Heating and Transport at the Magnetopause Associated with Kinetic Alfvén Waves

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Princeton University

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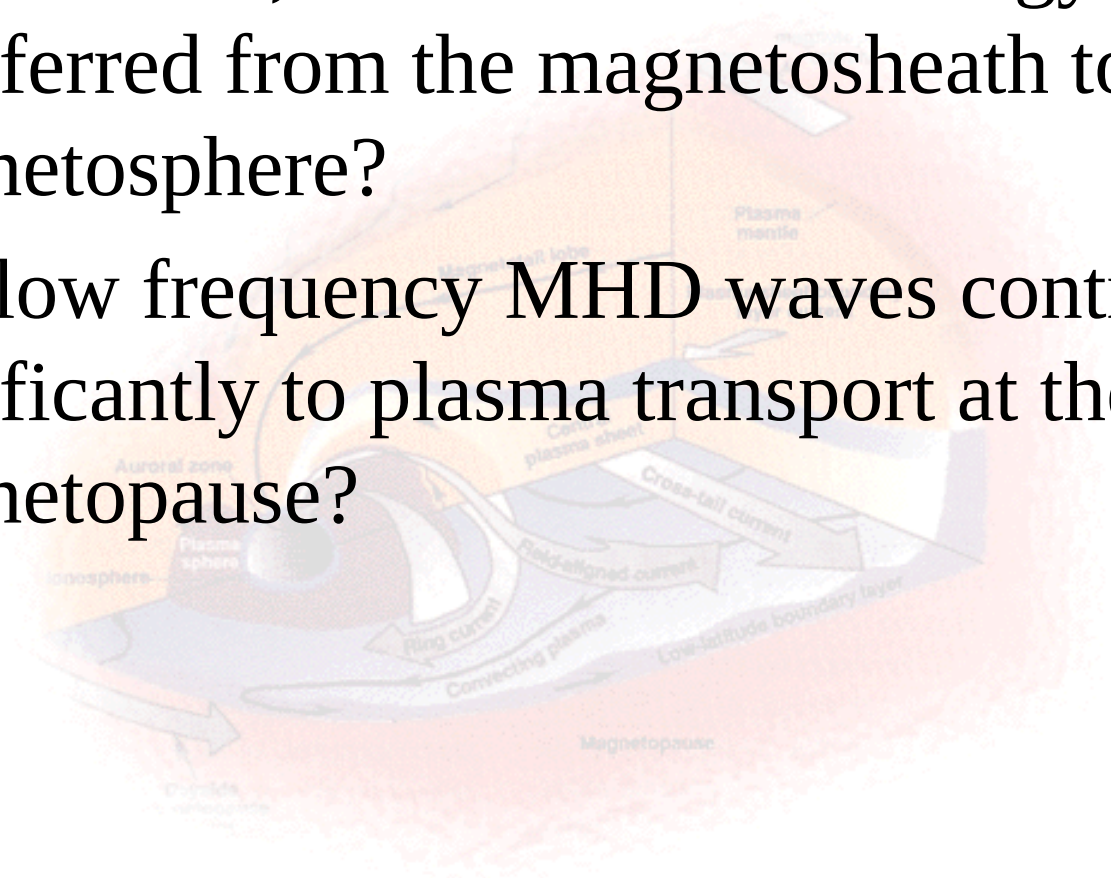
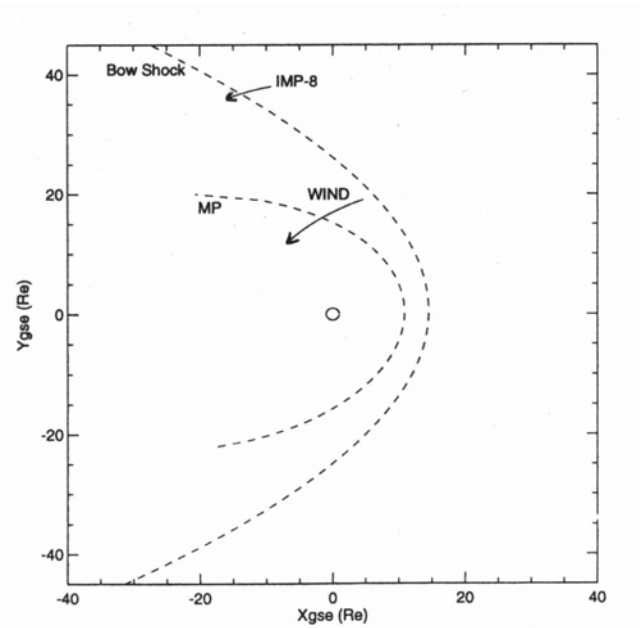
PPPL
PRINCETON PLASMA PHYSICS LABORATORY

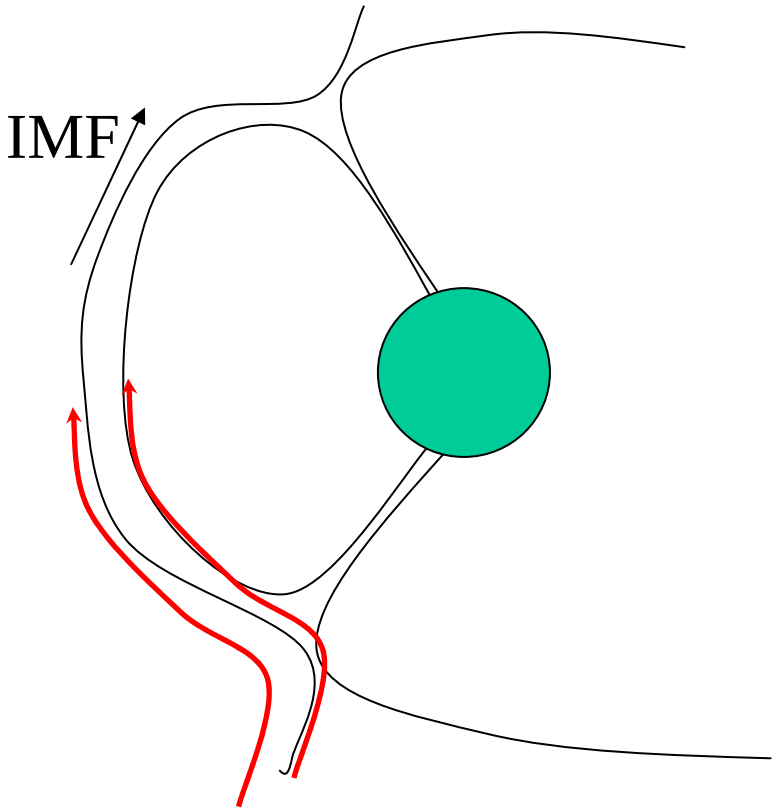
Outstanding Issues

- How is mass, momentum and energy transferred from the magnetosheath to the magnetosphere?
- Can low frequency MHD waves contribute significantly to plasma transport at the magnetopause?



Transport at the Magnetopause due to Reconnection





Transport at the Magnetopause due to Reconnection

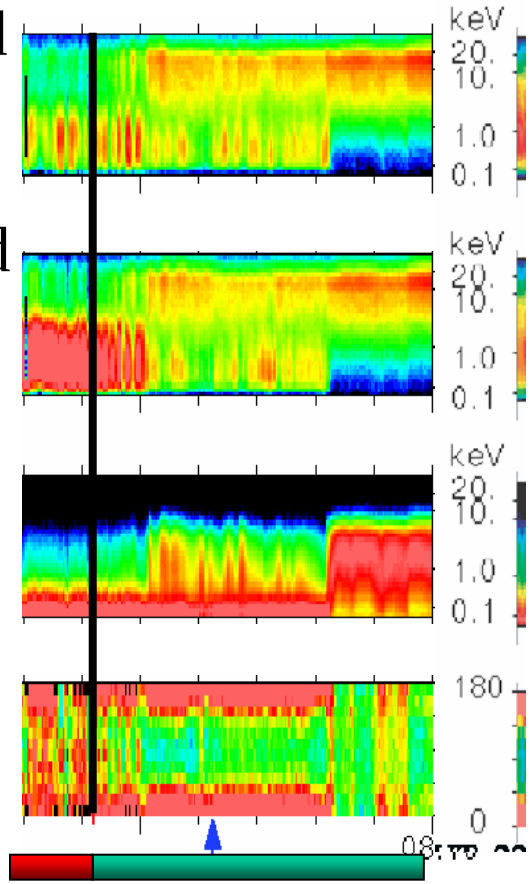
8/24/96 10-11UT

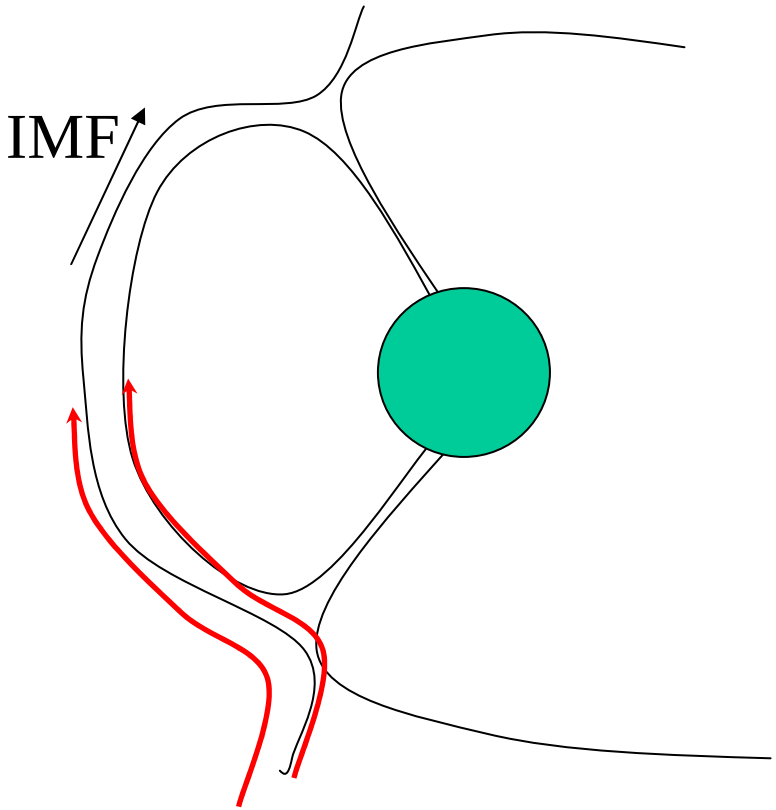
Sunward Ions

Tailward Ions

Electron Energy

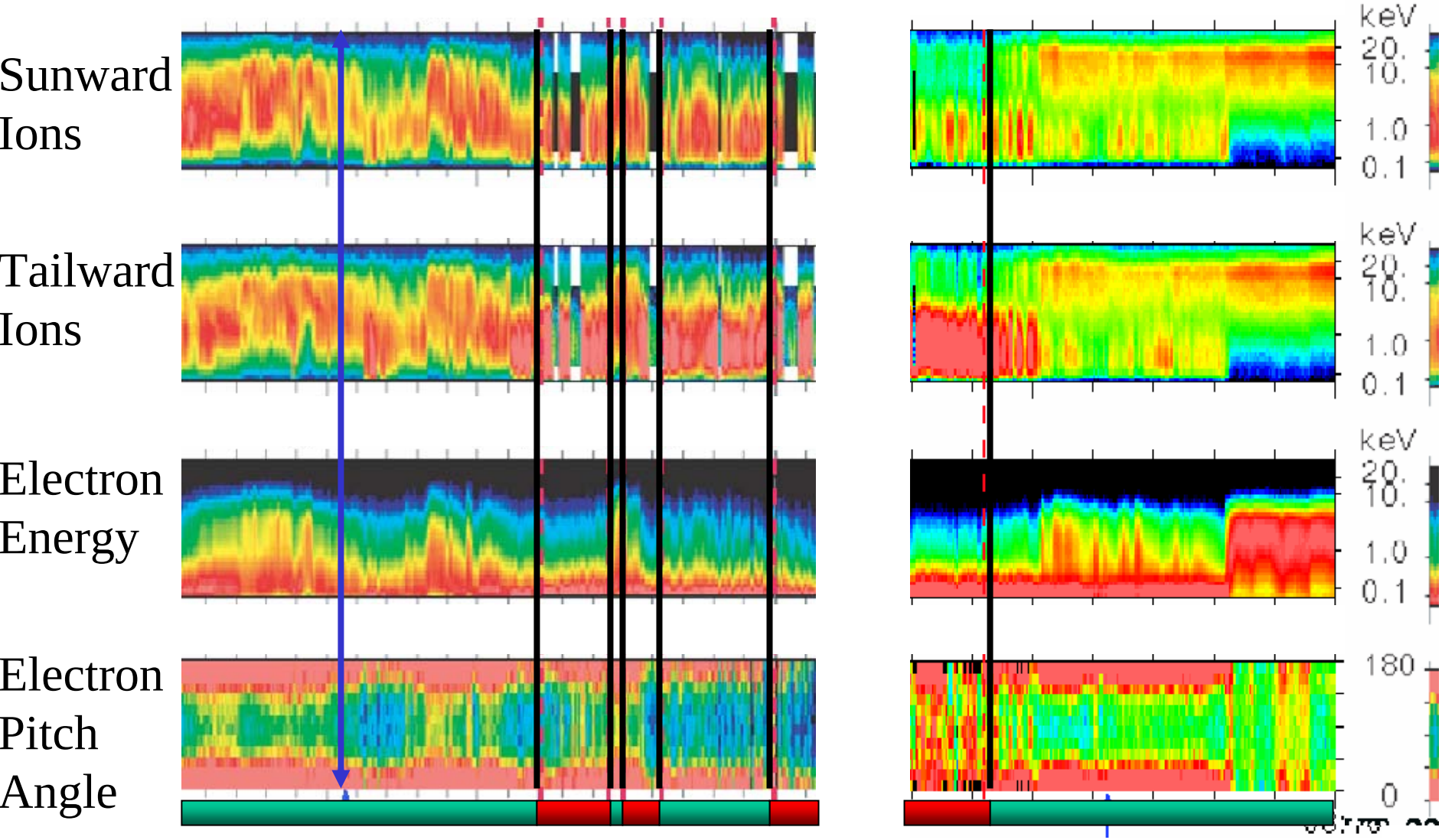
Electron Pitch Angle





a) Dawn: 2/26/97 22-24UT

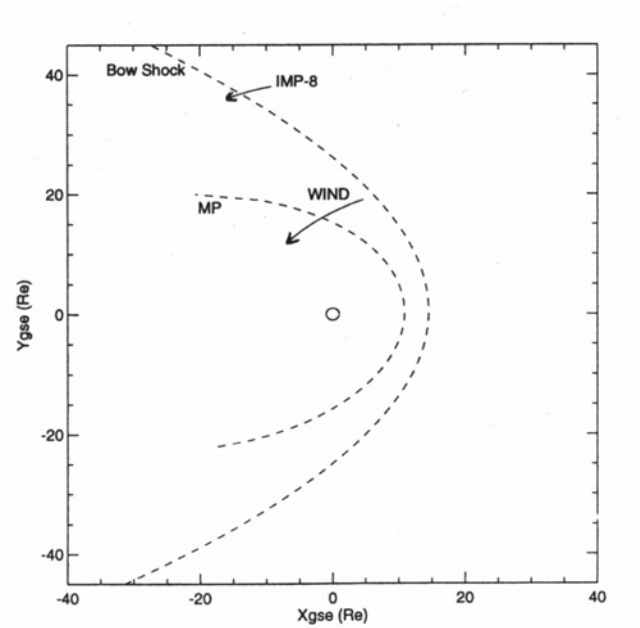
b) Dusk: 8/24/96 10-11UT

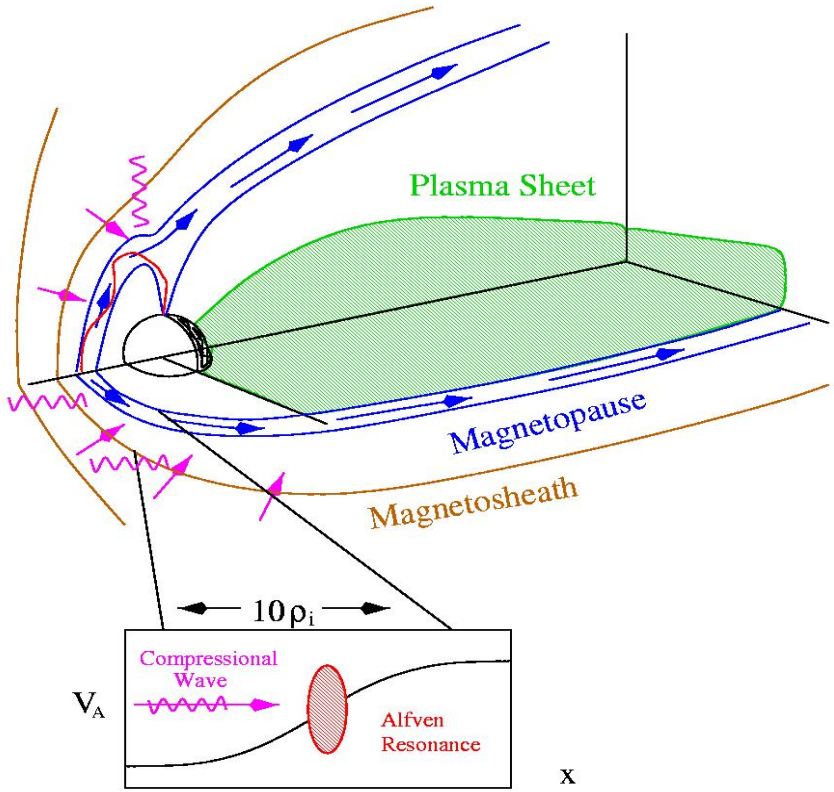


LLBL

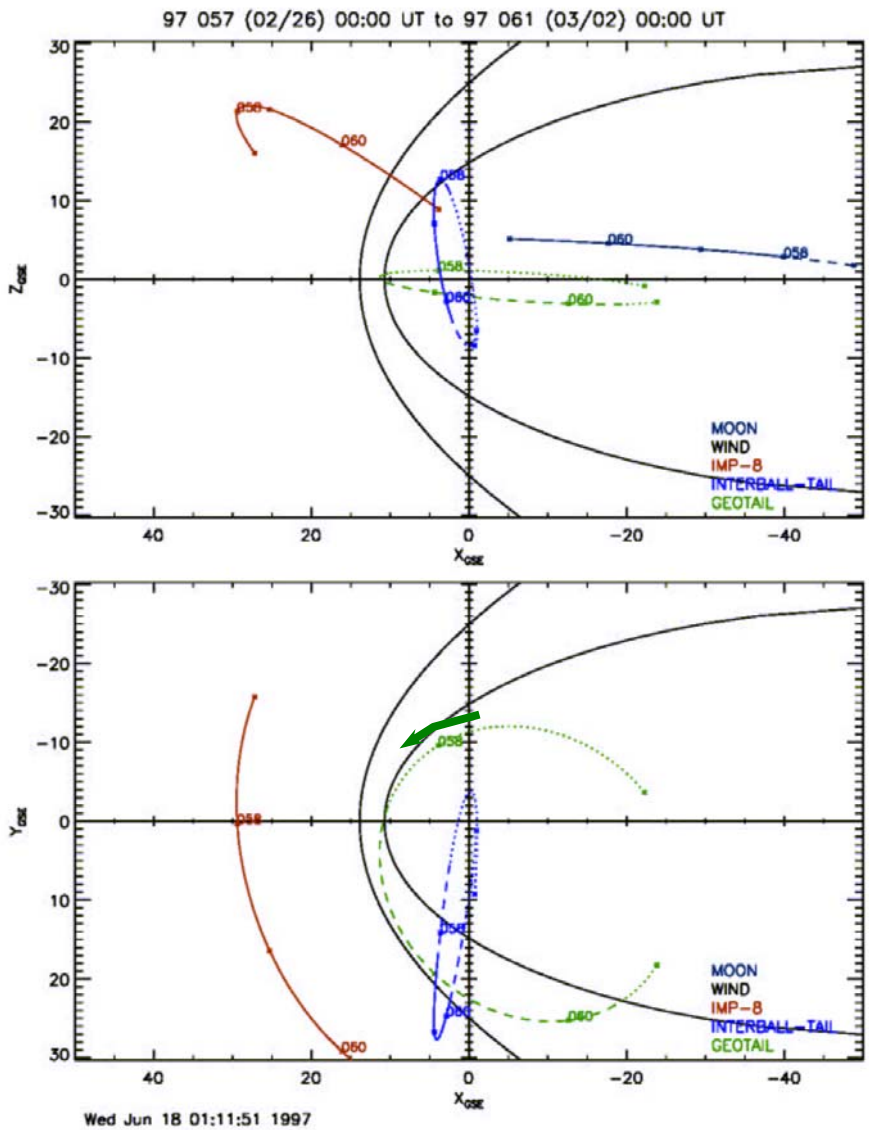
Magnetosheath

Transport at the Magnetopause due to Waves



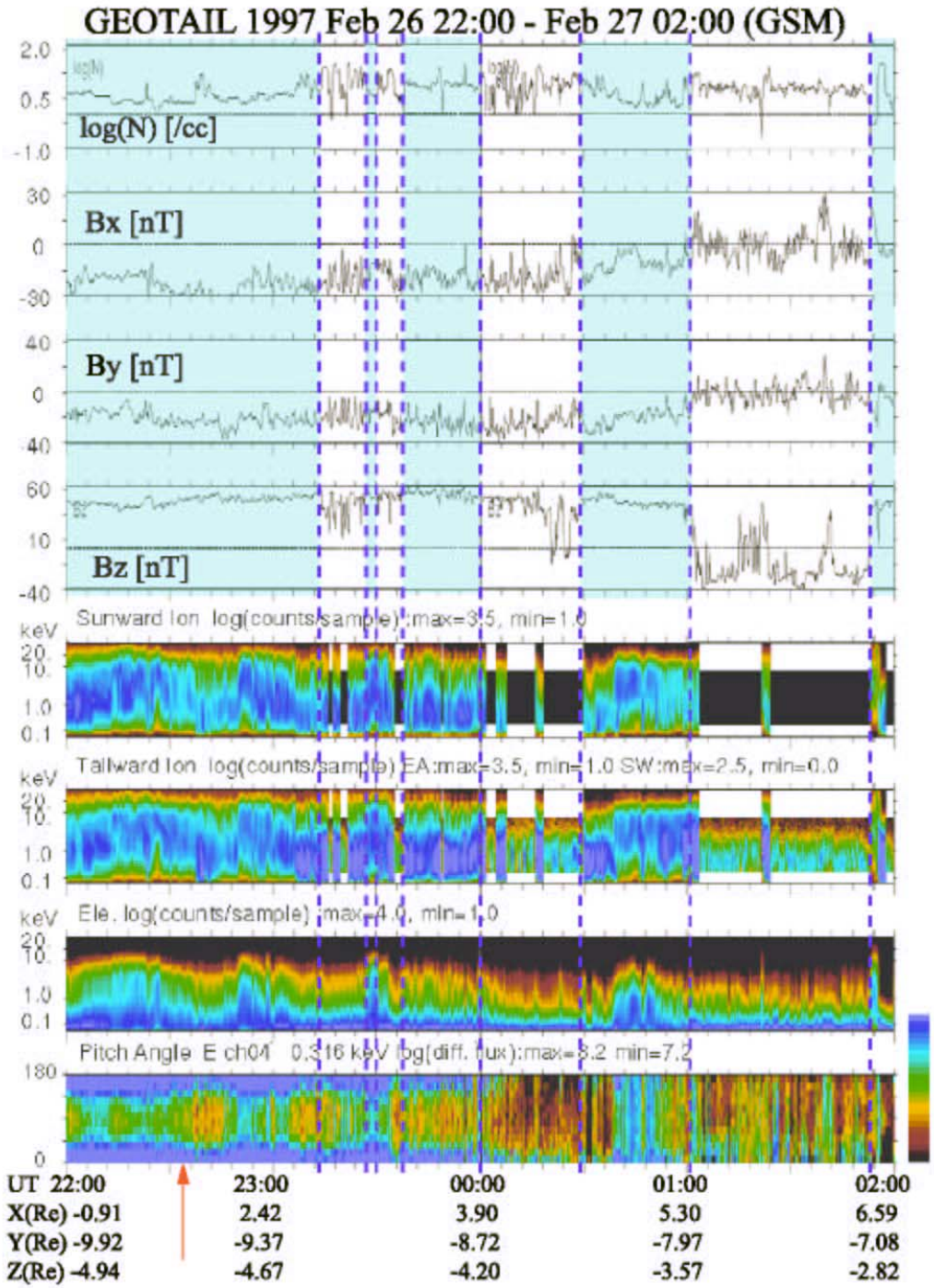


Geotail---Feb 26, 1997



GEOTAIL Magnetopause Crossing

- Dawnside LLBL to dayside magnetosheath



[Hasegawa et al., 2003]

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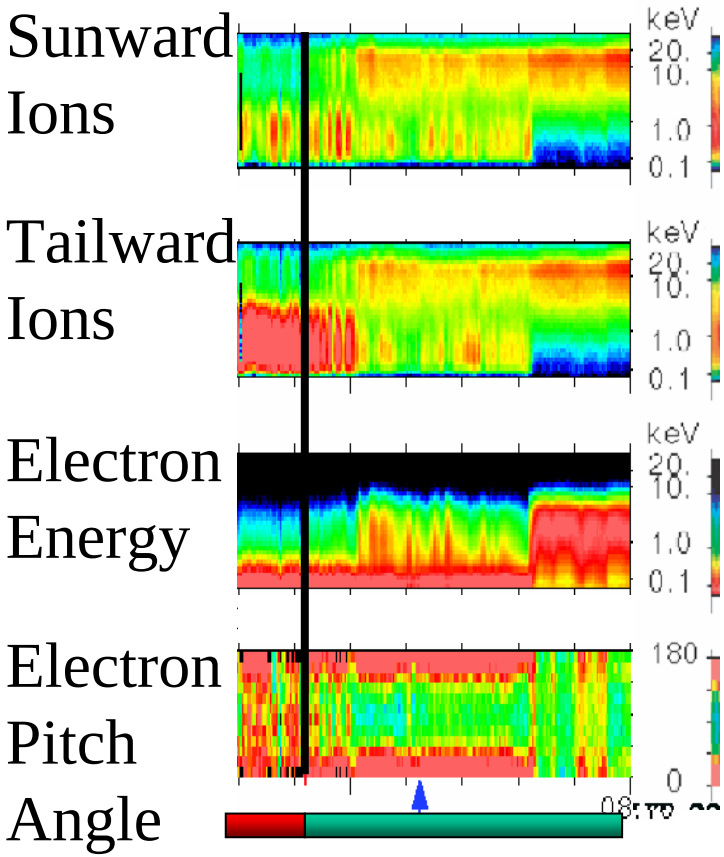

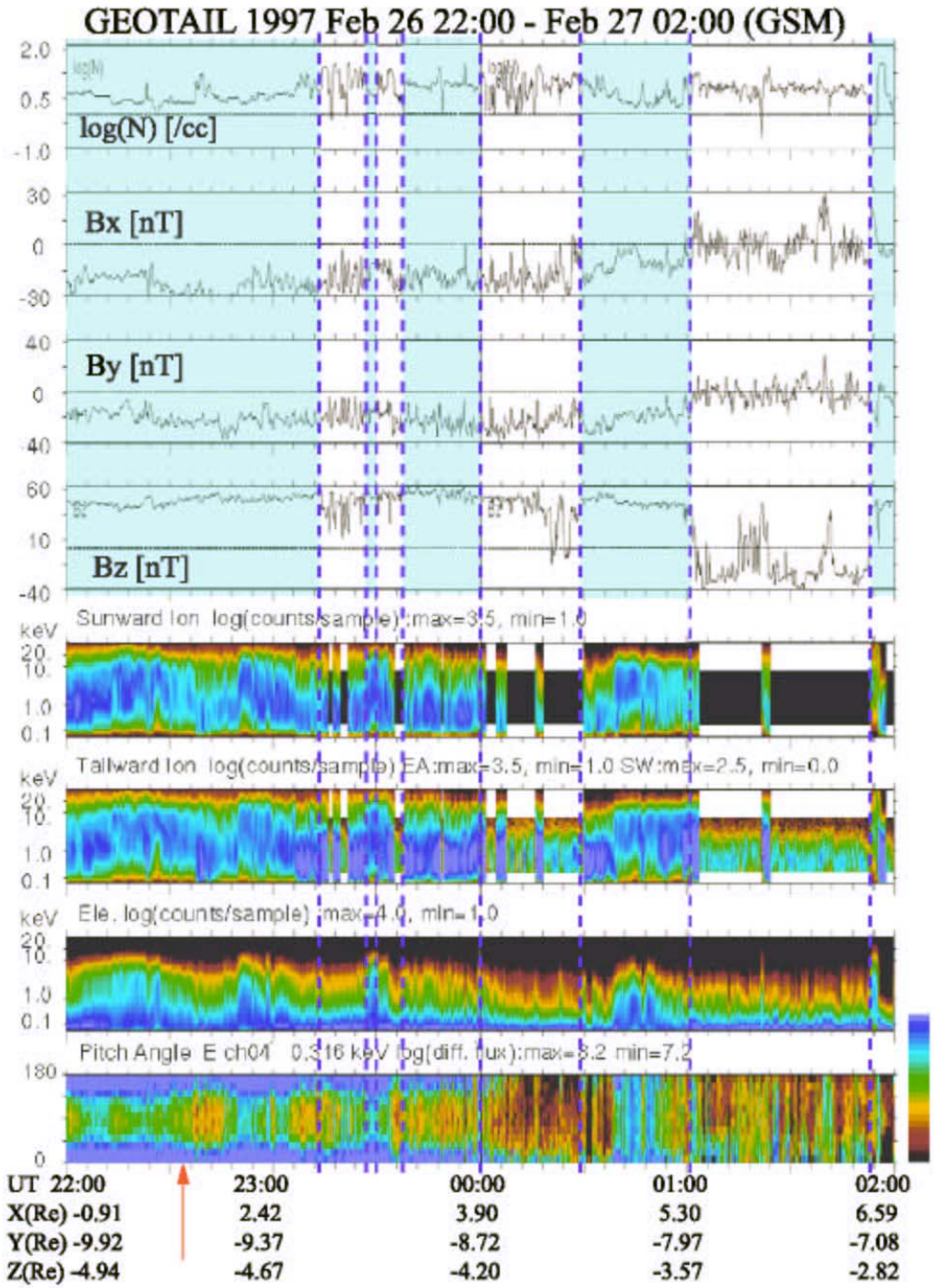

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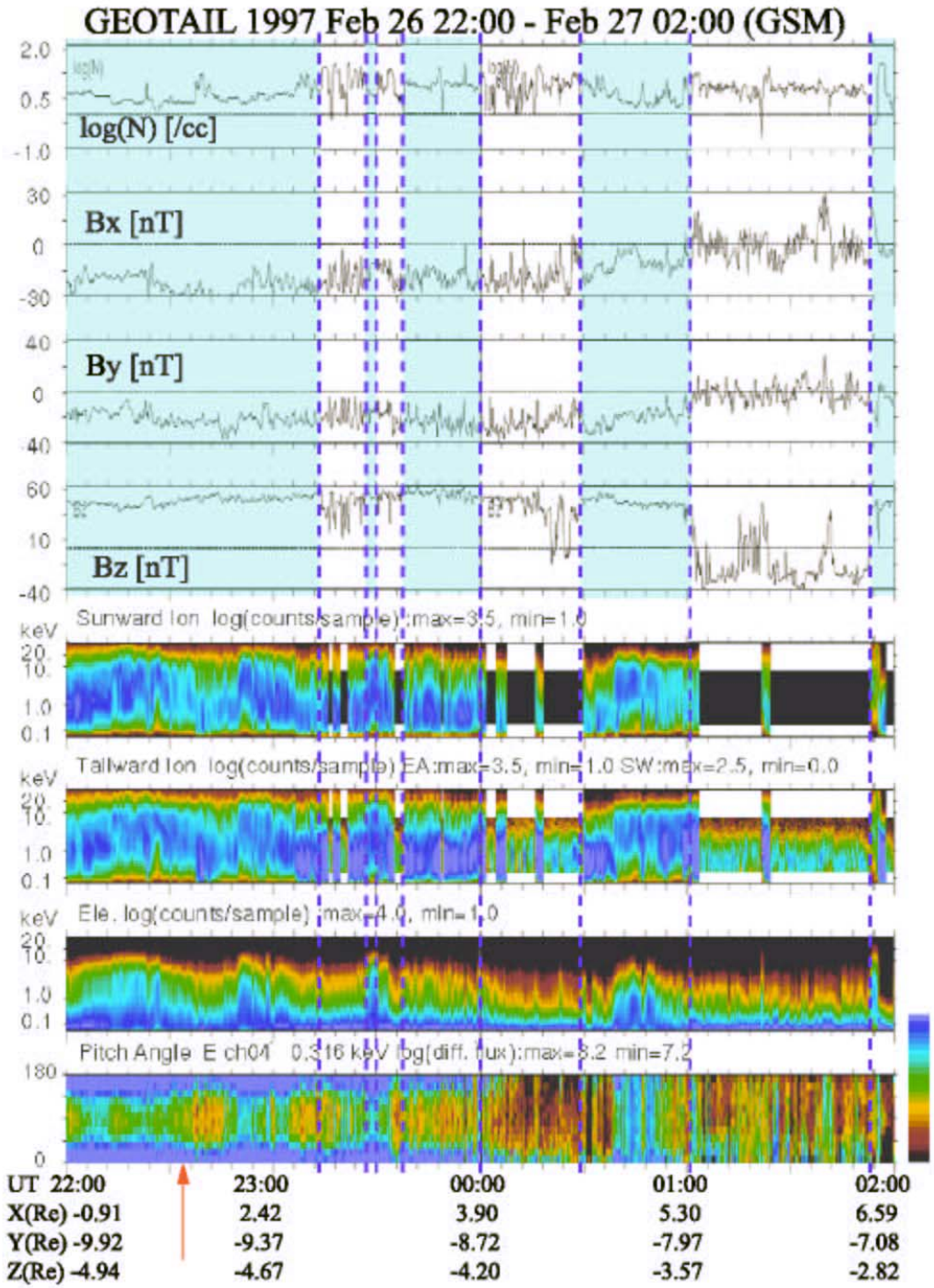

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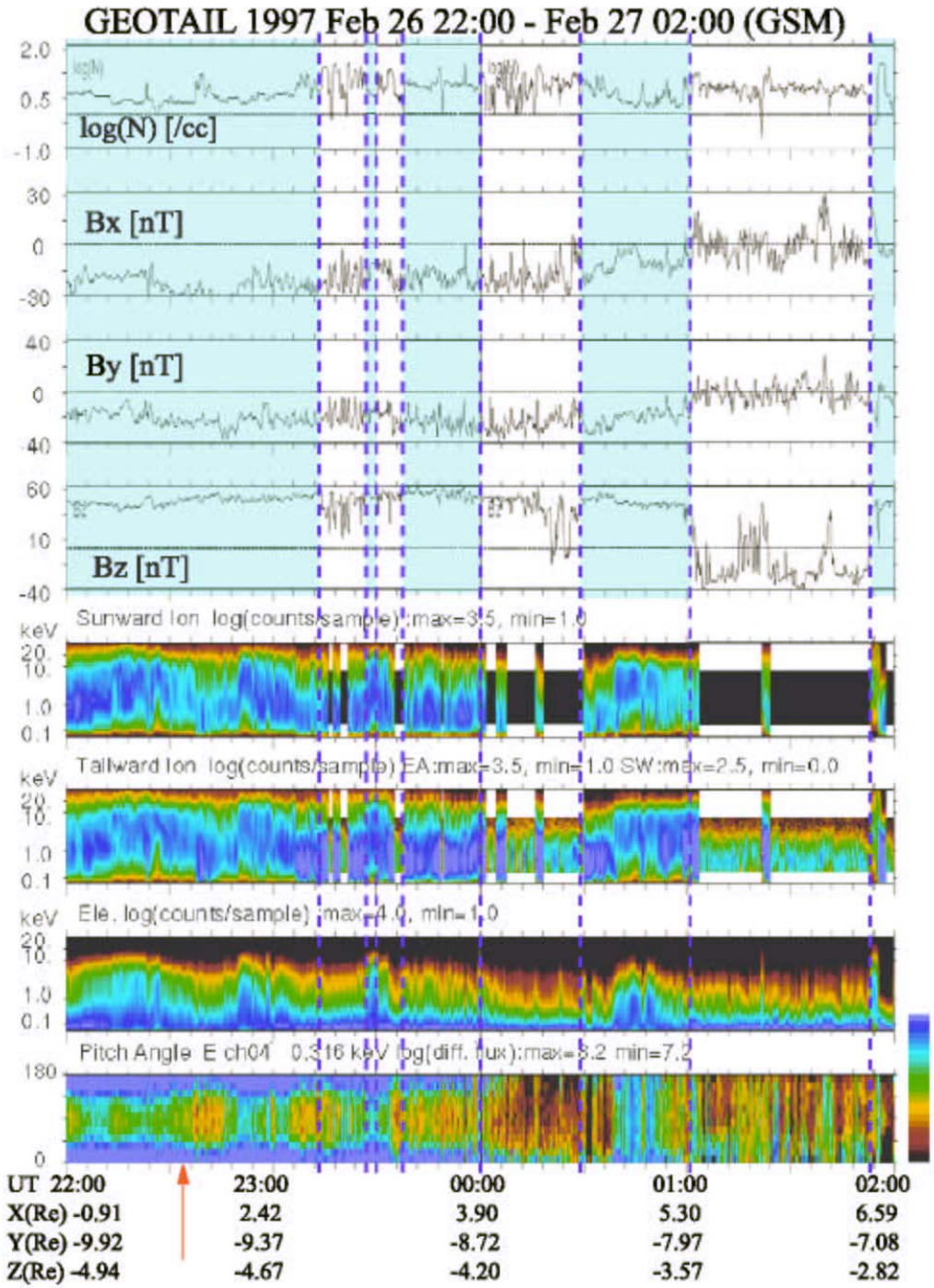
  - ➢ indistinct from sheath ions



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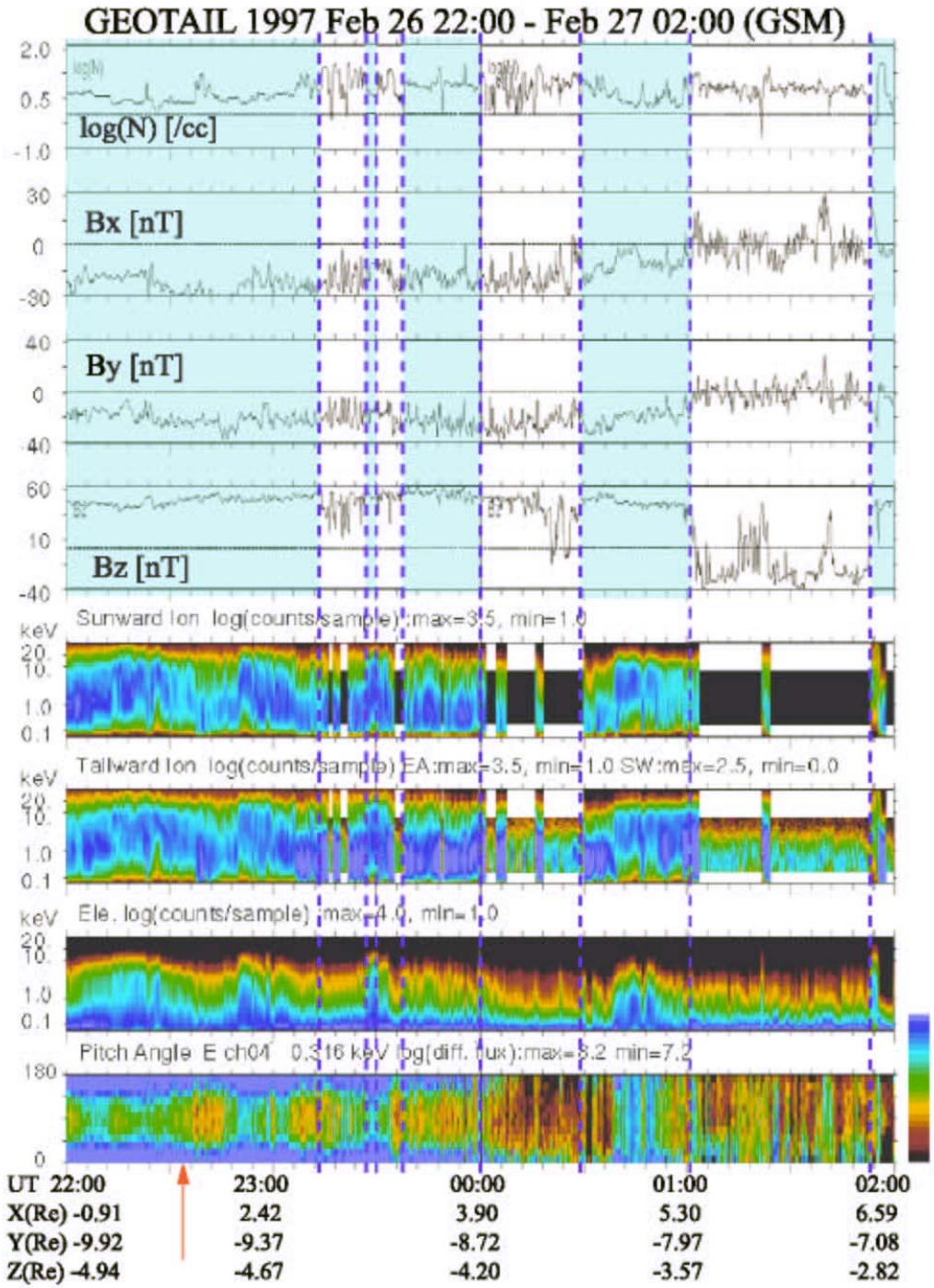

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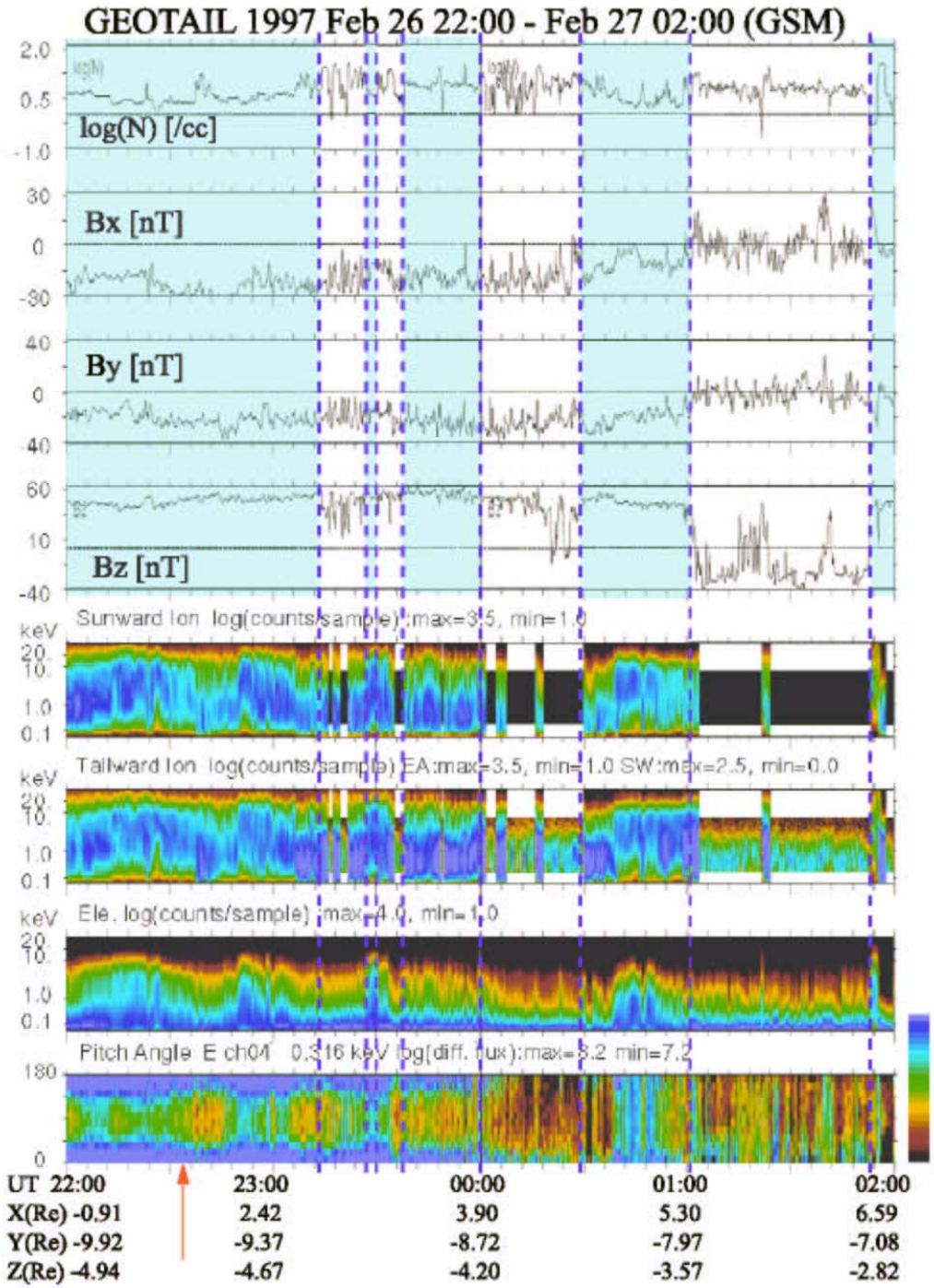
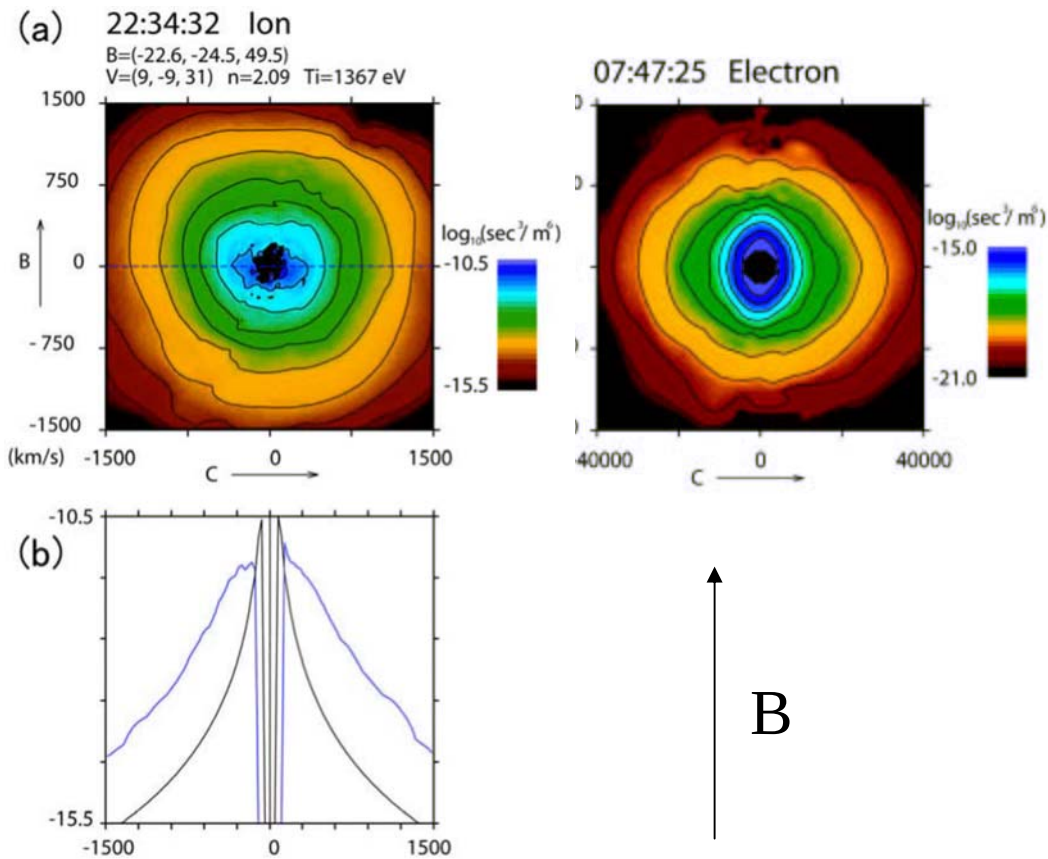
- Large Compressional Fluctionations in Sheath

[Hasegawa et al., 2003]



Particle Distributions

- Ions
  - Low energy: anisotropic
  - High energy: isotropic
  - No distinct populations



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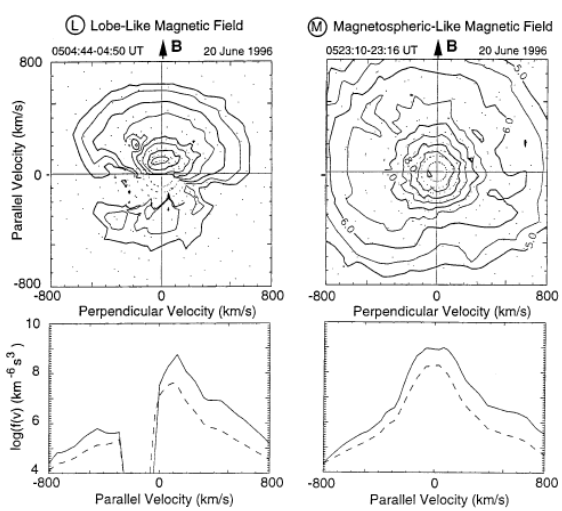

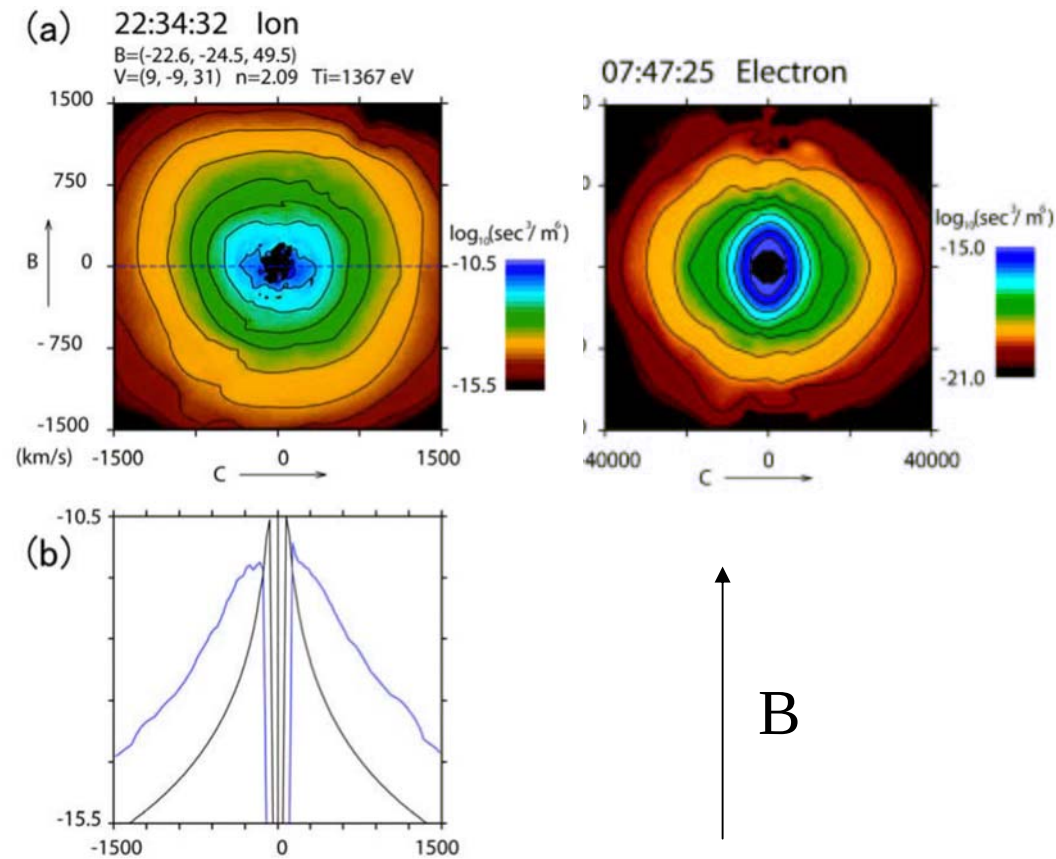

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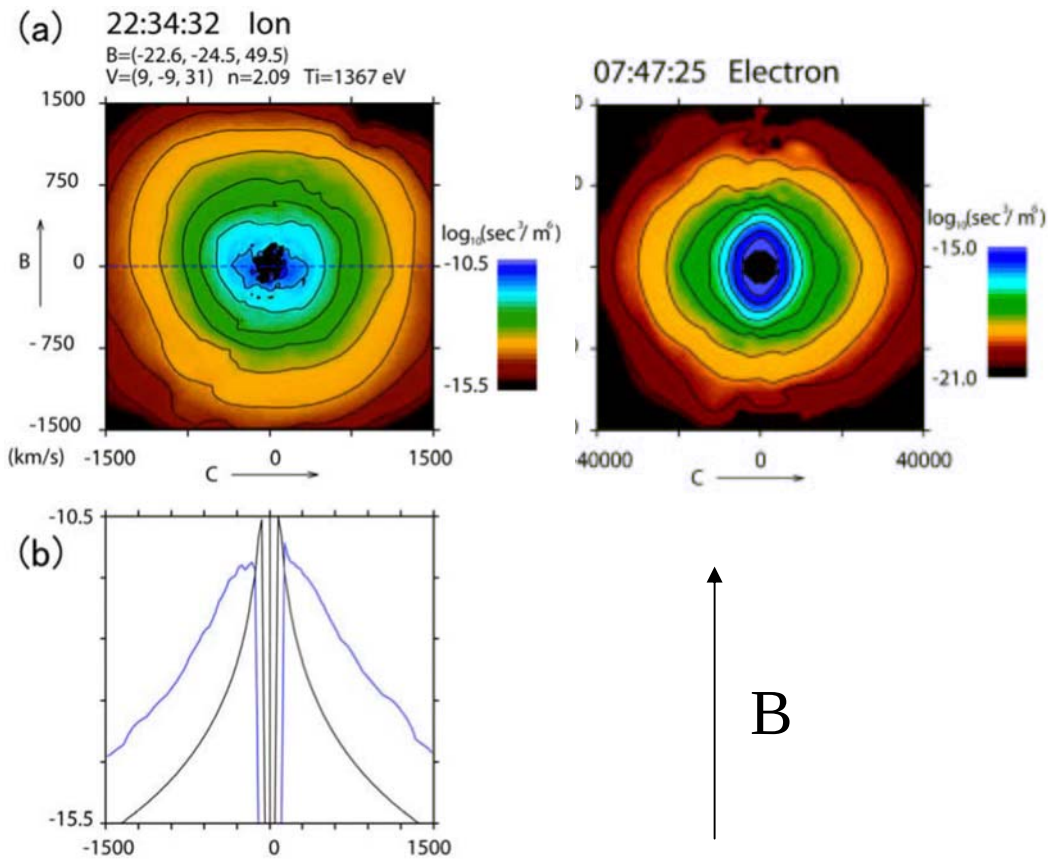

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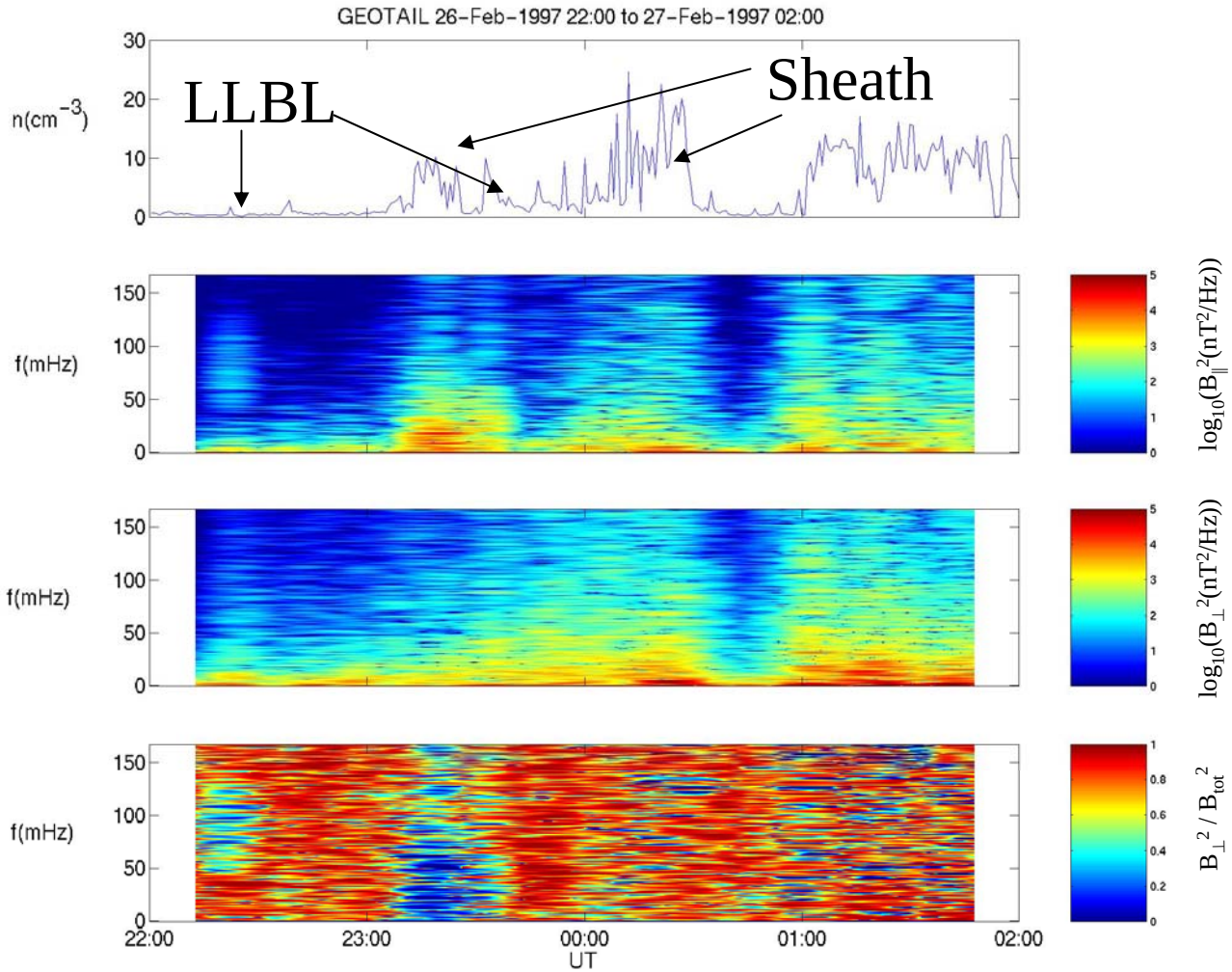
Wave Spectrum

Density

Compresional Spectrum

Transverse Spectrum

Fraction Transverse



GEOTAIL magnetic field data (and/or plasma data) were provided by S. Kokubun and T. Mukai through DARTS at the ISAS in Japan

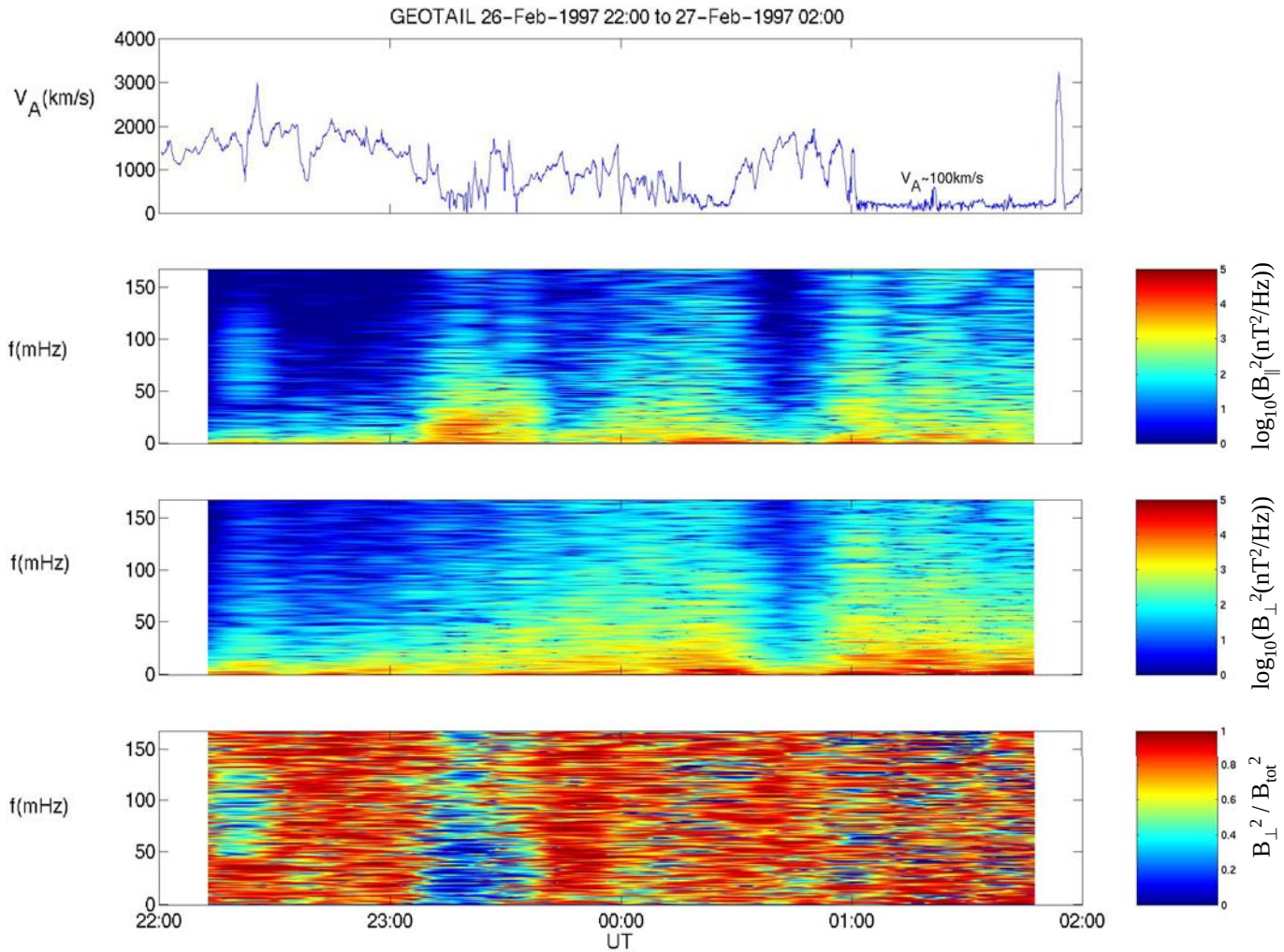
Steep Alfvén Velocity Gradients

Alfven Velocity

Compresional Spectrum

Transverse Spectrum

Fraction Transverse



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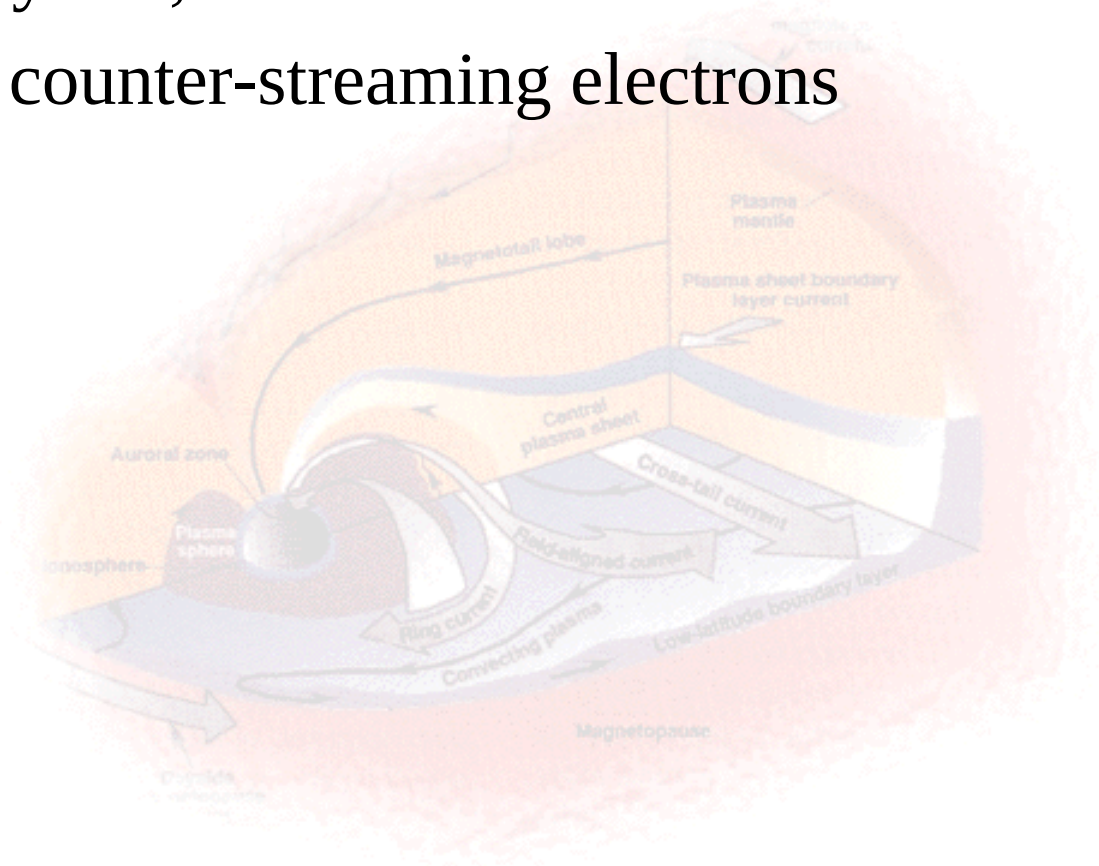

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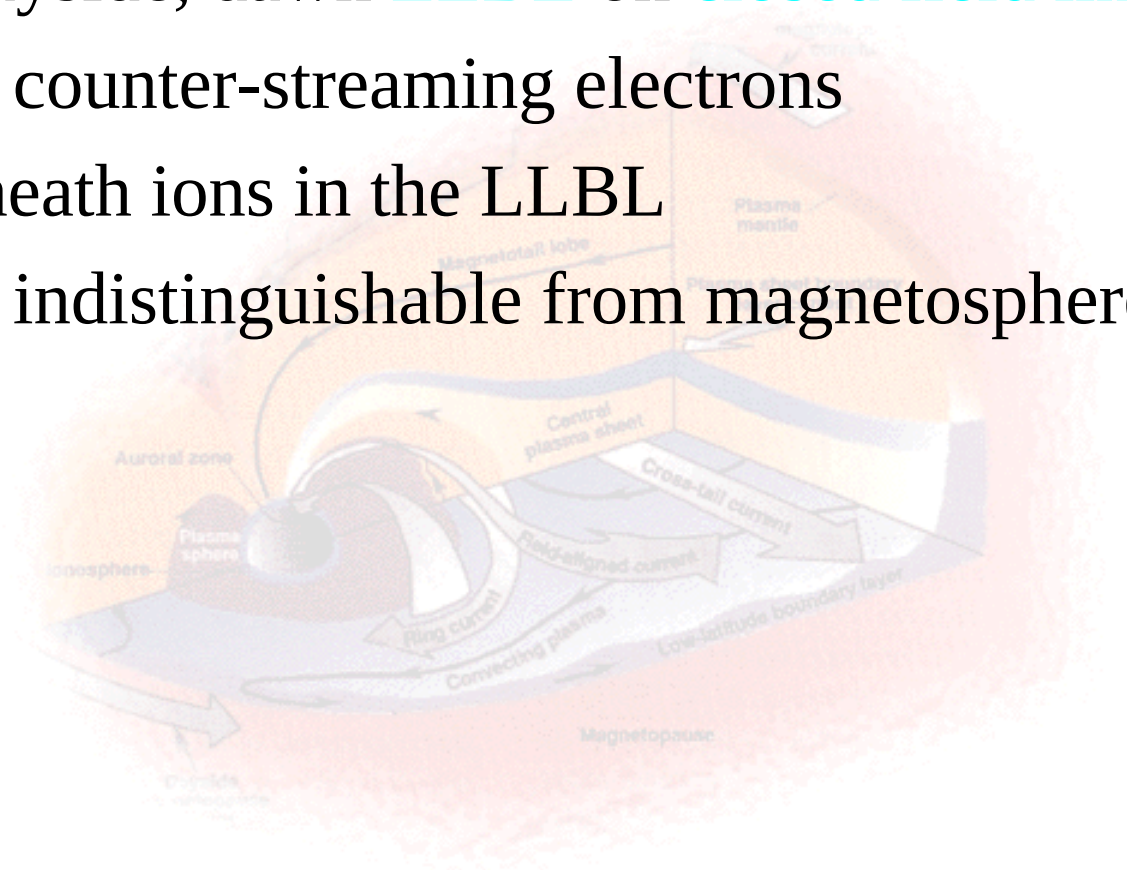

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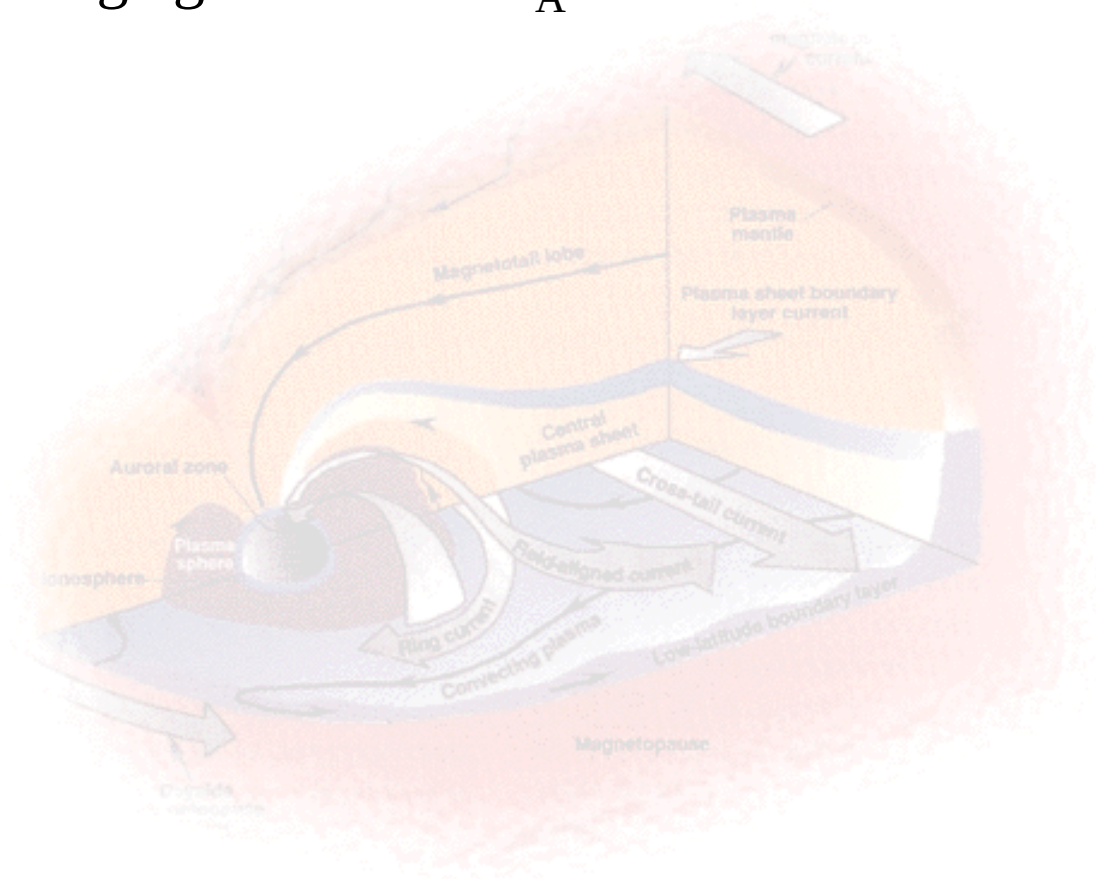

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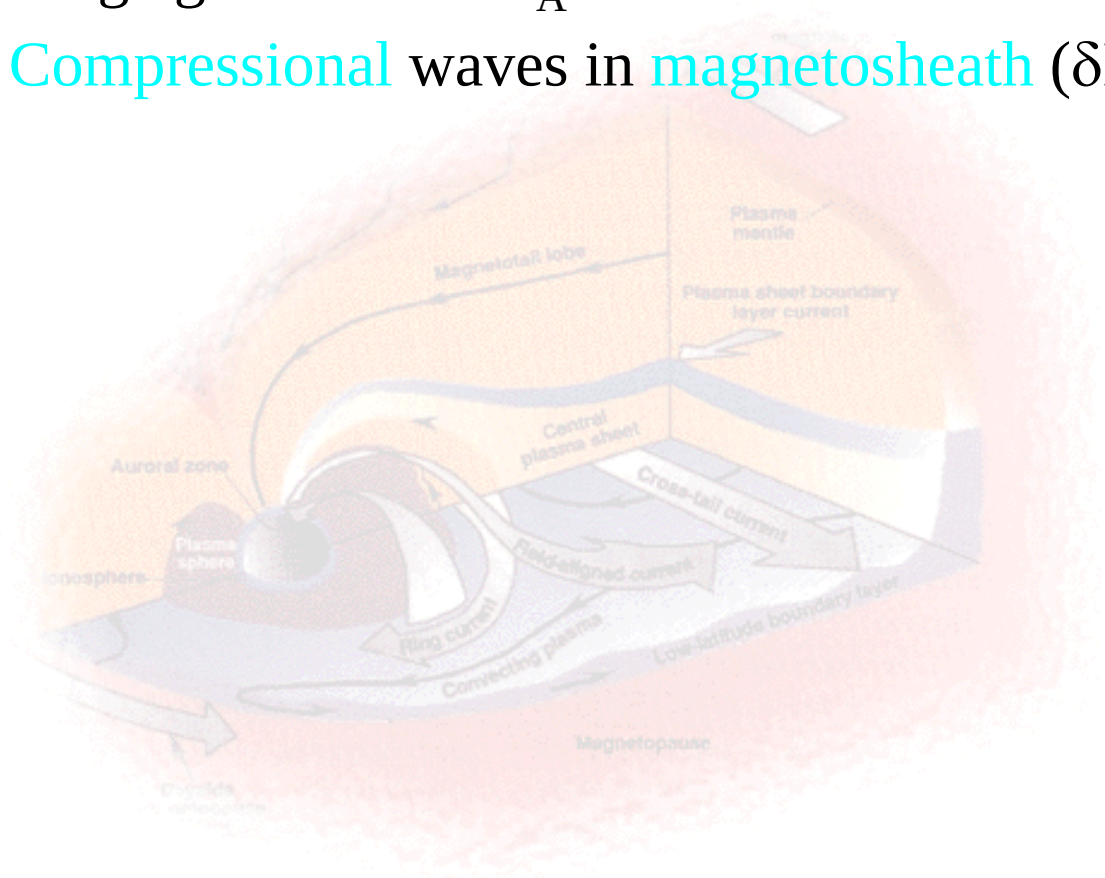

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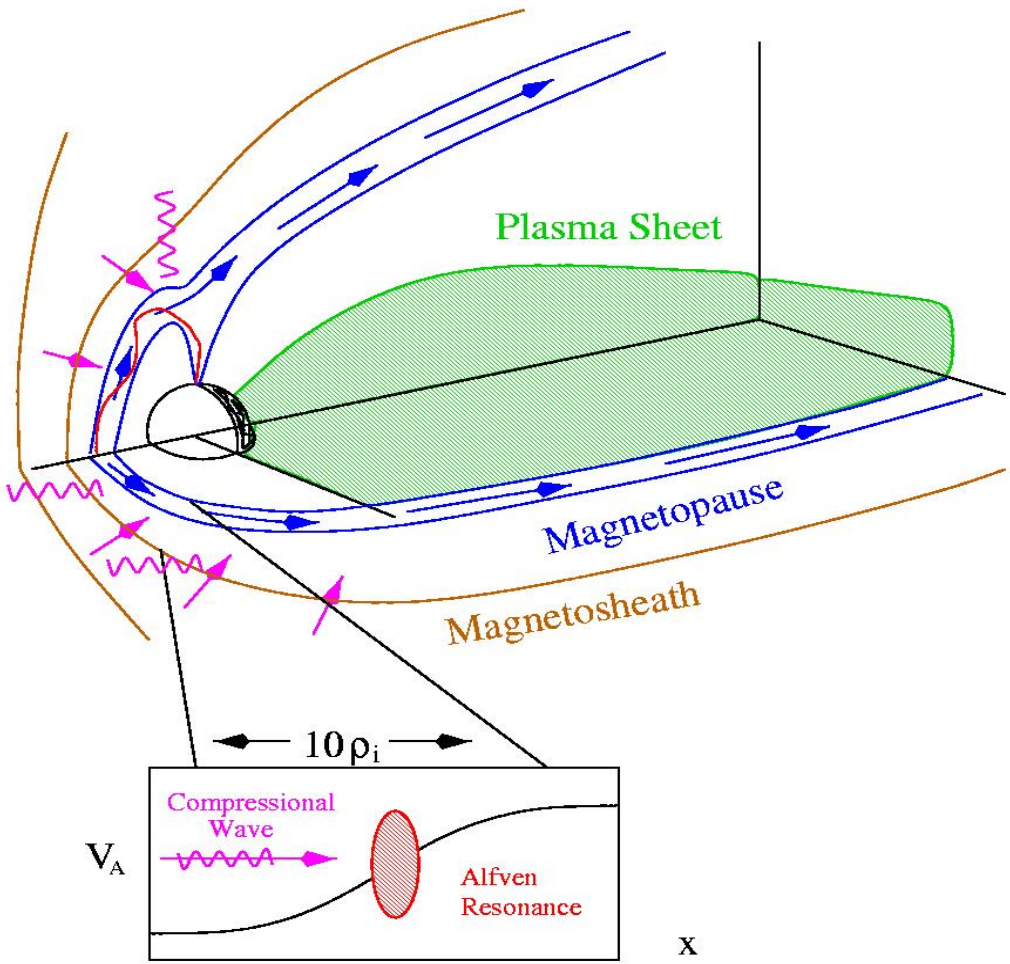
  - Transverse waves in LLBL

Kinetic Alfvén Waves at the Magnetopause



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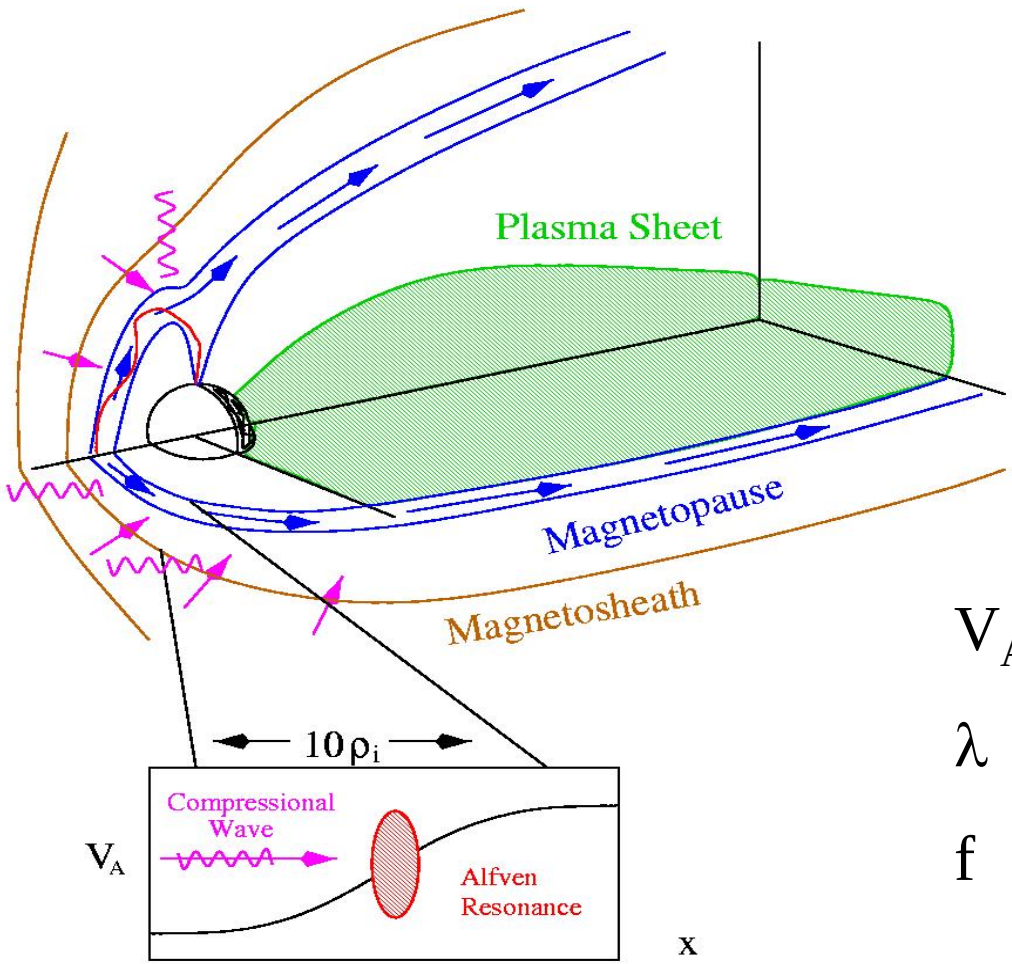


V_A ~200km/s

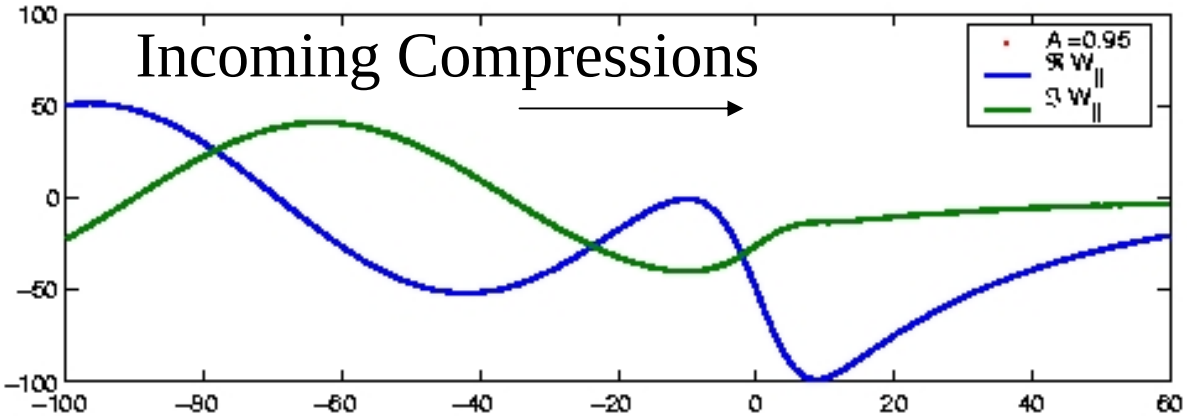
λ ~ R_E

f ~ 30 mHz

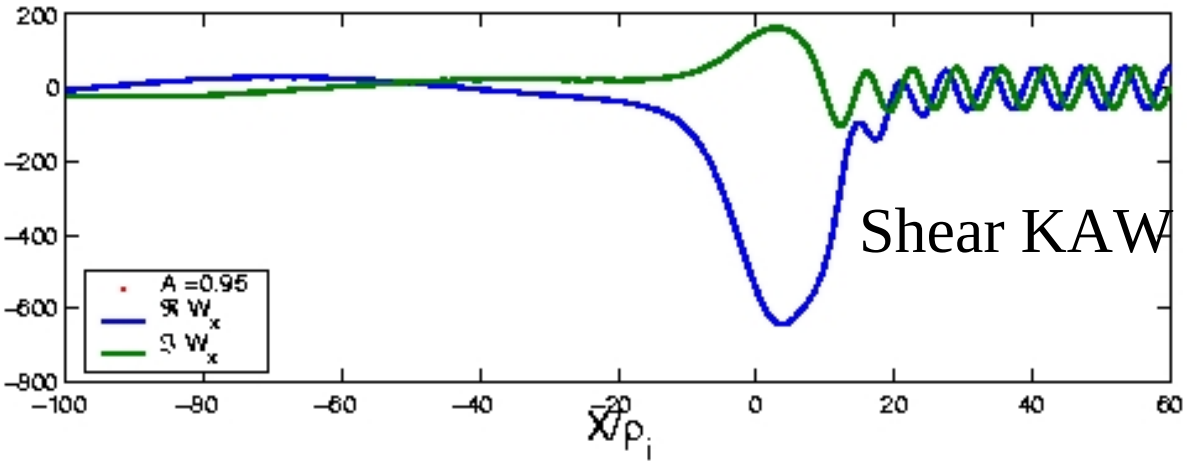
Example of Compressional Wave Incident on the Magnetopause

⇐ Magnetosheath Class II Magnetosphere ⇒

$\delta B_{\parallel}$



$\delta B_{\perp}$



Consequences for Transport

- Prescribe a kinetic Alfvén wave solution
  - wave dispersion:

$$\omega^2 \approx k_{\parallel}^2 V_A^2 (1 + (1 + T_e / T_I) k_{\perp}^2 \rho_I^2)$$

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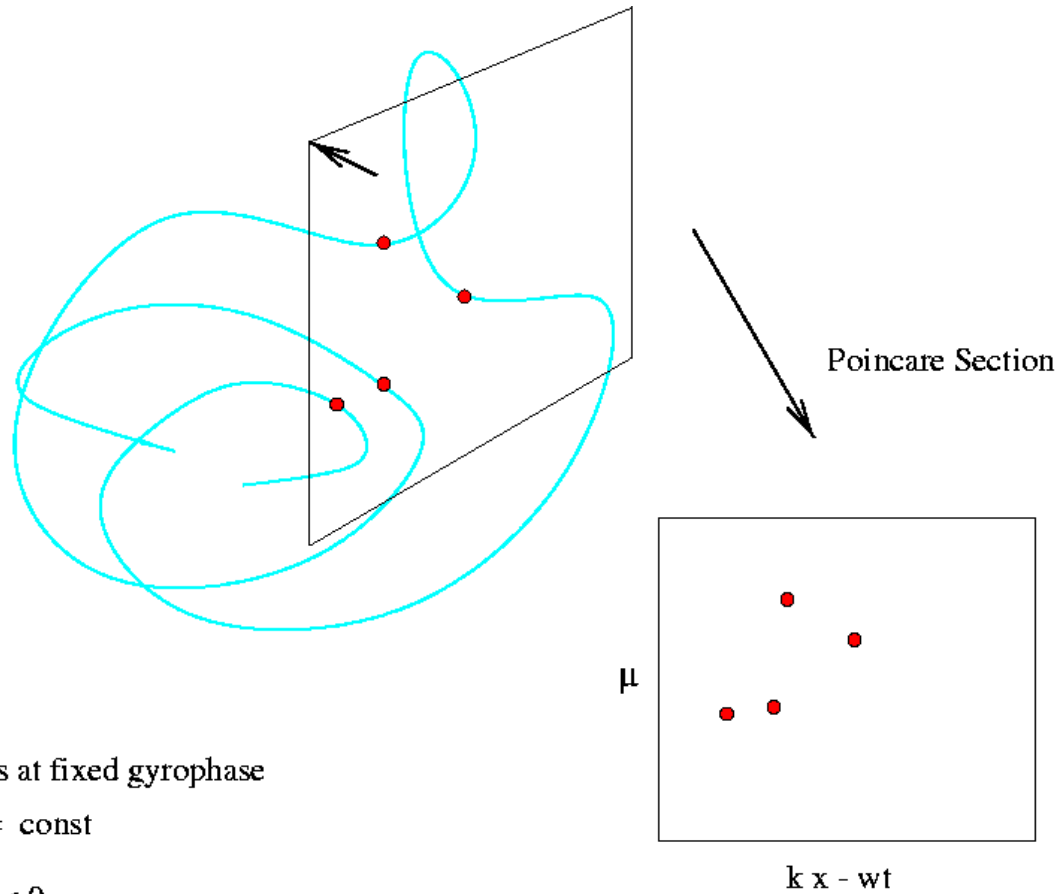
- Examine statistics of heating and transport

Poincare Section

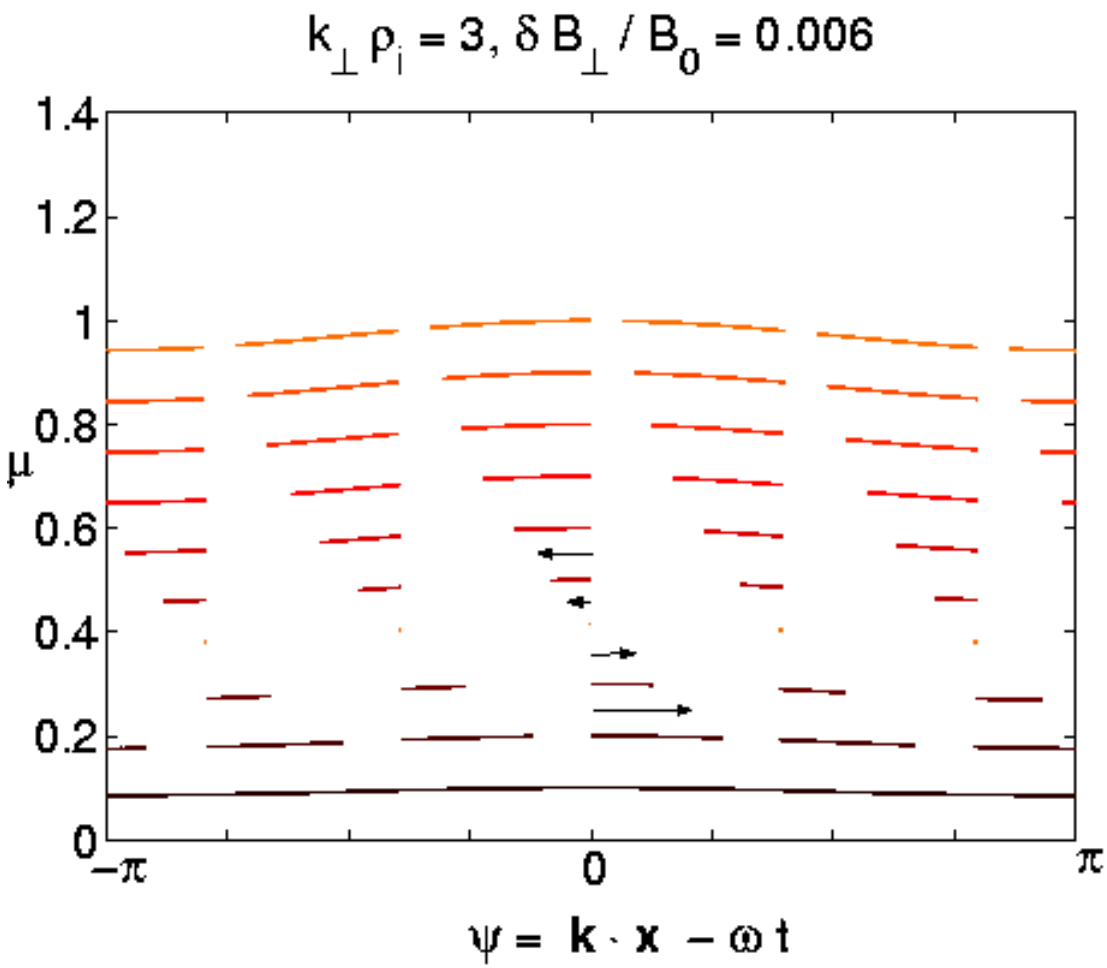


Surfaces at fixed gyrophase

$\phi = \text{const}$

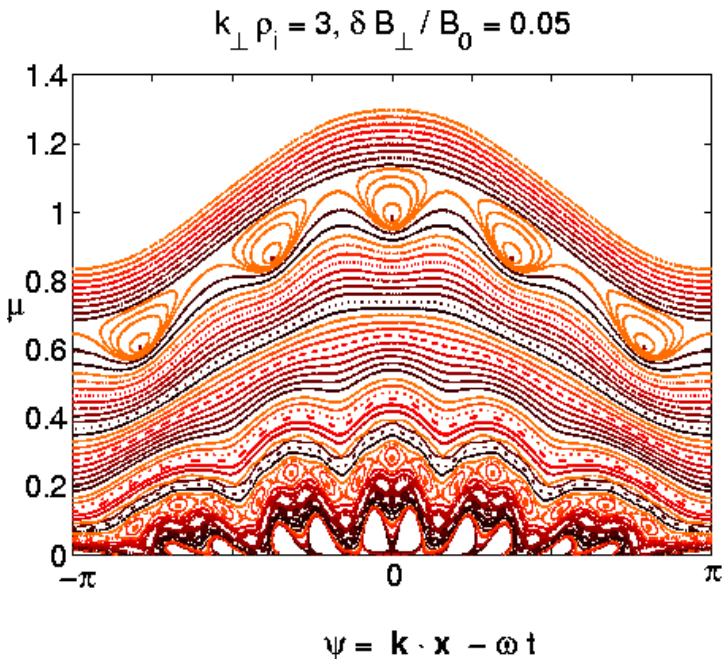
$\dot{\phi} < 0$

Wave-Particle Resonances



$\omega = \Omega/5$

Onset of Stochasticity



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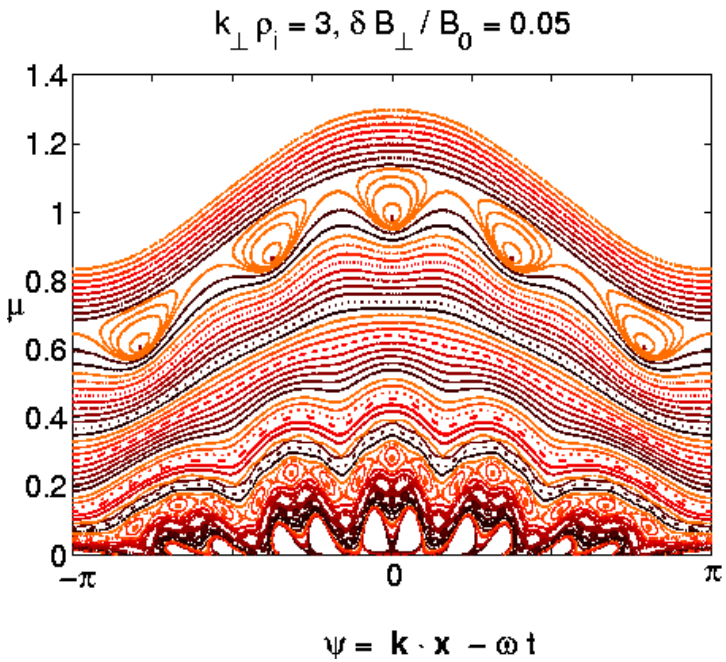
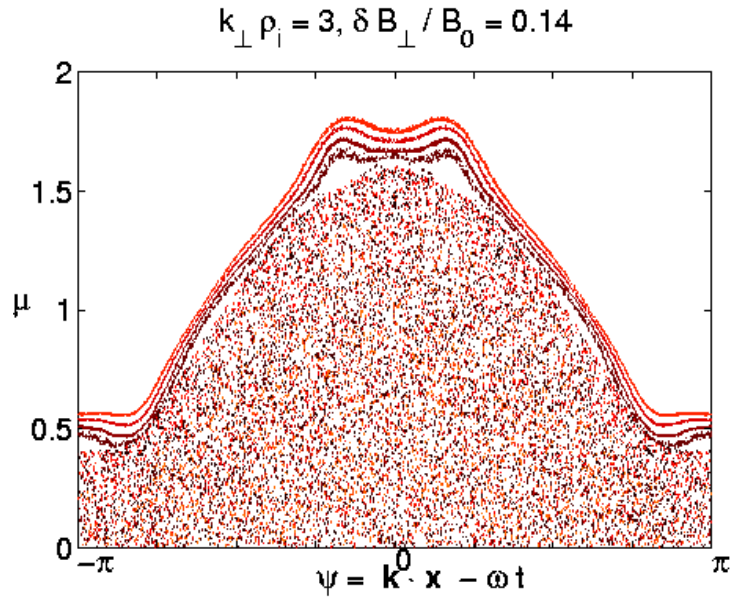
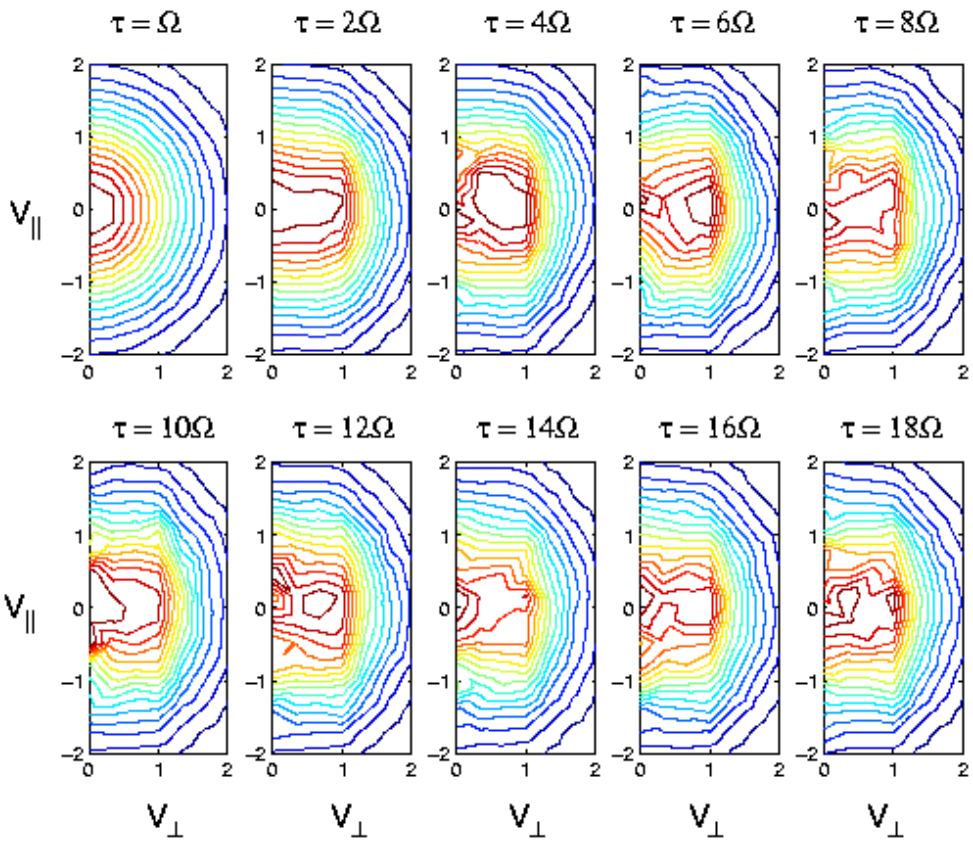




Core Heating of Ion Distribution

Distribution: Kinetic Alfven Wave



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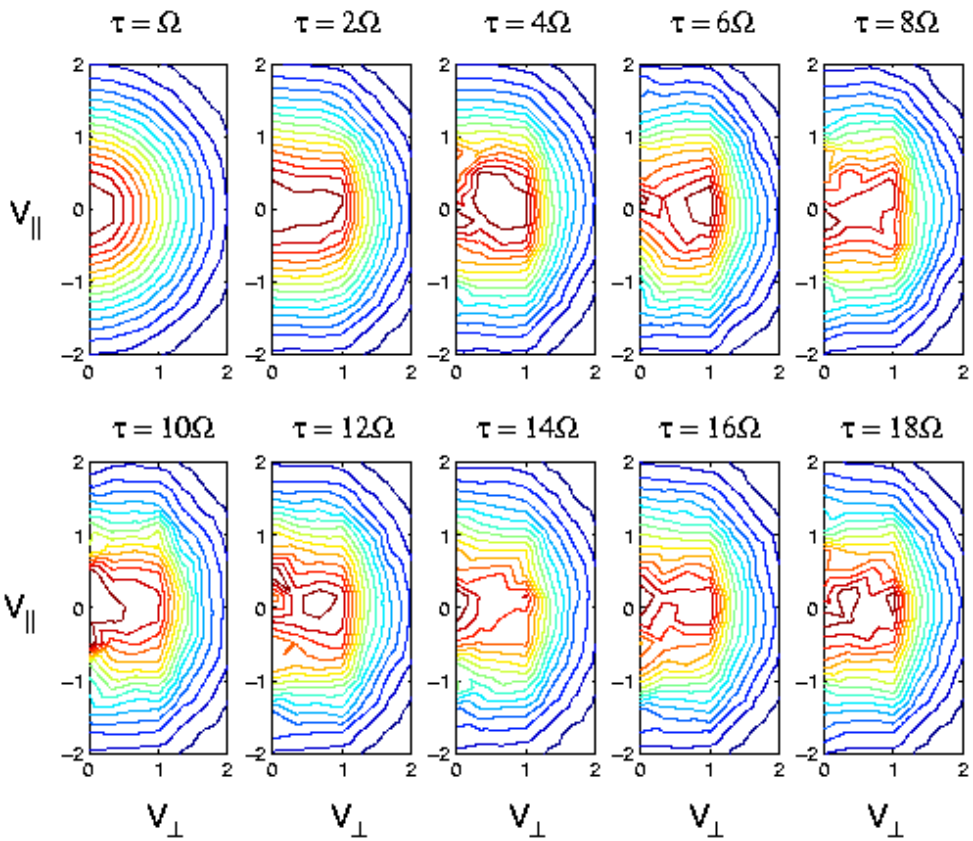
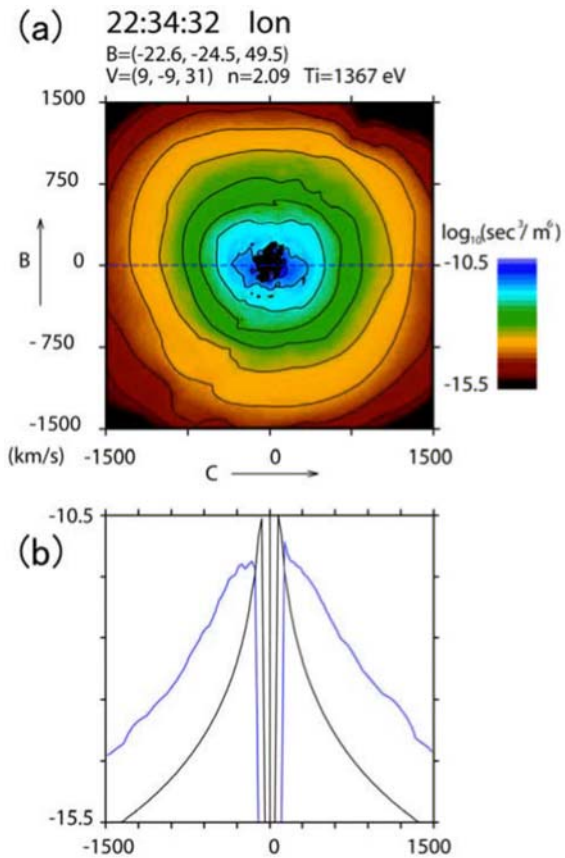


Observed Distribution:

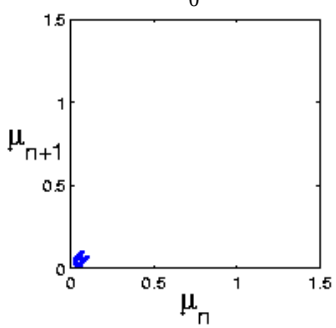


[Hasegawa et al., 2003]

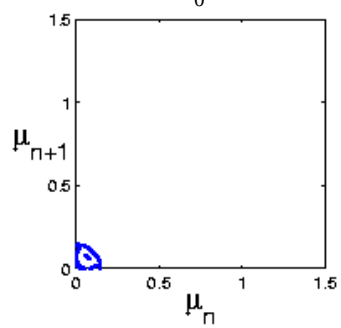
Multiple Waves Lower Threshold

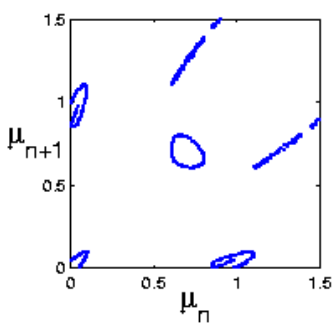
Single Wave

$\delta B/B_0$=0.1

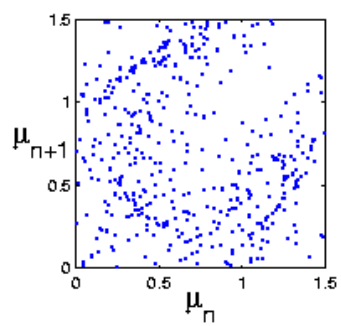


$\delta B/B_0$=0.25





δBB_0=0.6



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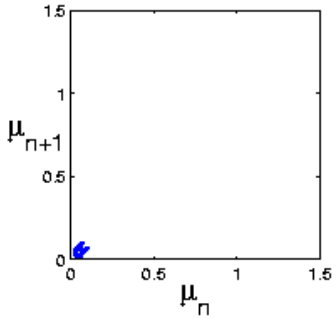

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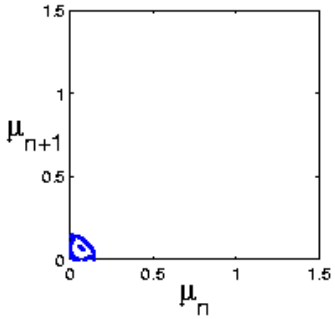
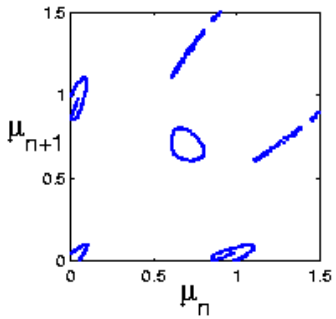
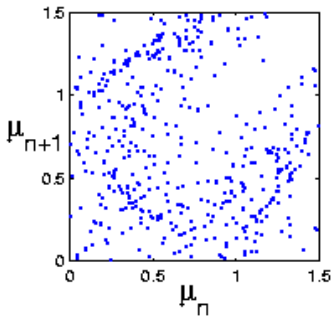




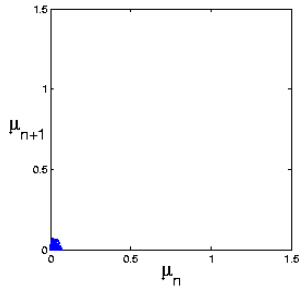
$\delta BB_0=0.6$



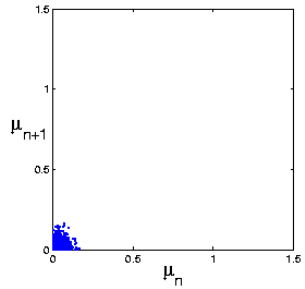
$\delta B/B_0=0.65$

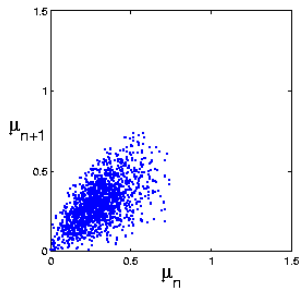
Ten Waves

$\delta B/B_0=0.1$

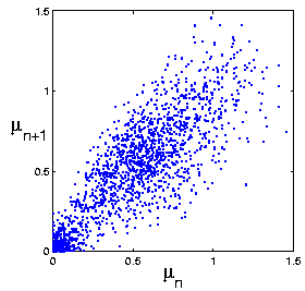


$\delta B/B_0=0.15$





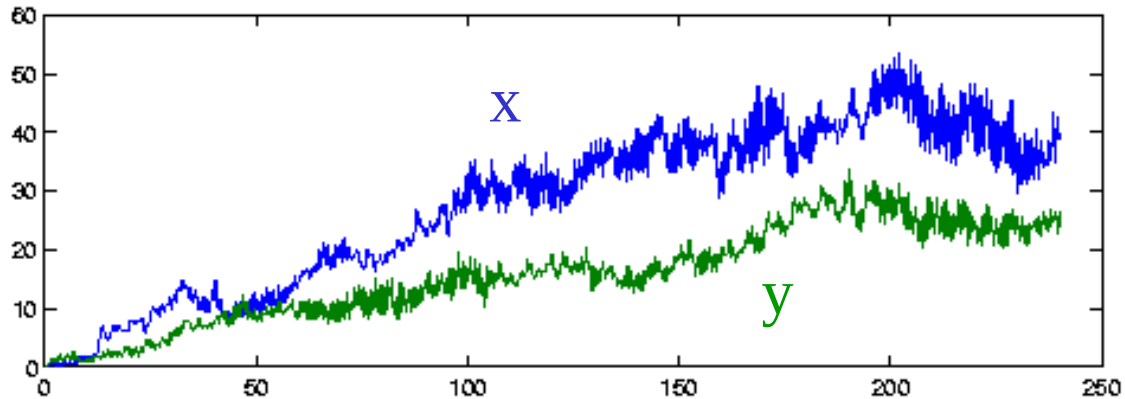
$\delta B/B_0=0.2$



$\delta B/B_0=0.25$

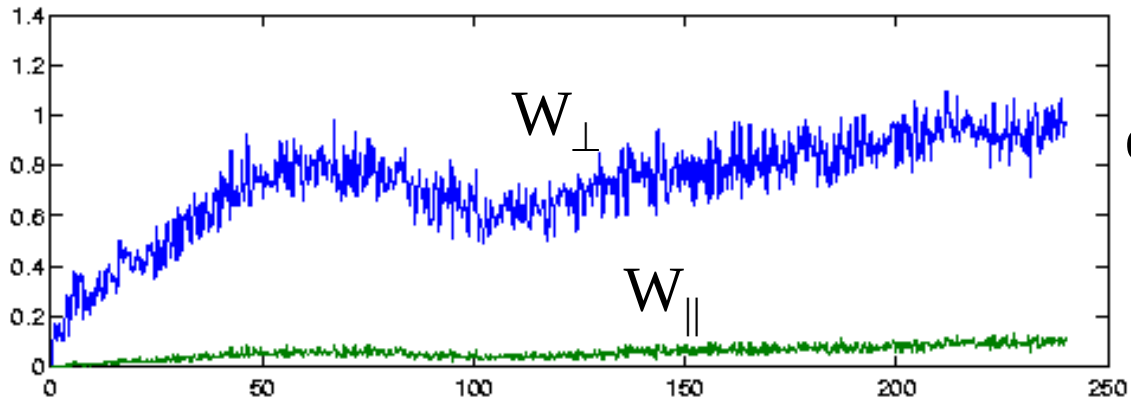
Diffusion and Heating Rate

$<X^2>/\rho_i$



Ωt

$D \sim 5 \times 10^9 m^2/s$



Ωt

$dW/dt \sim T_i\, \Omega_i/50$

$\sim (T_i/10)eV/s$

Conclusions

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Transverse waves at magnetopause:

- consistent with KAW mode conversion

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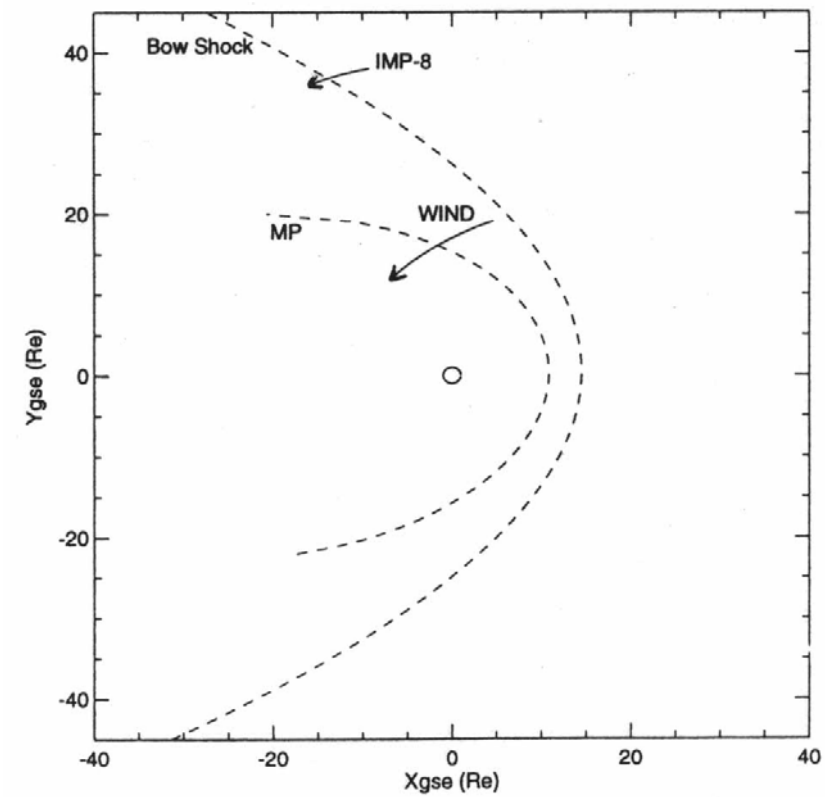
Transverse waves at magnetopause:

- consistent with KAW mode conversion
- accelerate electrons parallel to B
- heat ions perpendicular to B
- can produce flattened core distributions as observed
- Produce significant diffusion of sheath ions into dayside LLBL---D $\approx 5 \times 10^9$ m^2/s

Supplemental Material: Additional Evidence of Transport

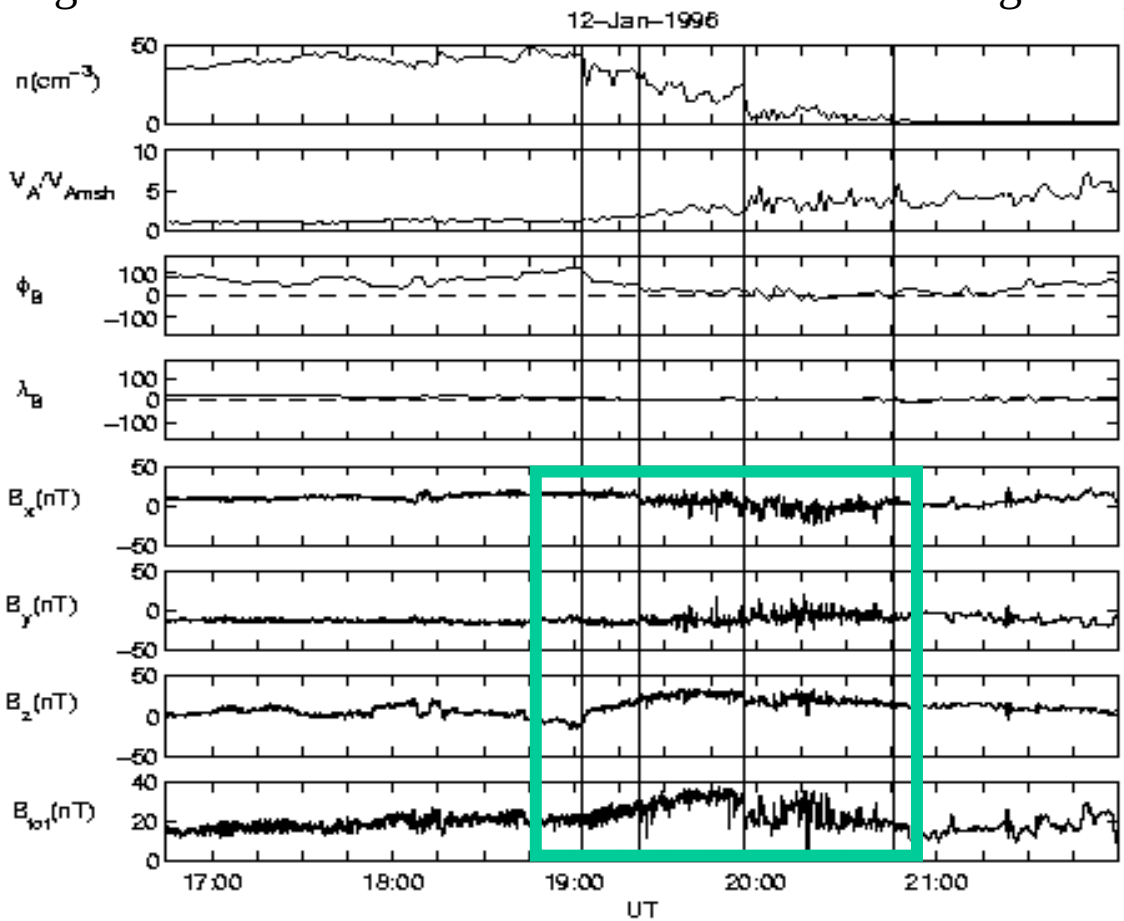
Evidence for Wave Induced Transport---Flank MP Crossing



Phan et al., 1997

Flank MP Crossing

Magnetosheath Magnetosphere

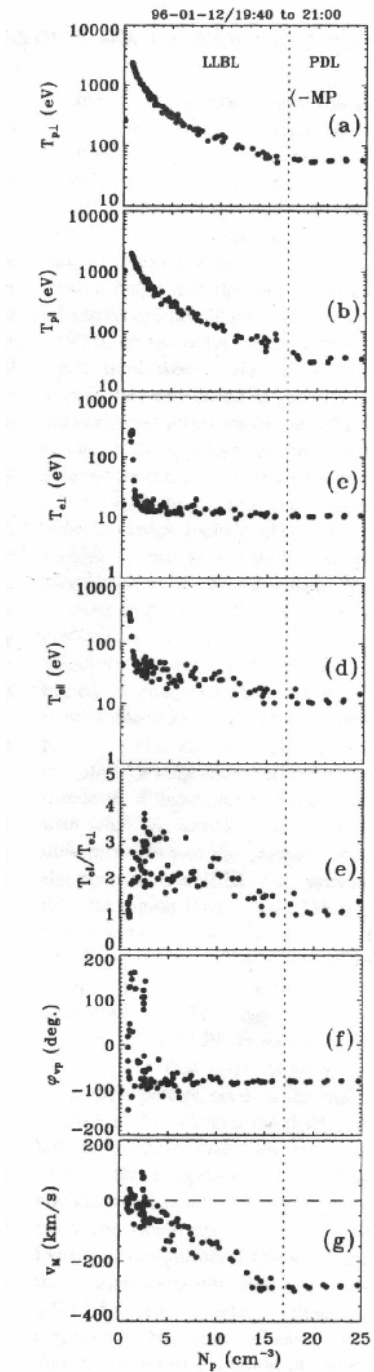


$V_{Ash} \uparrow 10V_{Asph}$

[Phan et al., 1997; Johnson et al., 2000]

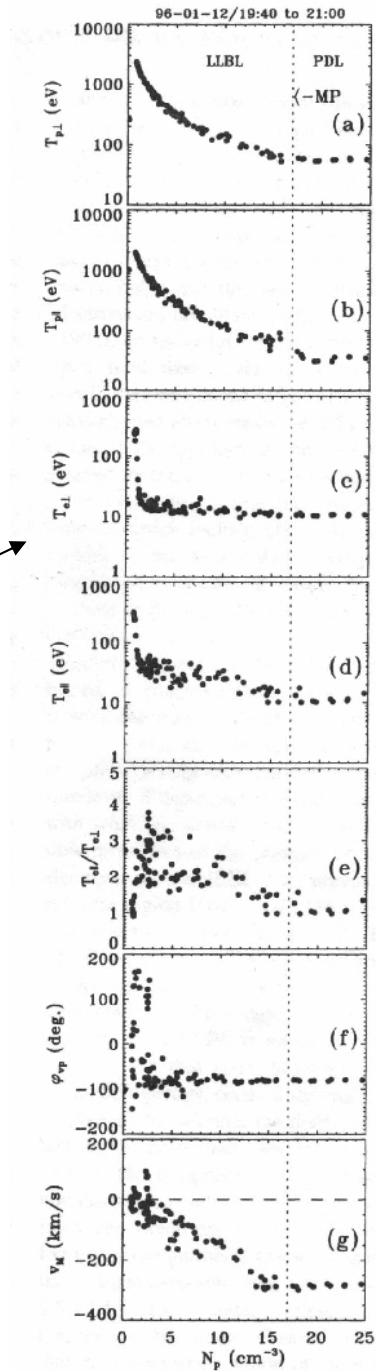
Evidence of Wave Induced Transport

- Transition Parameter
- Real LLBL Profile is Smooth and Gradual
- Smooth $T_{\perp}$ for ions and electrons indicates local transport
- Heating of ions $\perp$ to B and electrons || to B
- Gradual transition of flow across B
- No Evidence of Reconnection



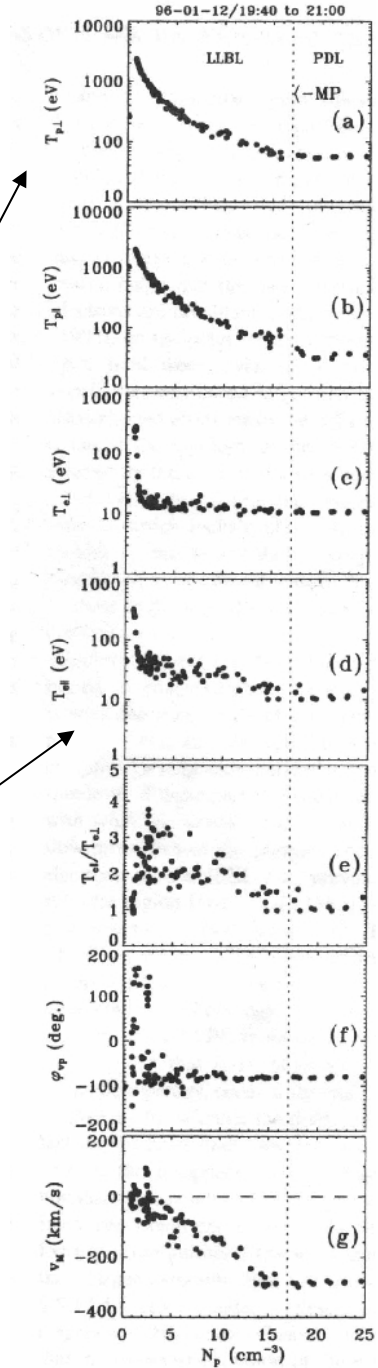
Evidence of Wave Induced Transport

- Transition Parameter
- Real LLBL Profile Smooth and Gradual
- Smooth $T_{\perp}$ for ions and electrons indicates local transport
- Heating of ions ⊥ to B and electrons || to B
- Gradual transition of flow across B
- No Evidence of Reconnection



Evidence of Wave Induced Transport

- Transition Parameter
- Real LLBL Profile Smooth and Gradual
- Smooth $T_{\perp}$ for ions and electrons indicates local transport
- Heating of ions $\perp$ to B and electrons $\parallel$ to B
- Gradual transition of flow across B
- No Evidence of Reconnection



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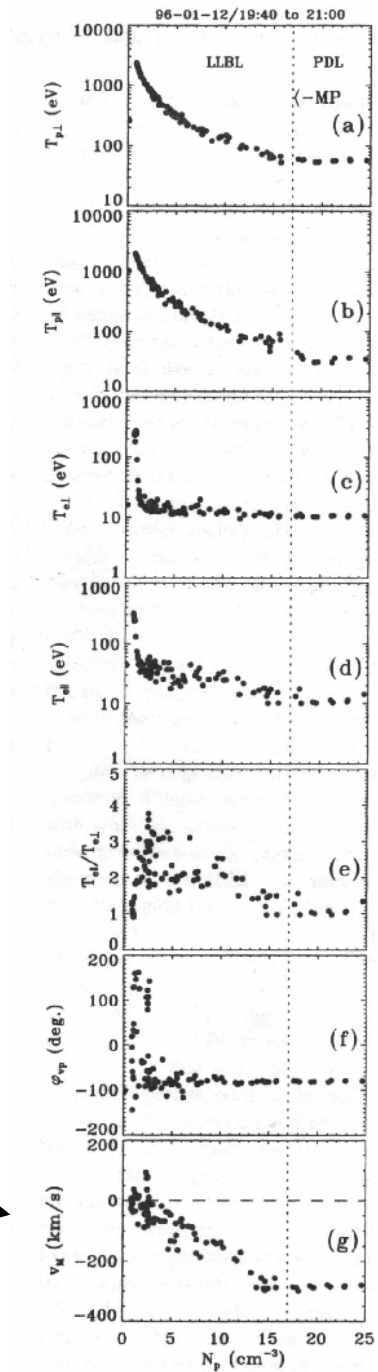
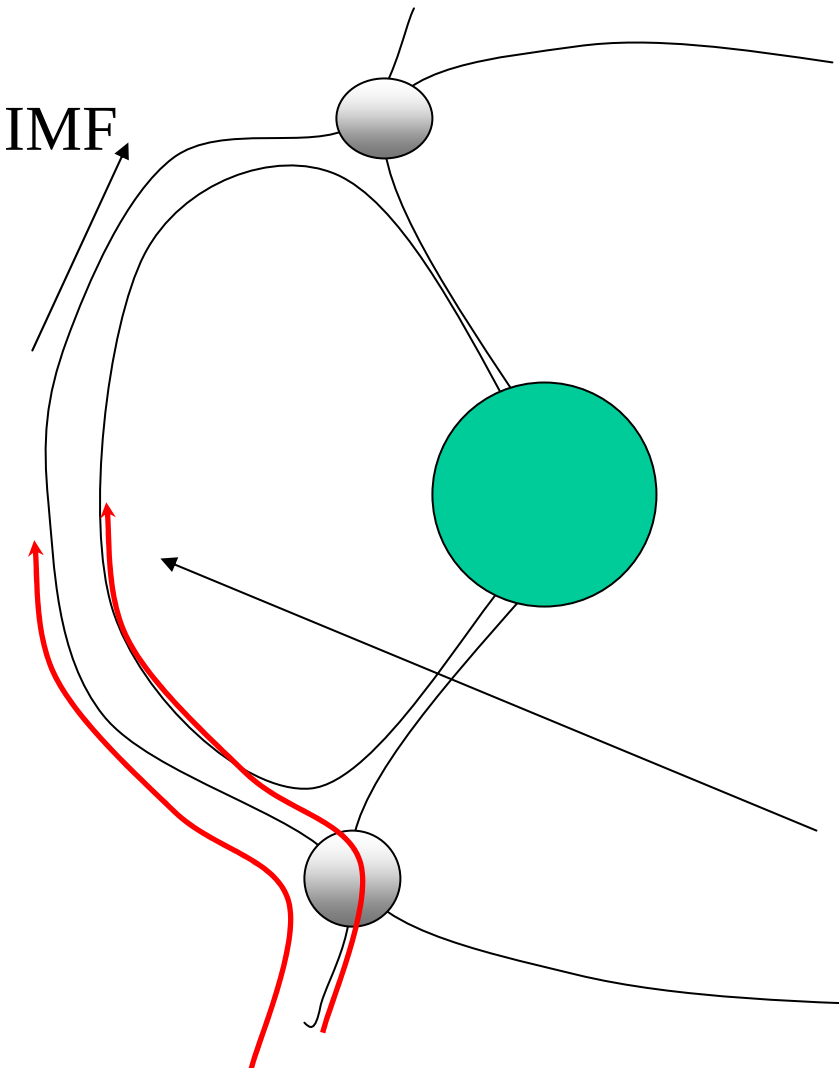
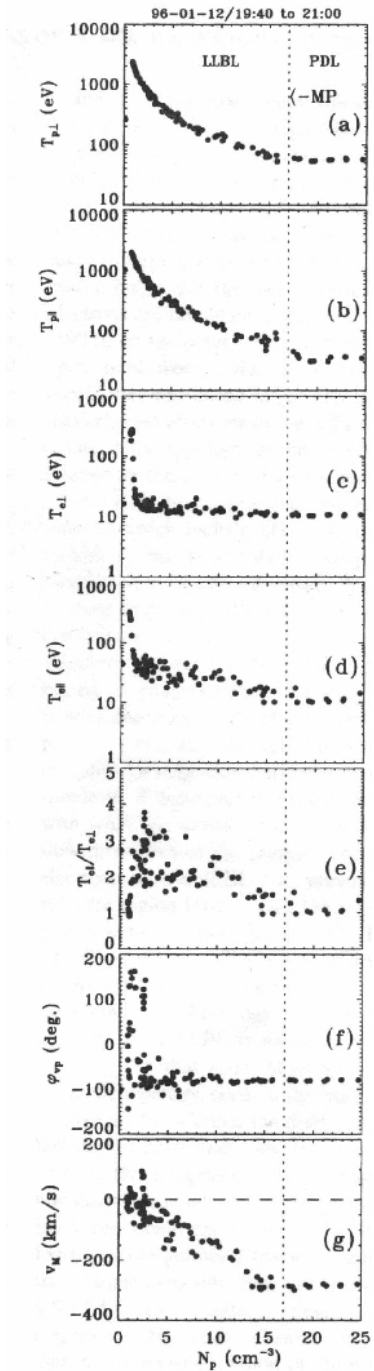


Evidence of Wave Induced Transport



If Reconnection Do Not Expect a Continuity of $T_\perp$



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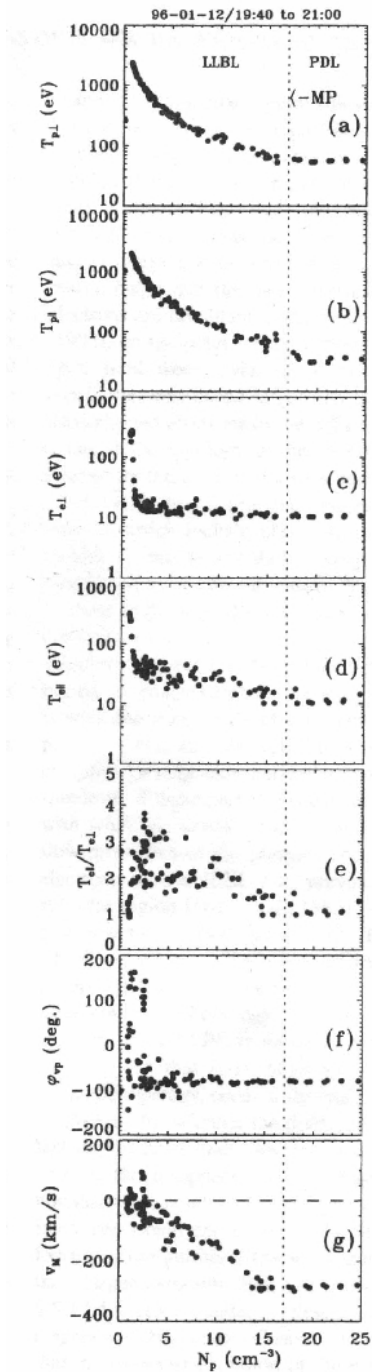
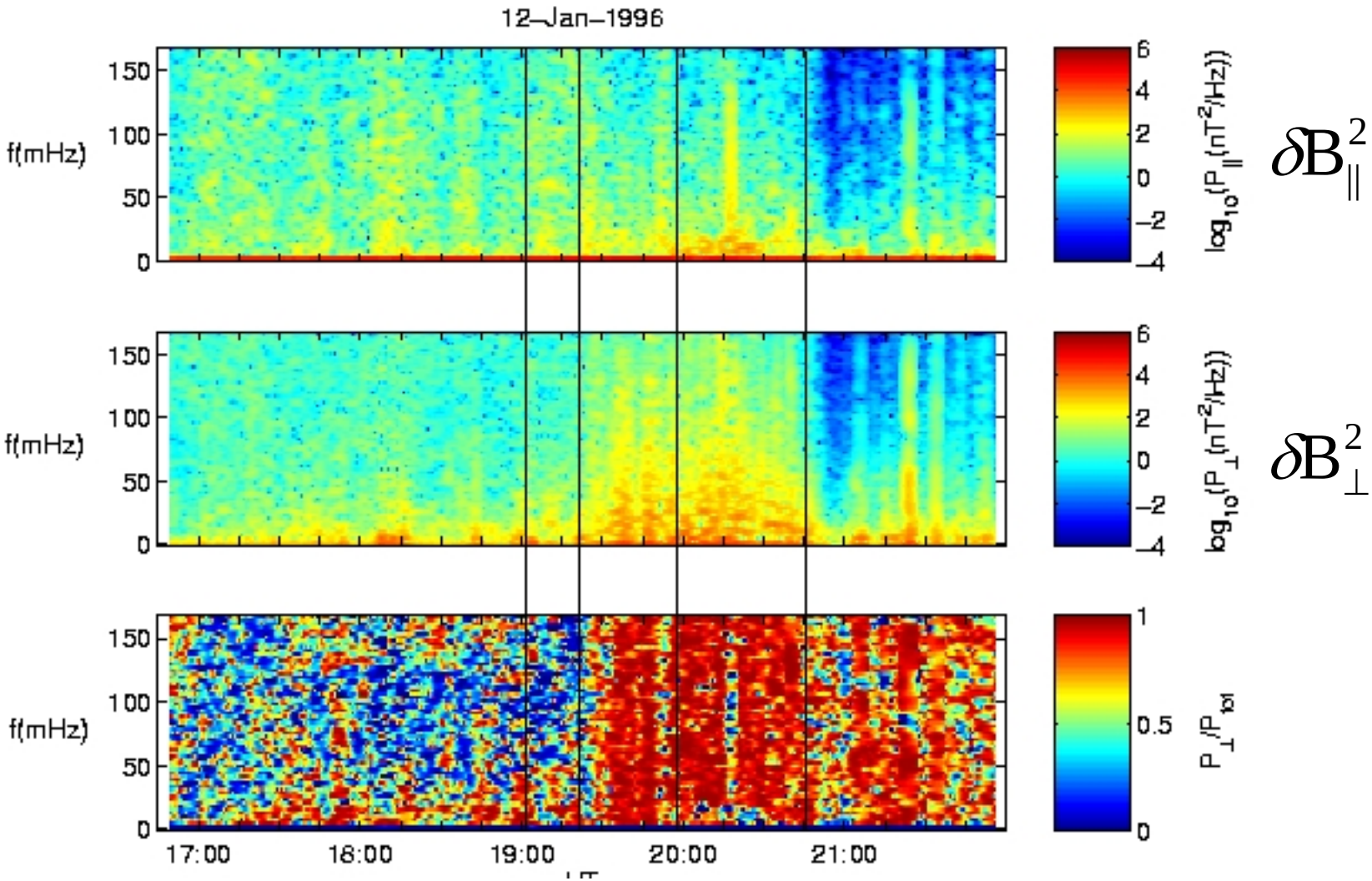
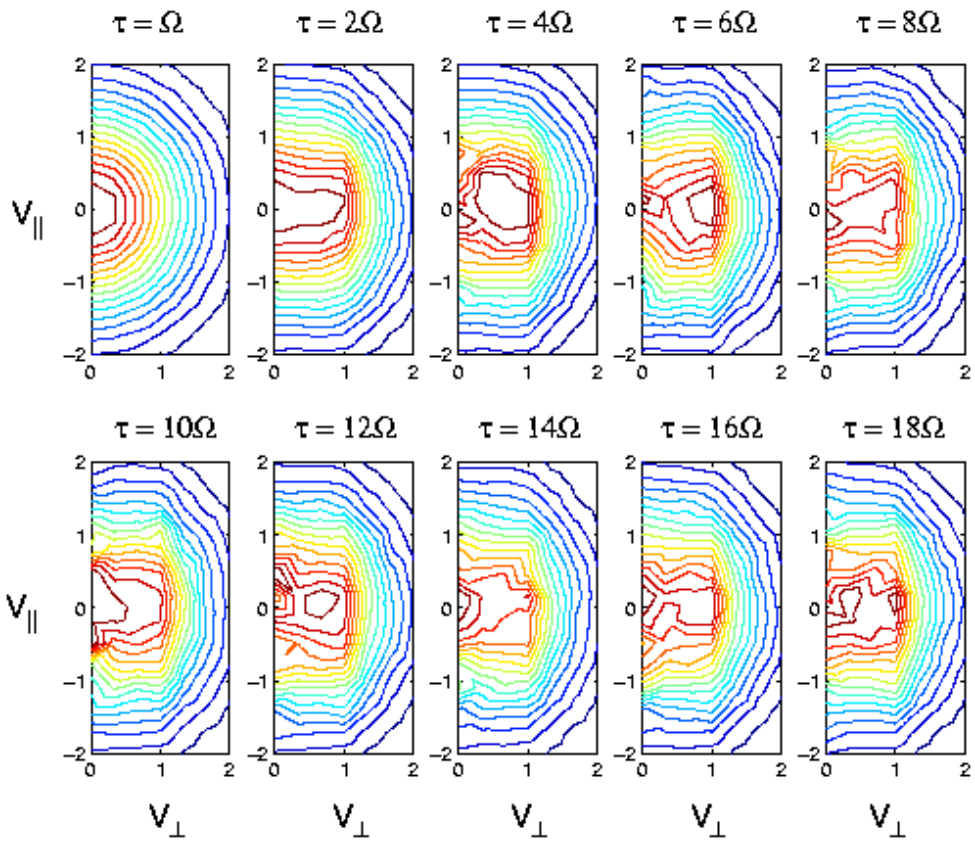
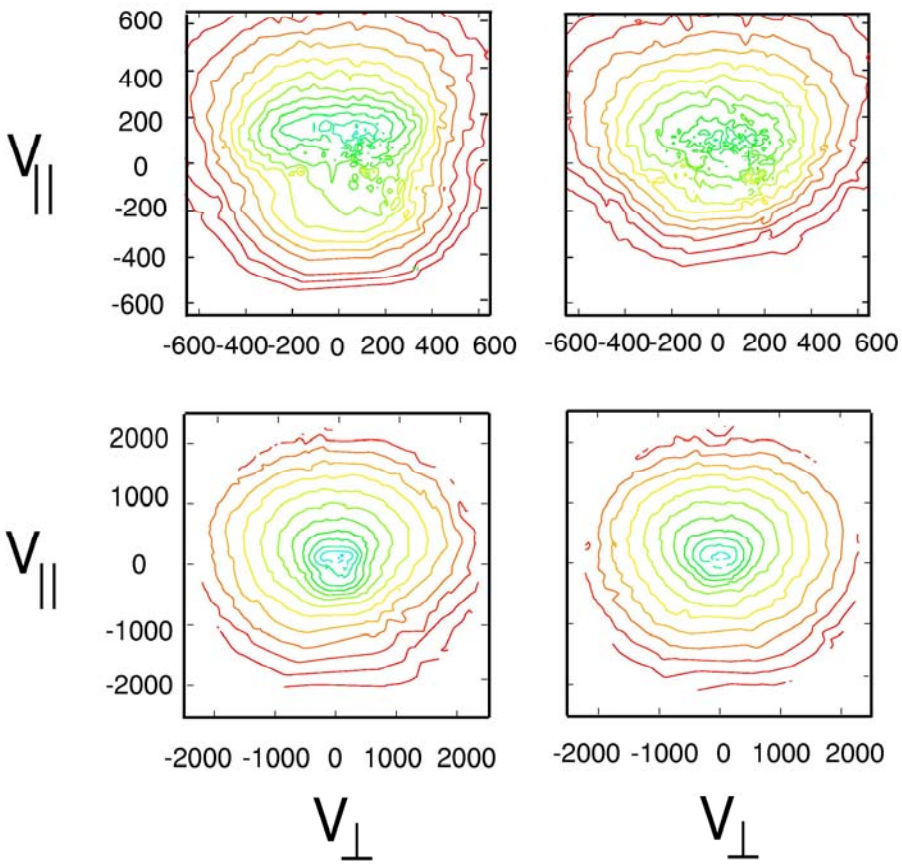


Wave Spectra for Flank Magnetopause Crossing



Core Heating of Ion Distribution

Distribution: Kinetic Alfven Wave



Observed Distribution:
Wilber,Lin,Parks