SM41A-02

Modeling Feedback Between Ion Outflows and Electromagnetic Alfven Ion Cyclotron Waves

Jay R. Johnson, Princeton University, Plasma Physics Laboratory

Eun-Hwa Kim, Princeton University, Plasma Physics Laboratory

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Energized Ions and Waves

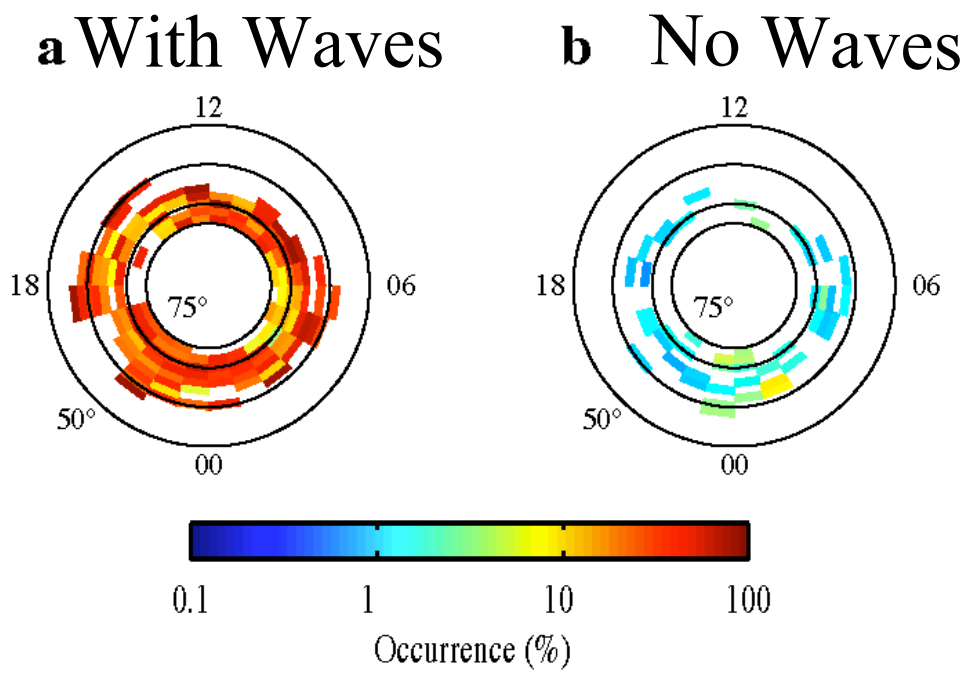
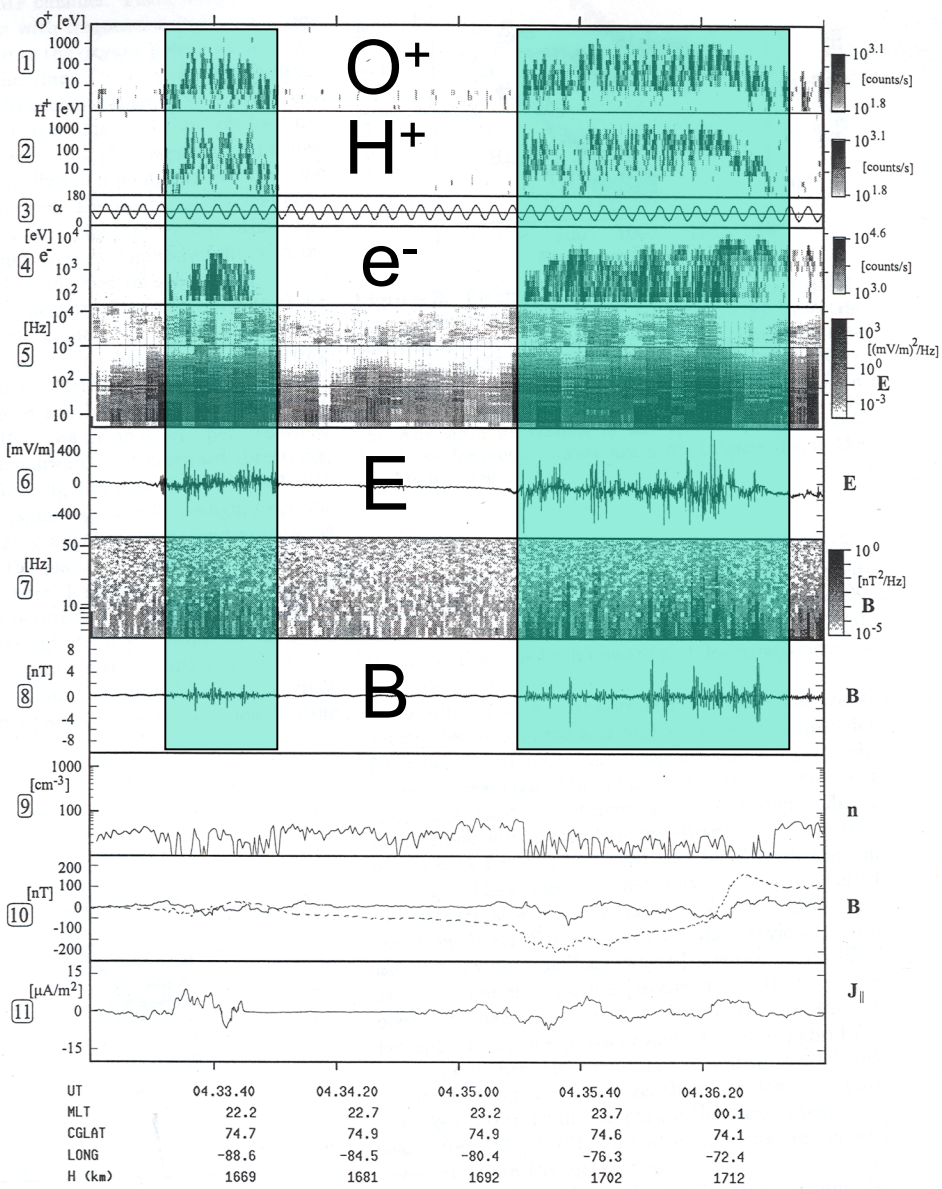


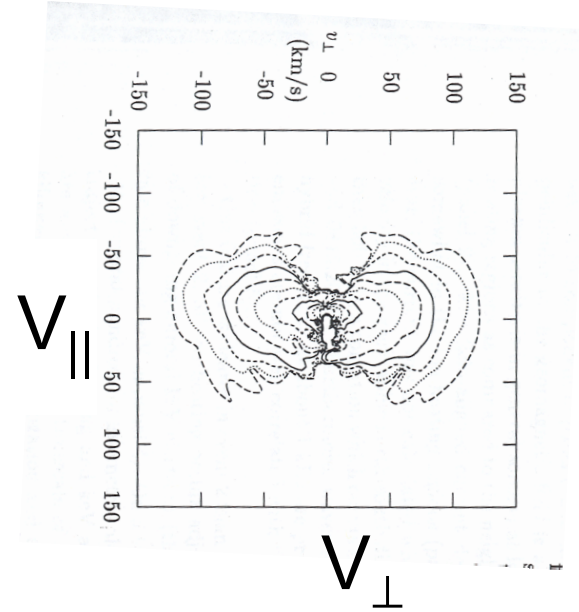
Fig. 3. Probabilities of detecting energized ions versus MLT and INV in the presence of (**a**) strong BB-ELF waves, strong EMIC waves, or strong waves around the lower hybrid frequency, and (**b**) no BB-ELF waves, no EMIC waves, and no waves around the lower hybrid frequency. The colour scale is the same as in Figs. 1 and 2.

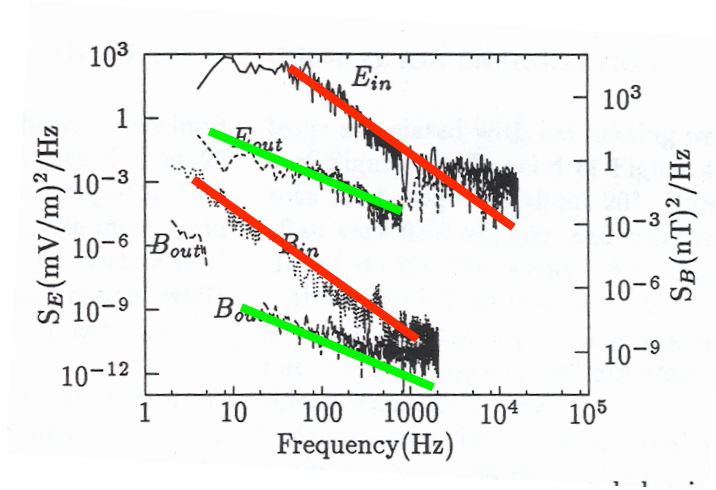
Hamrin et al., 2002

Broadband EMIC Heating

Example: FREJA---1700km

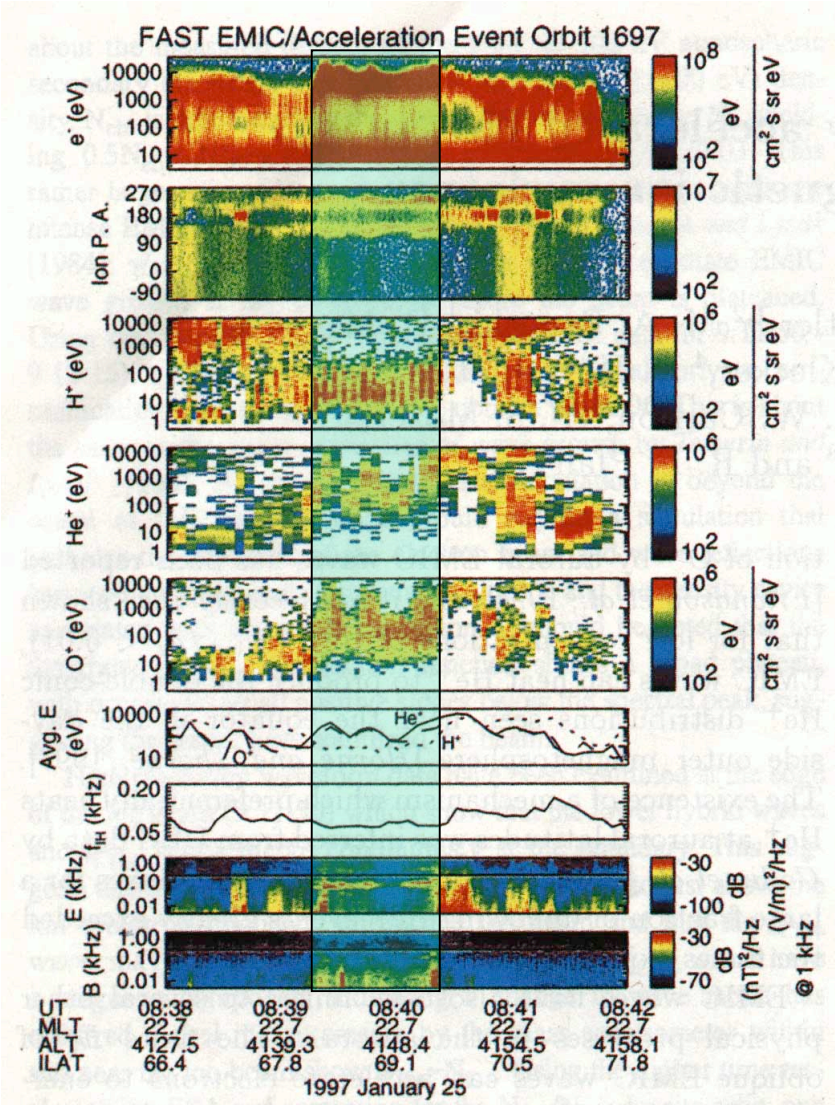






Andre et al., 1998

Example: Energetic Ions and EMIC Waves in Auroral Zone



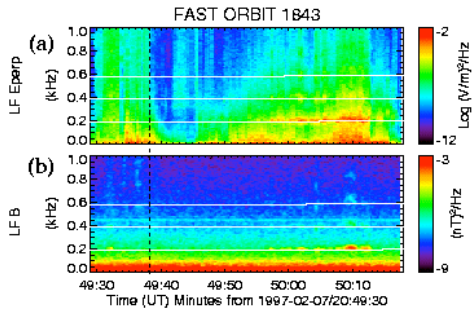
- [Lund et al., 1998]
- FAST satellite pass through Auroral zone at 4000km
- Heated Ion Conics
- Preferential Heating of He^+
- Electromagnetic Waves f~10-100Hz

Important Points

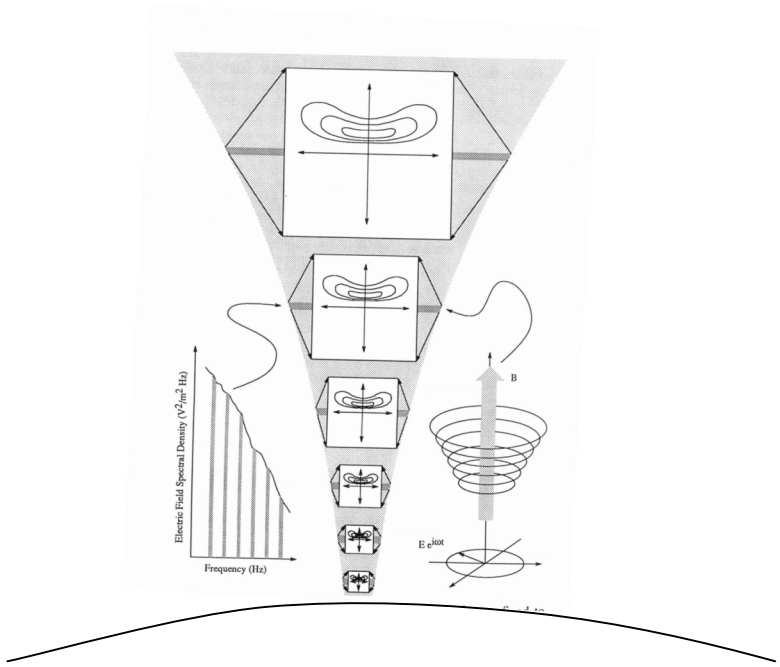
- Such events typically modeled by inferring the heating rate from the observed spectrum
- Observations of heated ions above the heating region
- Poynting fluxes are downward ($S \sim 3 \times 10^{-5}$ W/m^2) [Chaston et al., 1998]
- Waves of same frequency observed in the ionosphere ($S \sim 10^{-5}$ W/m^2) [Lund, 1997]

Waves Propagate Downward

Poynting Flux
~3×10^{-5} W/m^2
[Chaston,1998]

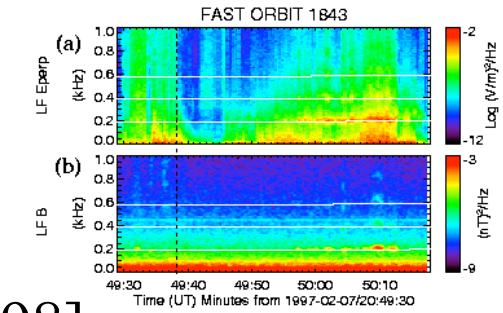


Fast Satellite
[Ergun, 1998]

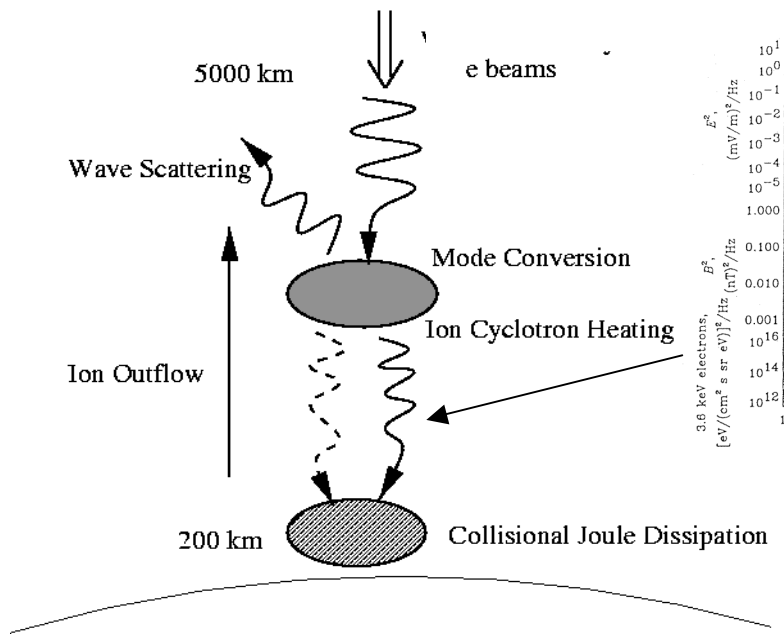


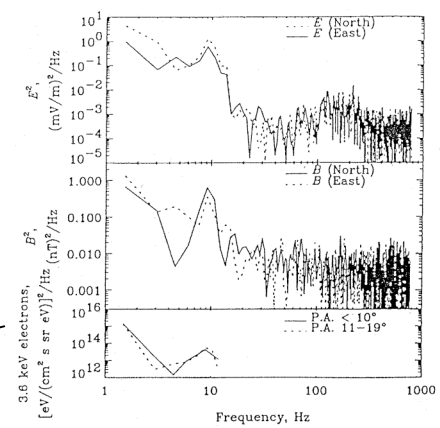
Waves Reach Rocket Altitudes

Poynting Flux
~3×10^{-5} W/m^2
[Chaston et al.,1998]



Fast Satellite
[Ergun et al., 1998]
at 4000km





Poynting Flux

~10^{-5} W/m^2

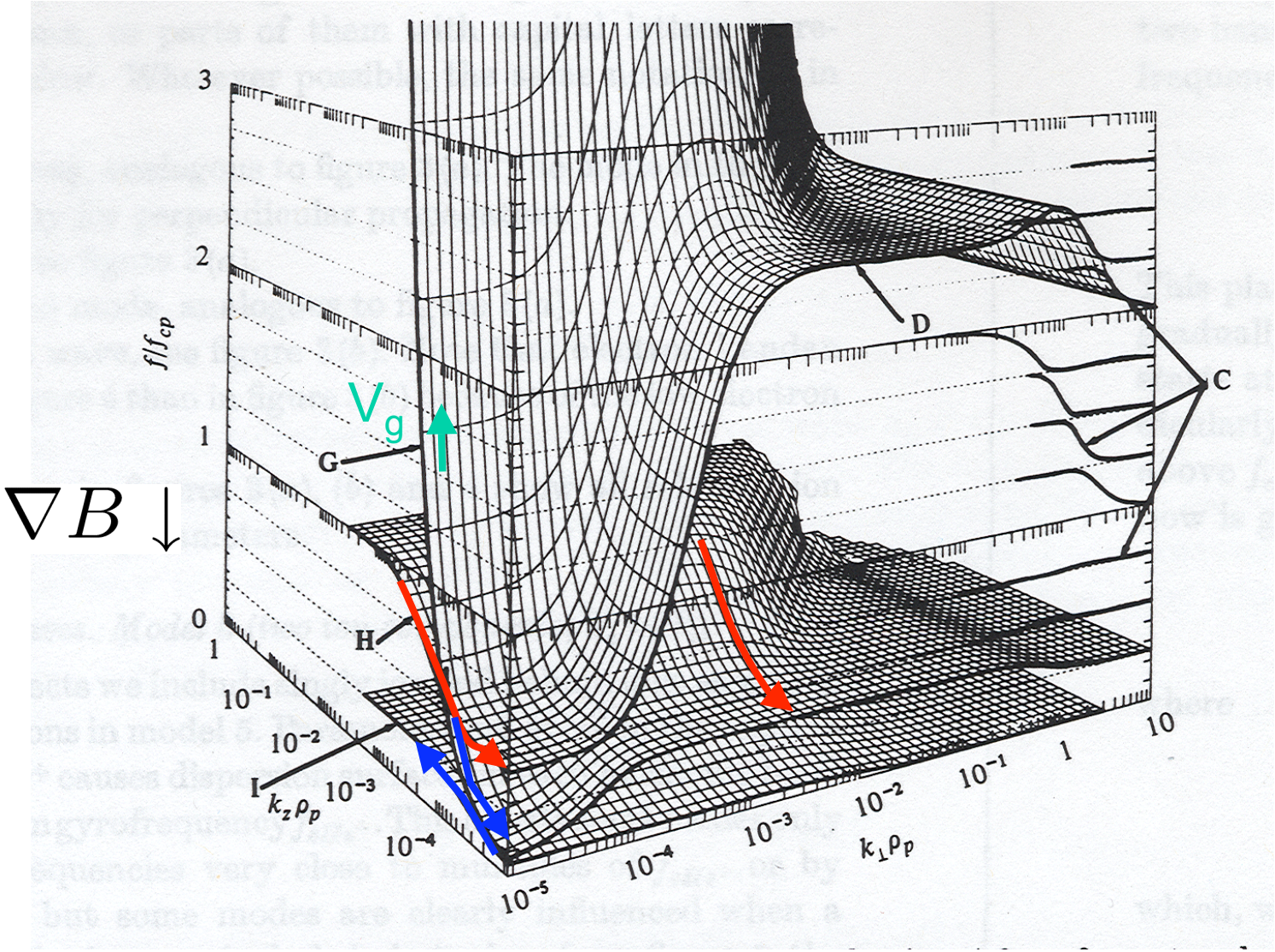
at 400km

Rocket Observation
[Lund et al., 1997]

Questions

- Can the waves propagate into the ionosphere?
- Can the wave energy be absorbed by the ions?
- Is there feedback between the ion outflows and the waves?

Dispersion Surface



Andre, 1985

Wave Equation

Equations for collisional fluid plasma with 1-D solution for propagation along B. Energetic Ions treated with an integral equation.

$$\nabla^2 \mathbf{E} - \nabla(\nabla \cdot \mathbf{E}) + \frac{\omega^2}{c^2} \boldsymbol{\varepsilon}(s) \cdot E = 0$$

$$\boldsymbol{\varepsilon}(s) = S(\mathbf{I} - \mathbf{bb}) - iD(\mathbf{e}_1\mathbf{b} \times \mathbf{e}_2 - \mathbf{b} \times \mathbf{e}_1\mathbf{e}_1) + P\mathbf{bb}$$

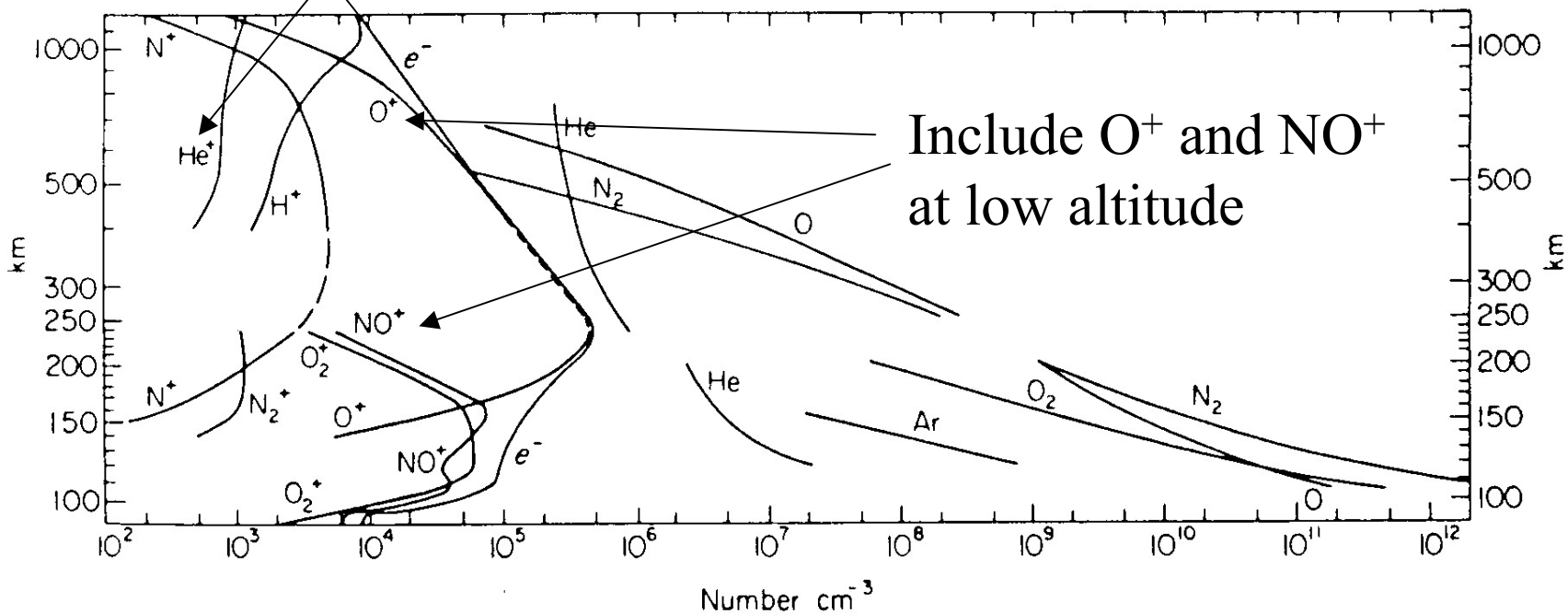
$$S = 1 - \sum_j \frac{\omega_{pj}^2(\omega + i\nu_j)}{\omega[(\omega + i\nu_j)^2 - \Omega_j^2]}$$

$$D = 1 - \sum_j \frac{\omega_{pj}^2 \Omega_j}{\omega[(\omega + i\nu_j)^2 - \Omega_j^2]}$$

$$P = 1 - \sum_j \frac{\omega_{pj}^2}{\omega(\omega + i\nu_j)}$$

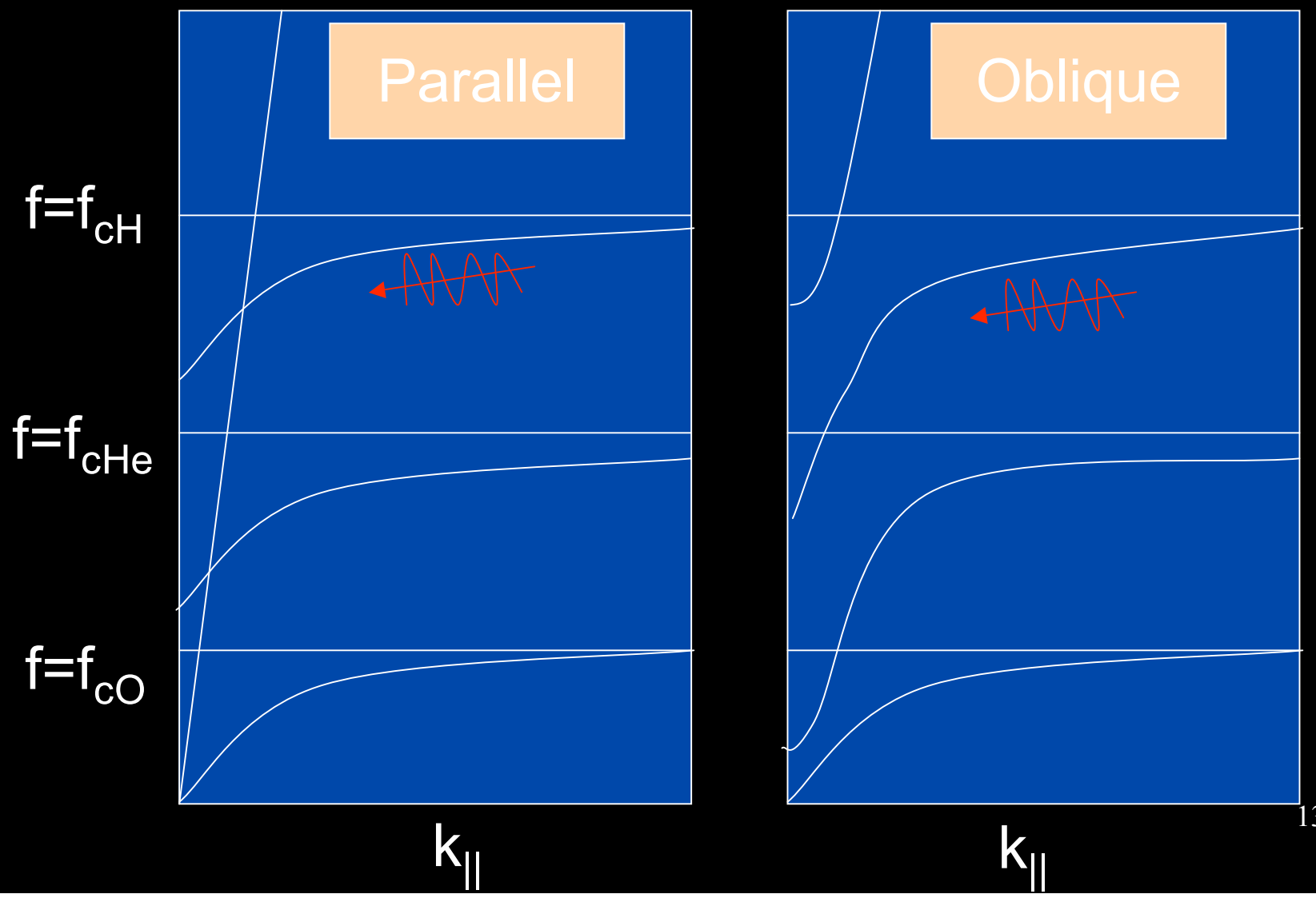
Model Ionosphere

Exponential Falloff to $n=10cm^{-3}$
Fraction of H^+, He^+ and O^+ varies

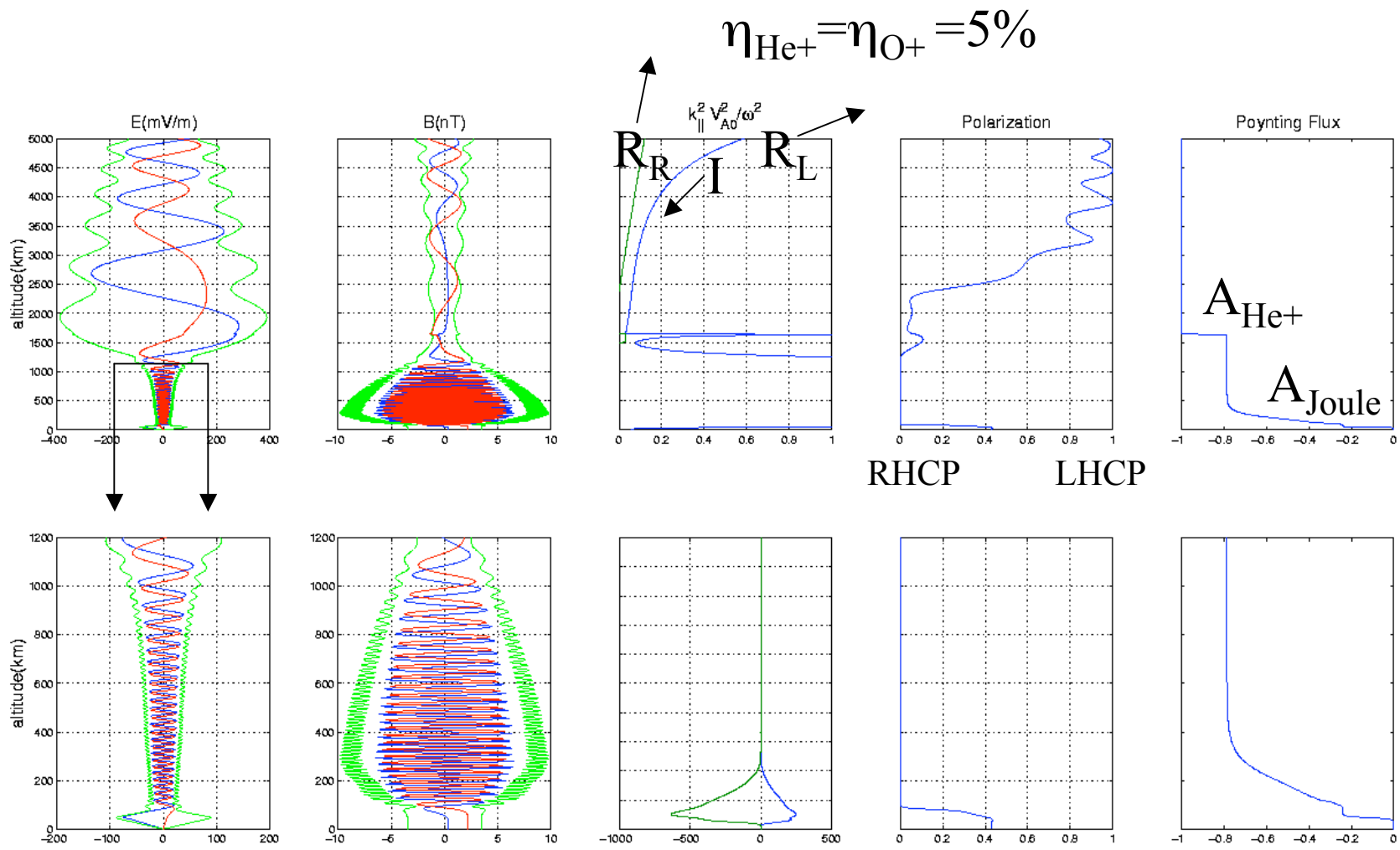


[Banks and Kockarts, 1973]

Wave Branches---Hydrogen



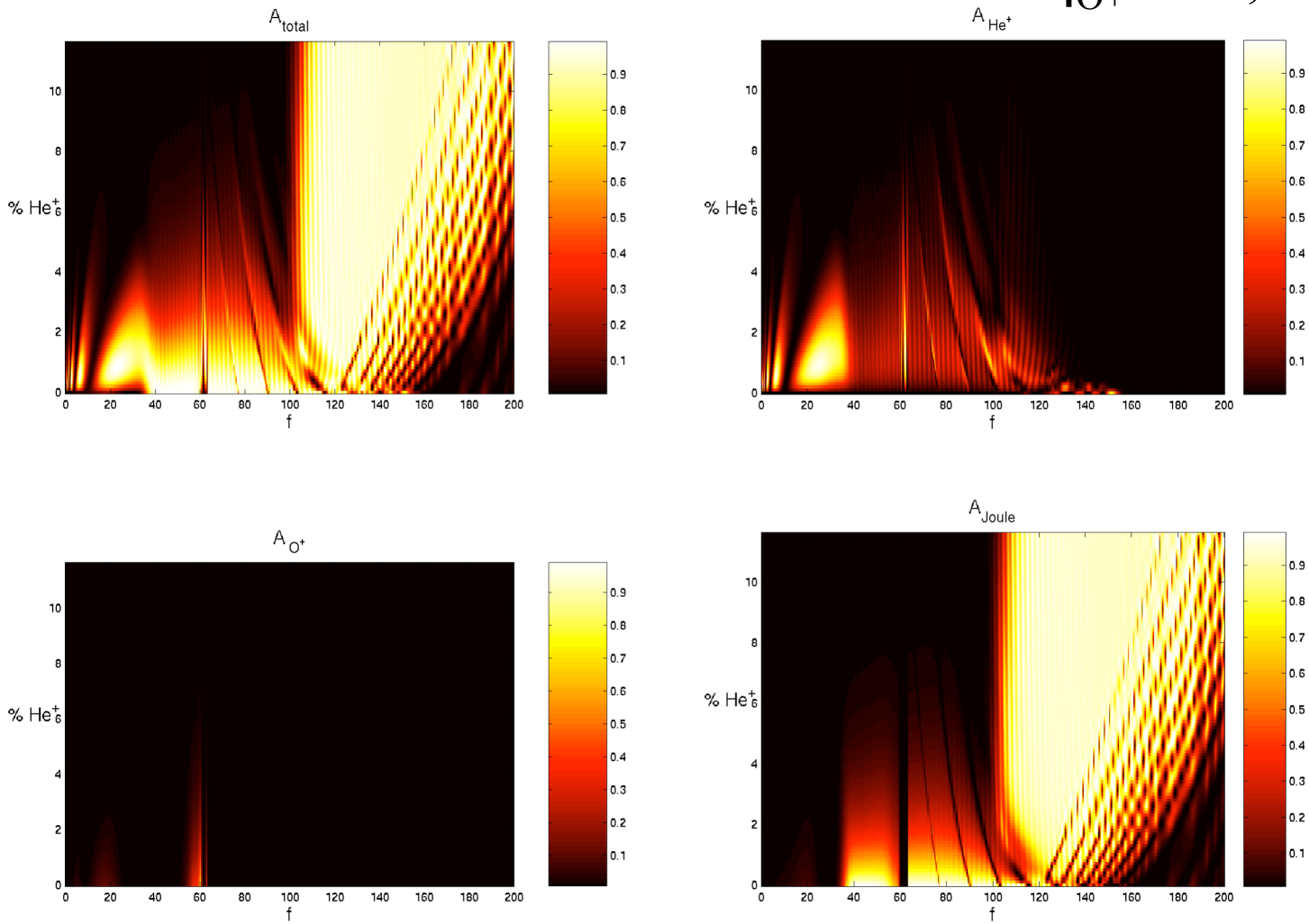
Wave Solutions (f=128Hz, θ=15) $\theta=\tan^{-1}(k_{\parallel}/k_{\perp})$



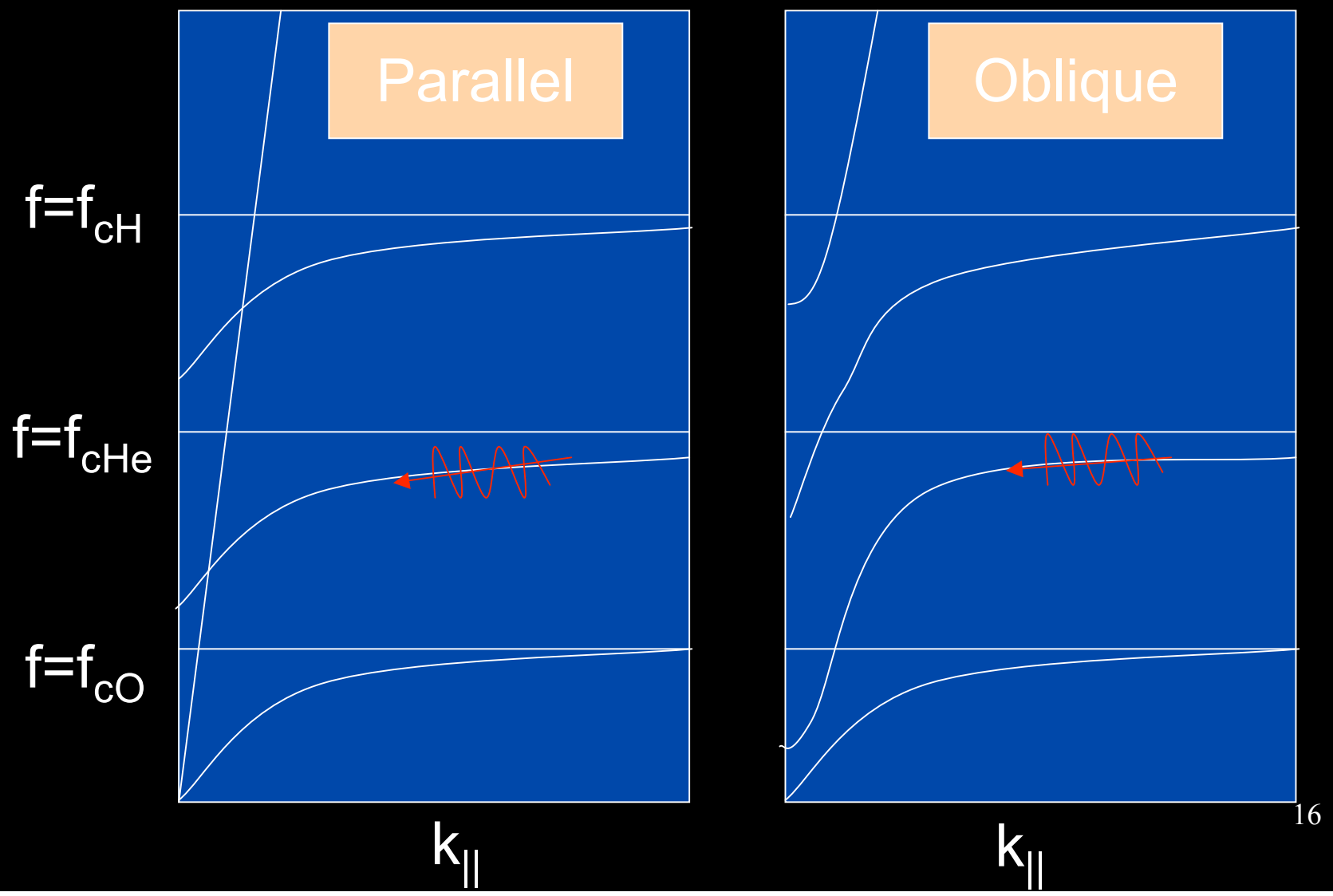
Expanded View in the Ionosphere

Absorption He^+ Concentration

η_{O+} =5%; θ=60

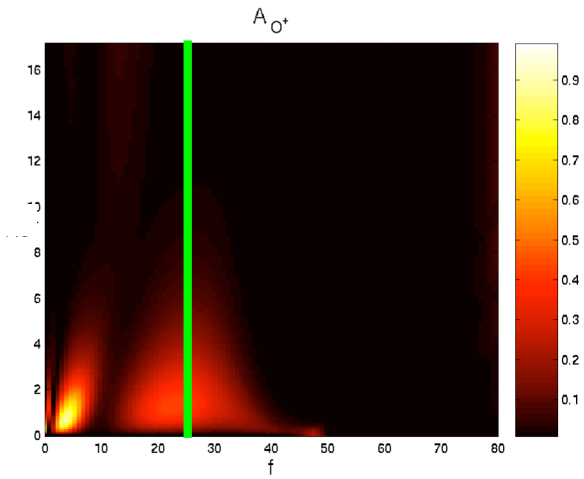


Wave Branches---Helium

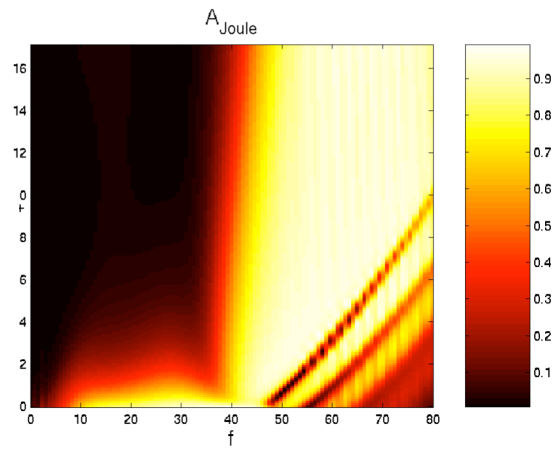


Coefficients for He^+ Branch (20% He and θ=60)

%O^+

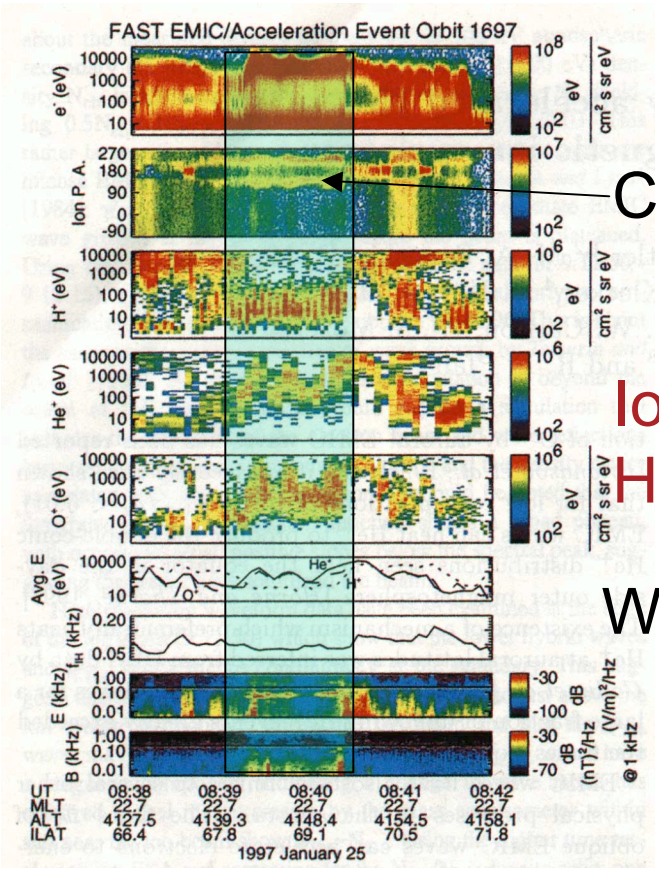


%O^+

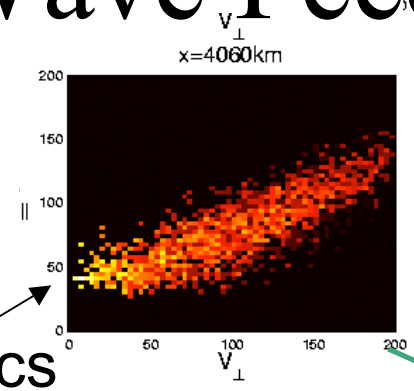


Most ion heating events at 1700 km can be explained by heating due to electromagnetic ion cyclotron waves with 25 Hz [Andre, 1998]

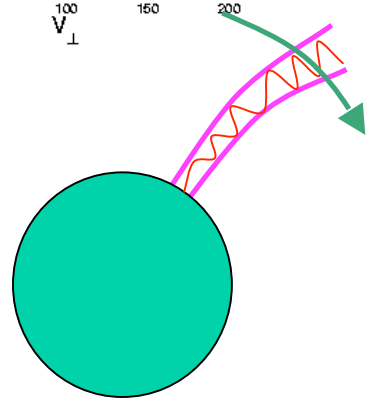
Modeling Ion Outflows with EMIC Wave Feedback

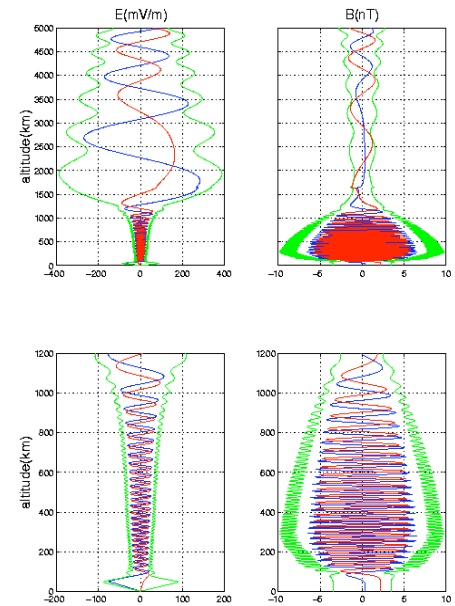


Conics



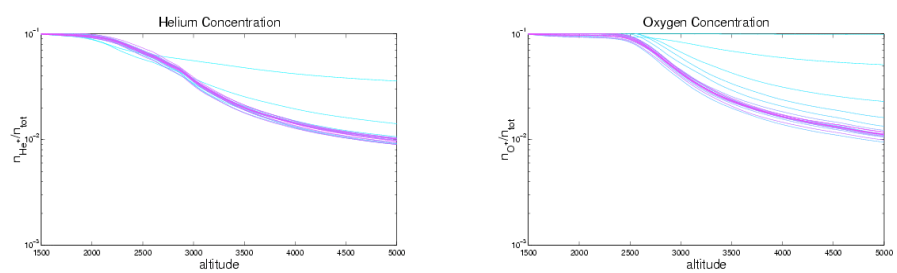
Ion Heating





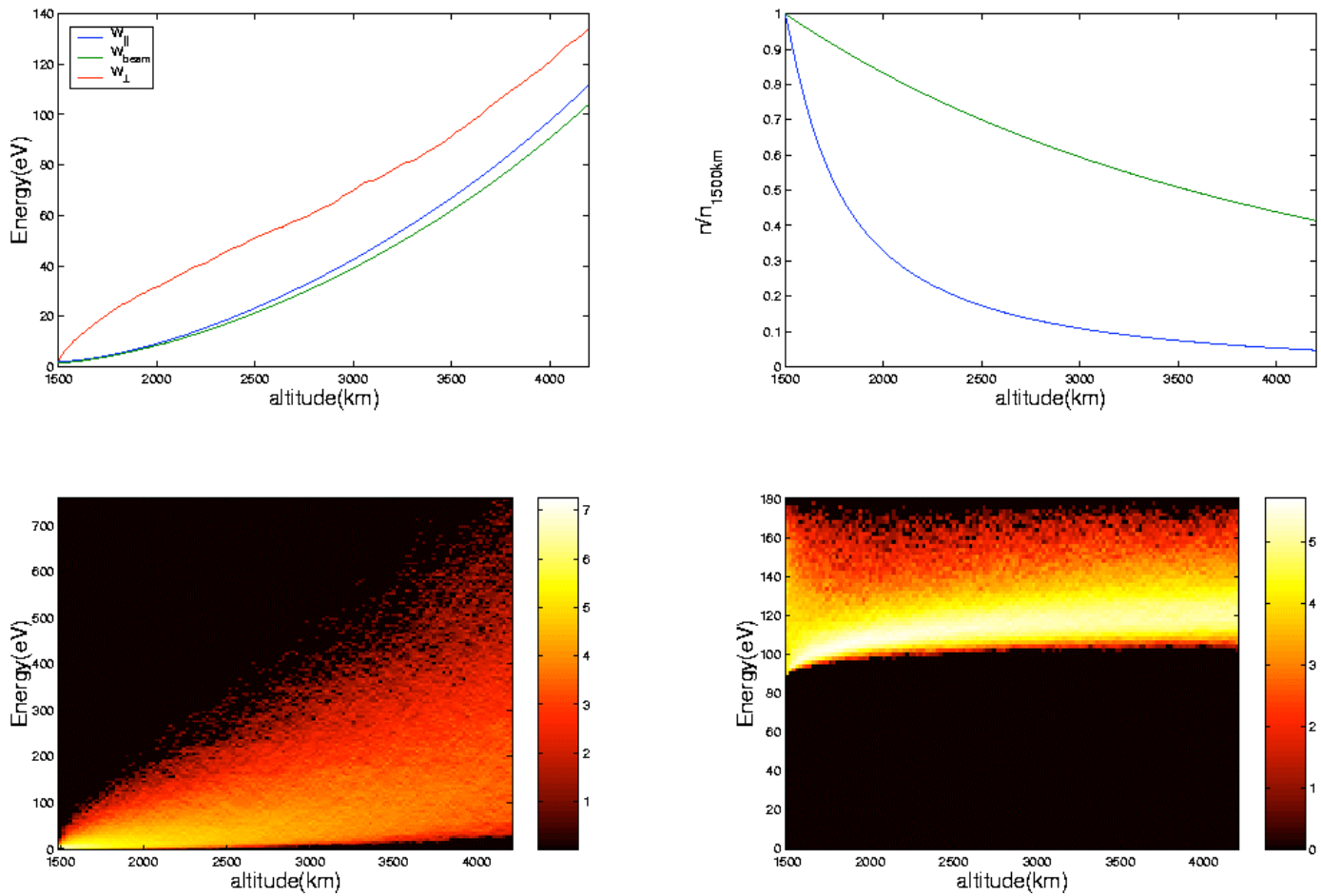
Wave Propagation

Waves



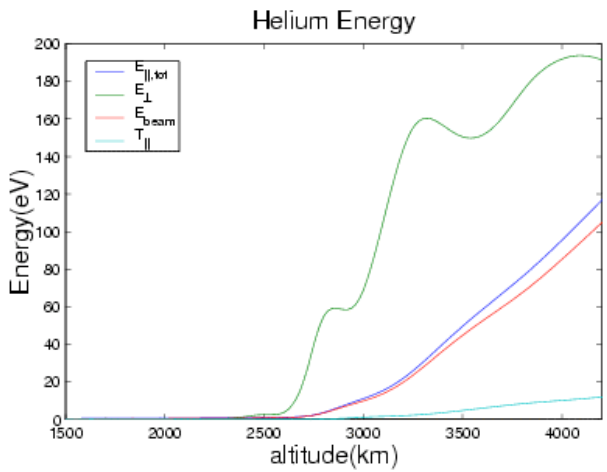
Convergence

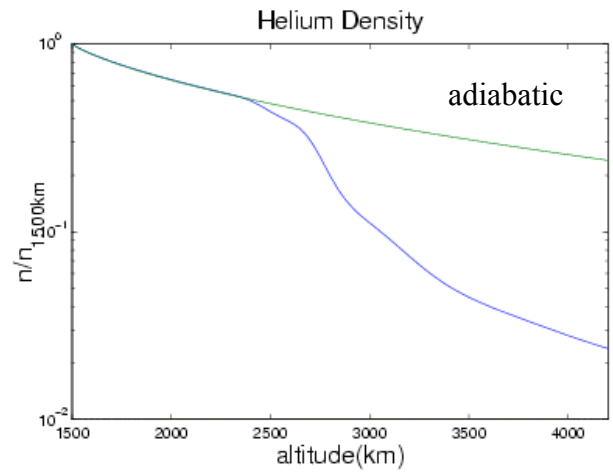
Ion Profiles (Heuristic)

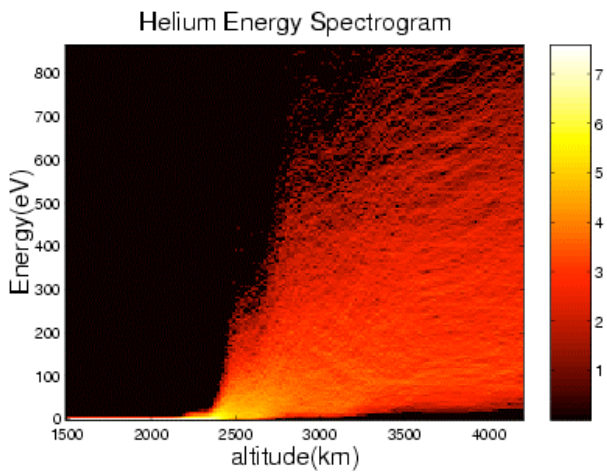


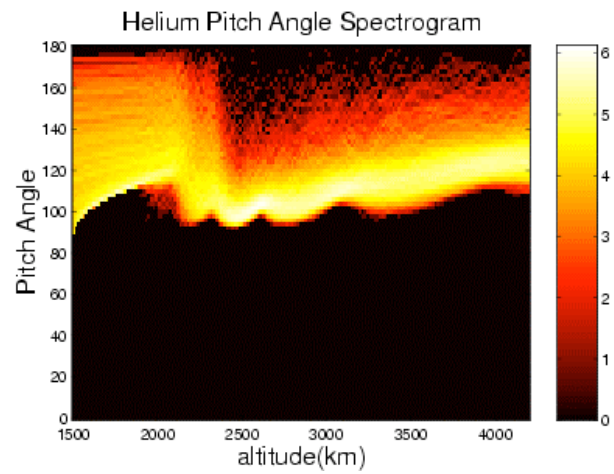
$dW_{\perp}/dt = \eta\ (q^2/2m)\ |E_{\perp}(\omega = \Omega)|^2$ with $|E_{\perp}(\omega = \Omega)|^2 \gg f^{-\alpha}$

Steady State Helium Profiles
θ=60 η_{He}=5%,η_O=1%



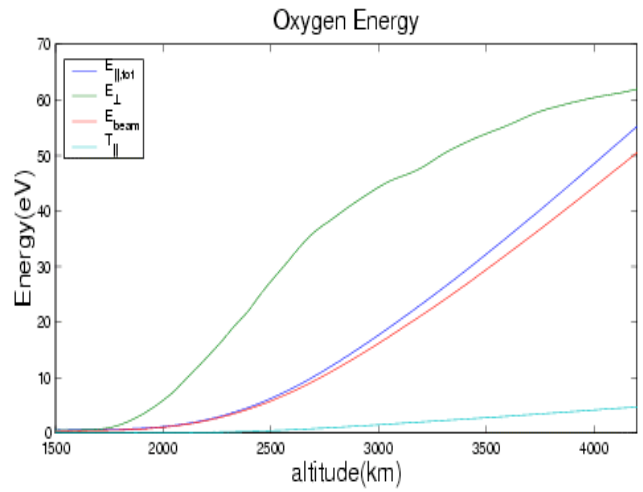


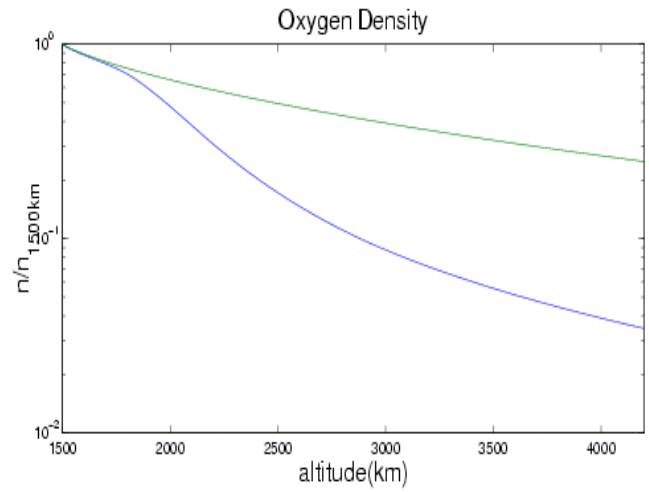


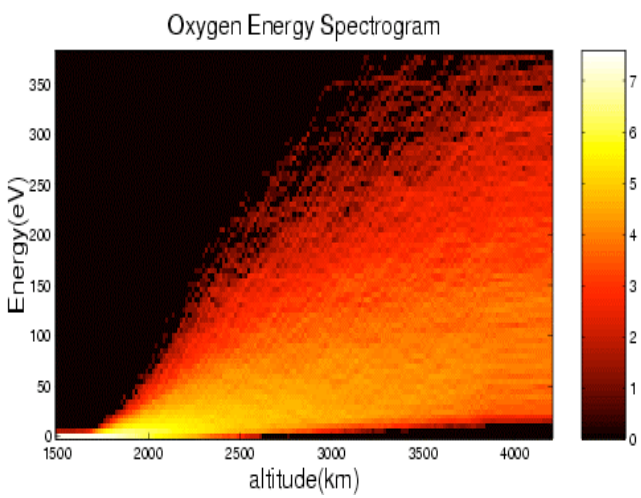


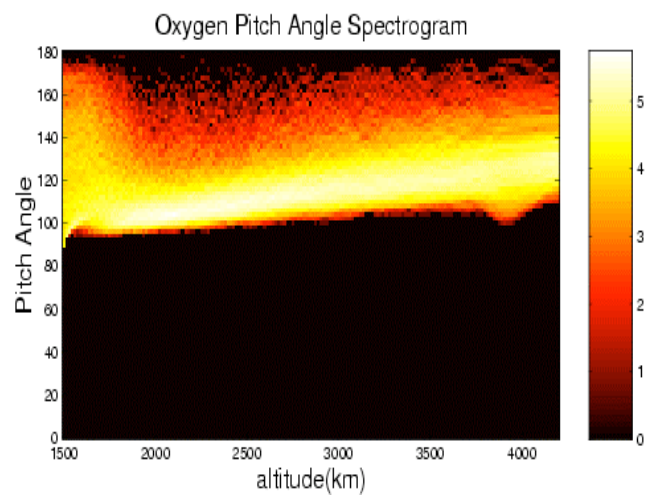
Steady State Oxygen Profiles

$\theta=60, \eta_{He}=5\%, \eta_{O}=1\%$







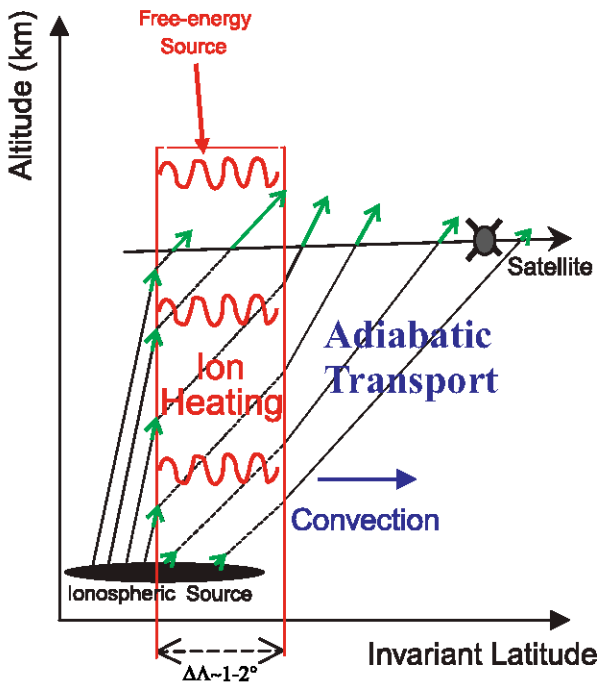


Important Considerations

- Concentrations of ions and wave structure are important to model ion heating
- Driven by beams, electric field gradients, currents, loss-cone, anisotropy
- Need to predict wave amplitude (requires nonlinear wave analysis)

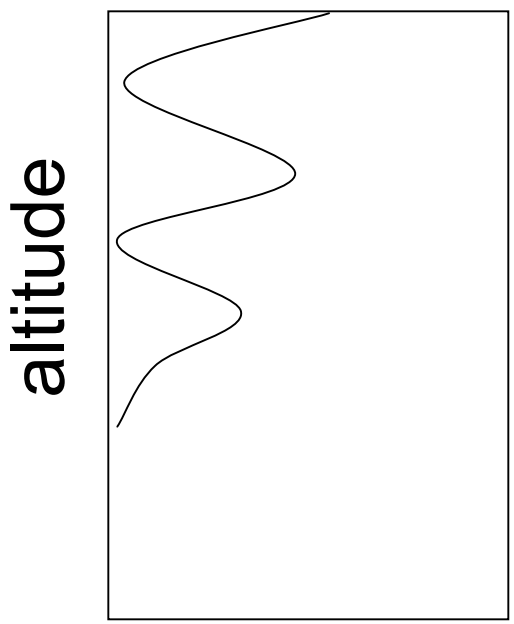
Nonlinear Stochastic Heating

Some Modifications to Ion Heating

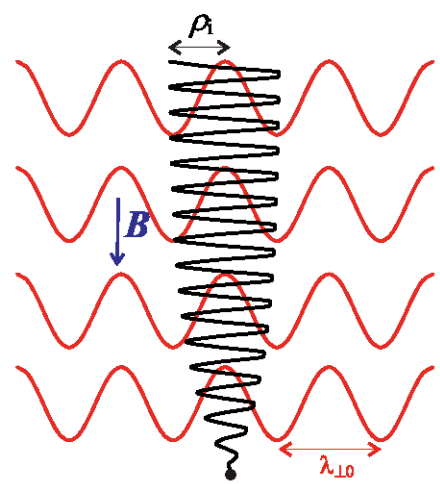


Limited Source
"Heating Wall"

Knudsen



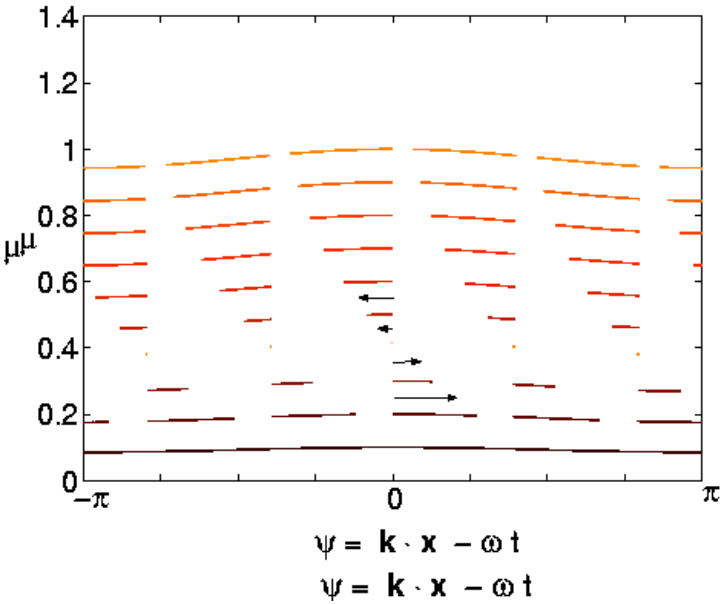
Heating
Rate

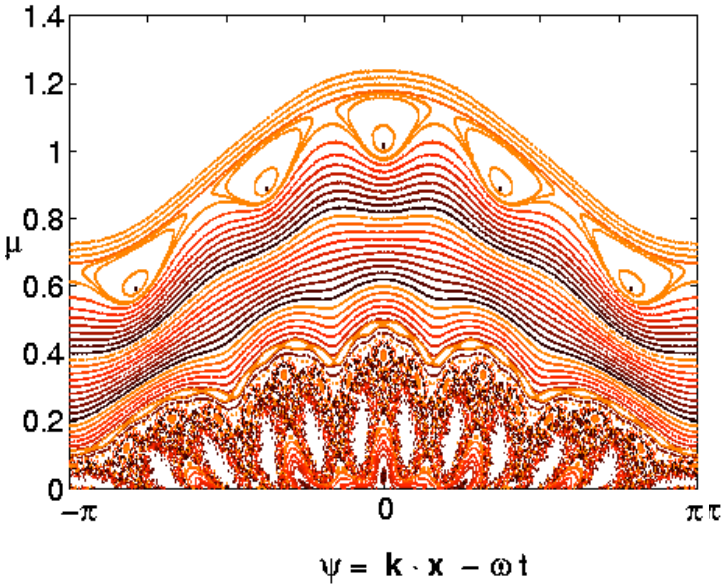


Gyroradius
Limitations

Bouhram, 2004

Stochastic Heating in Alfven Waves





$\omega = \Omega/5$

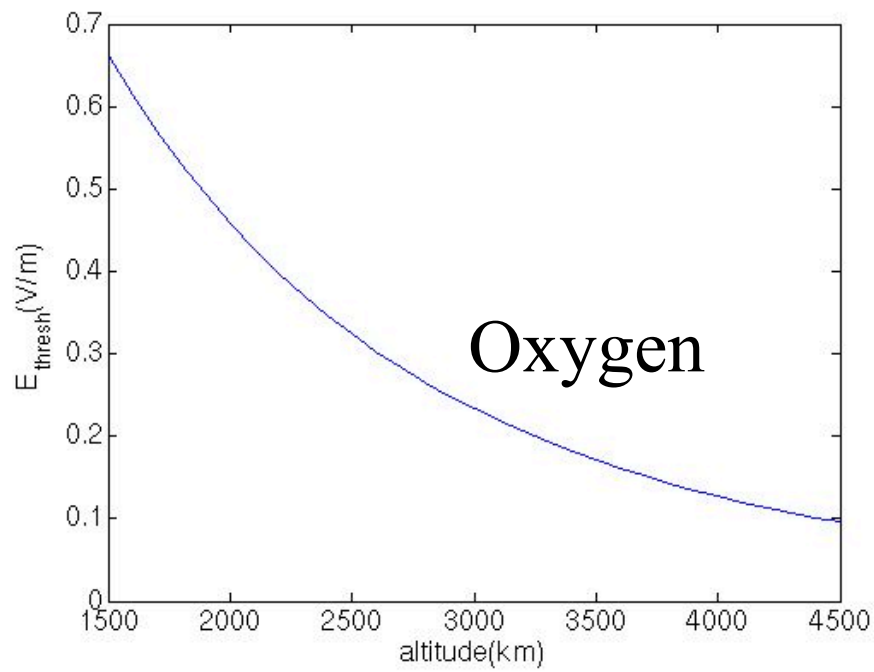
$kx_g = ek^2\Phi/(m\Omega^2) \sim 1$

Onset of Stochasticity

- $k\,\delta x_p \sim 1$ (threshold)
- $\delta x_p = \delta E / \Omega_{ci} B$
- $\delta E \sim f_{ci}\,\lambda\, B$
- $\delta E \sim 150 \lambda B^2/\mu$ V/m;

$\mu = m/m_p$, B in gauss,

λ in km



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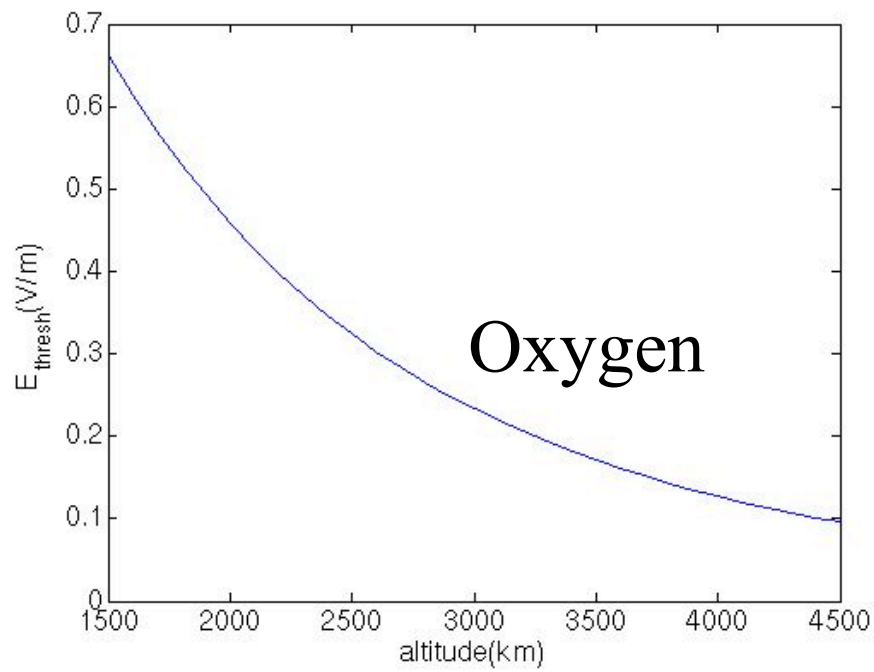
$\mu = m/m_p$, B in gauss,

λ in km

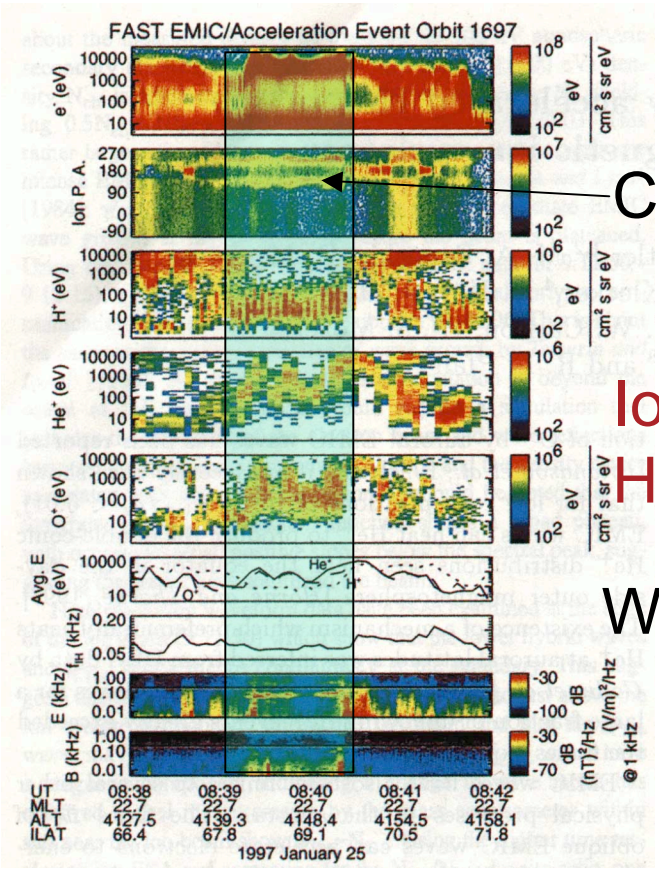
Preference for heavy ions



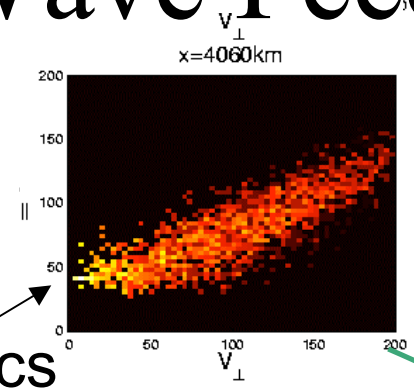
Parameterizing Stochastic Heating

- Must include Alfven wave driver, resolve structure along field line, and be able to handle small $\lambda_\perp$
- Can provide heating rate (diffusive if broadband)

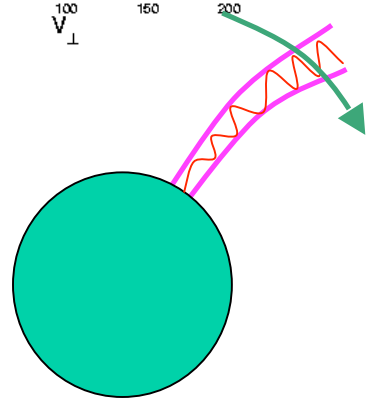
Modeling Ion Outflows with EMIC Wave Feedback

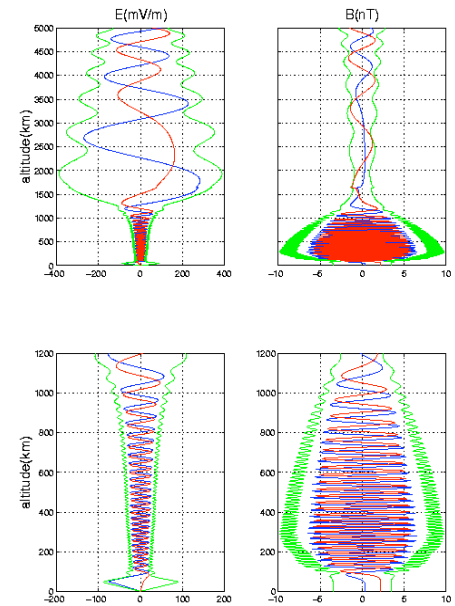


Conics



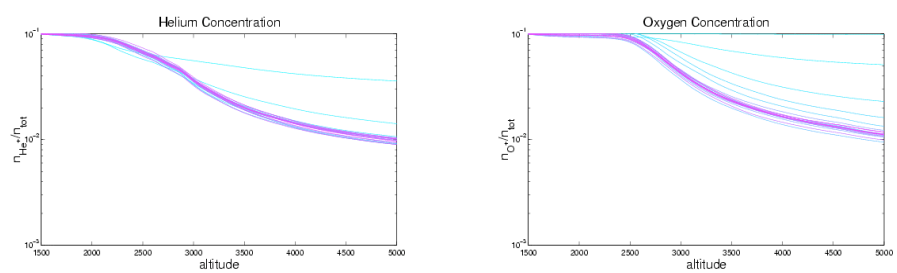
Ion Heating





Wave Propagation

Waves



Convergence

Future Work

- Time development of plasma profile
  - Multiple timescale (fast waves and slow profile)
  - Quasi-linear treatment
- Feedback on the Wave Source
  - Kinetic integral equation for waves
  - Large-scale field (Alfven Wave) accelerates electrons and provides free energy for EMIC waves
- Coupling Wave Heating Rate Code to More Sophisticated Transport Model
  - Other iononspheric transport mechanisms (convection-2d, photoelectrons, precipitating electrons, …)