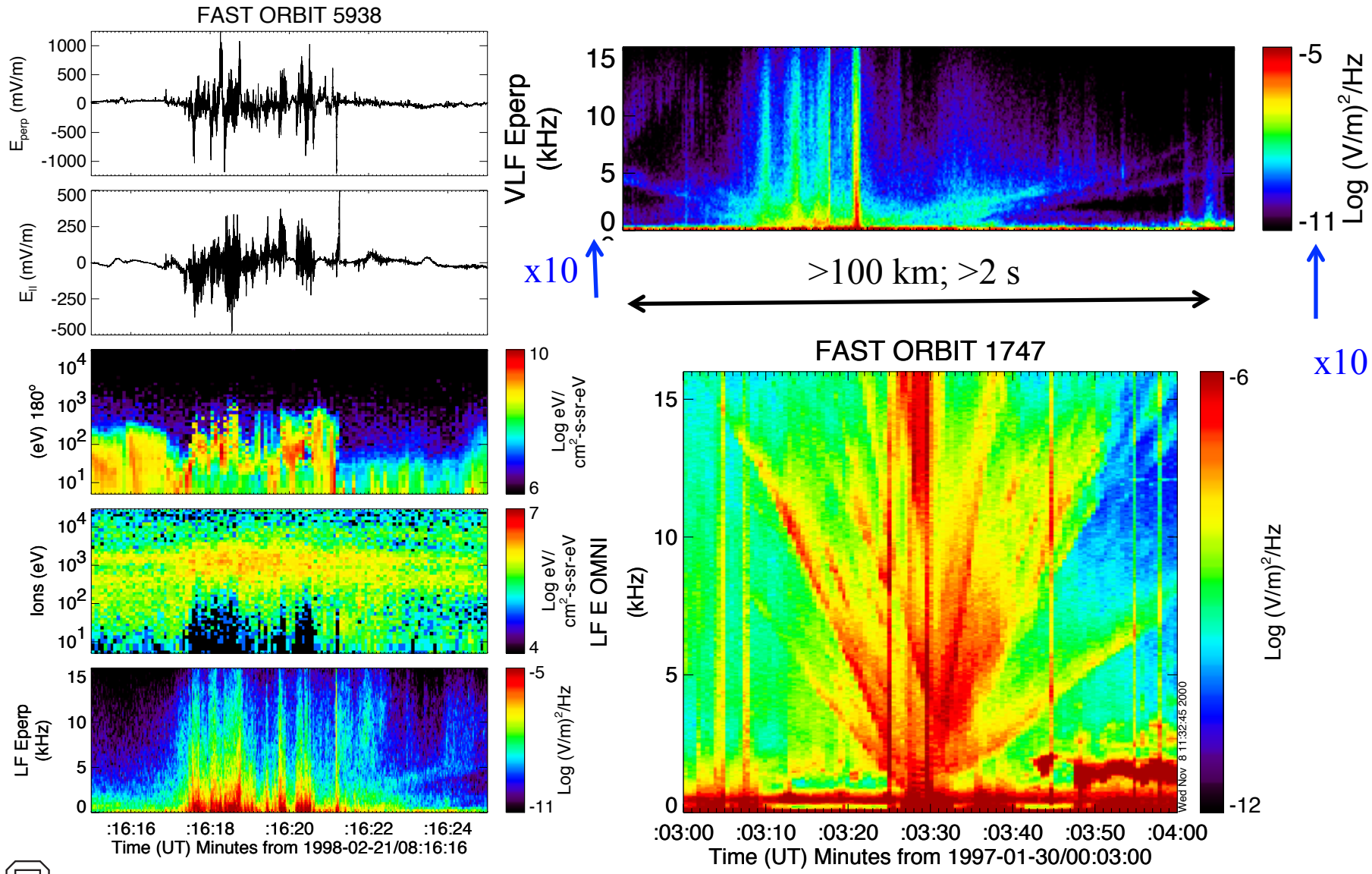
~50 km; 1 s

???

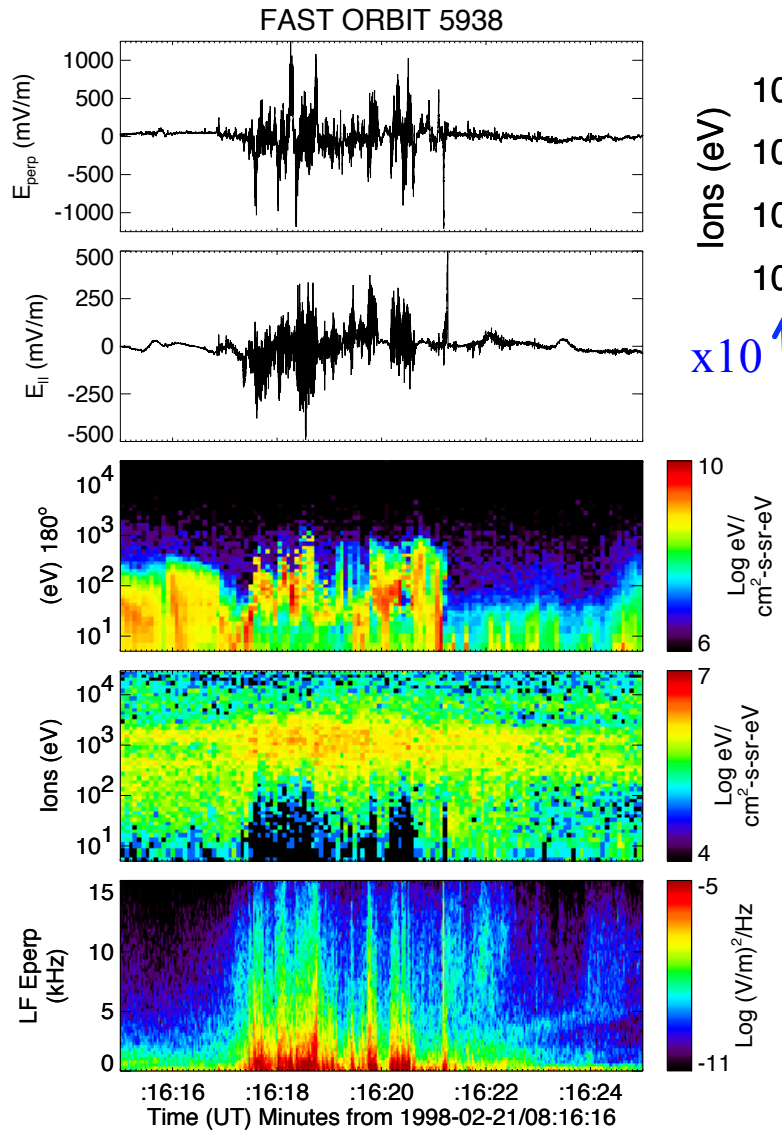
About the same

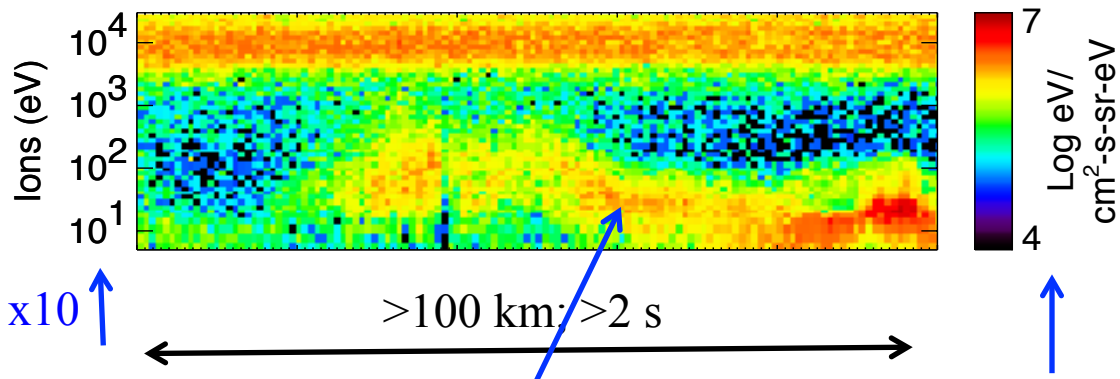
Anti-Jovian, field-aligned electron beams. Broad energy.

Downward Current Region: Waves



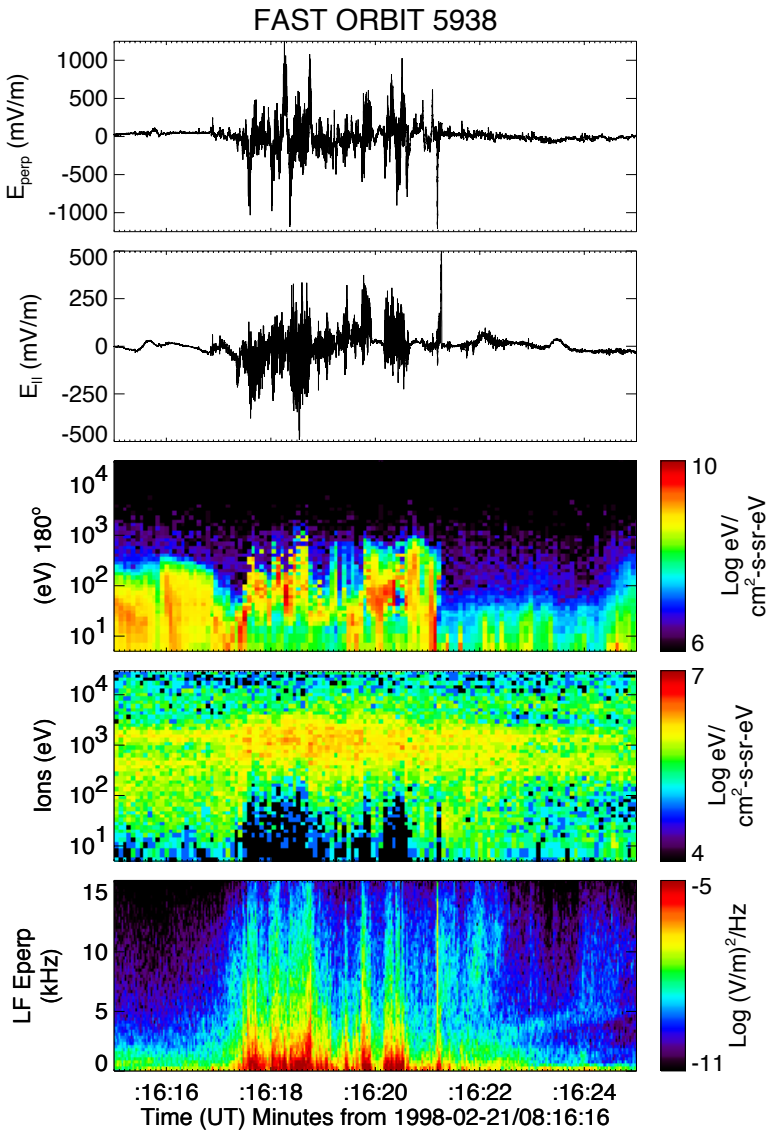
Downward Current Region: Ions

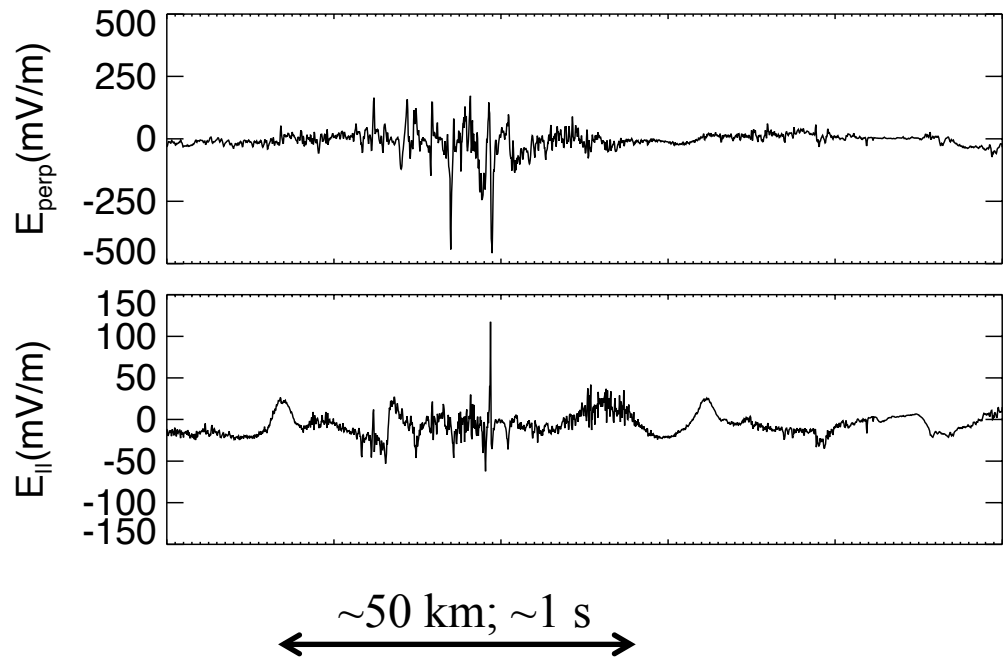




Ion conics?

Downward Current Region: Electric Fields





Electric field amplitudes should be considerably larger and, depending on boundary layer thickness, much faster time scale.

Conclusions

Main Oval/Io Tail: Upward Current Region

(1) East-West Magnetic Field
(2) Electrostatic Shocks (Converging)
(3) Accelerated Electrons. Nearly mono-energetic with broad pitch angles.
(4) Anti-Jovian Ion Beams
(5) Density Cavity?
(6) Strong Wave Activity.
(7) Parallel Electric Fields.

Ion Spot (if we are so lucky): Alfven Aurora

(1) Strong Magnetic Field Fluctuations
(2) Strong, Spiky Electric Fields
(3) Bi-Directional Field-Aligned Electrons (Broad Energy)

Conclusions

Somewhere: Downward Current Region

(1) East-West Magnetic Field

(2) Anti-Jovian Accelerated Electrons. Field-aligned with broad energy.

(3) Strong Wave Activity. VLF saucers.

(4) Ion Conics

(5) Electrostatic Shocks (Diverging)

(6) Parallel Electric Fields.

Polar Cap: Alfven/Upward/Downward

(1)All of the Above.