Fast Stochastic Electron Heating in the Ionosphere

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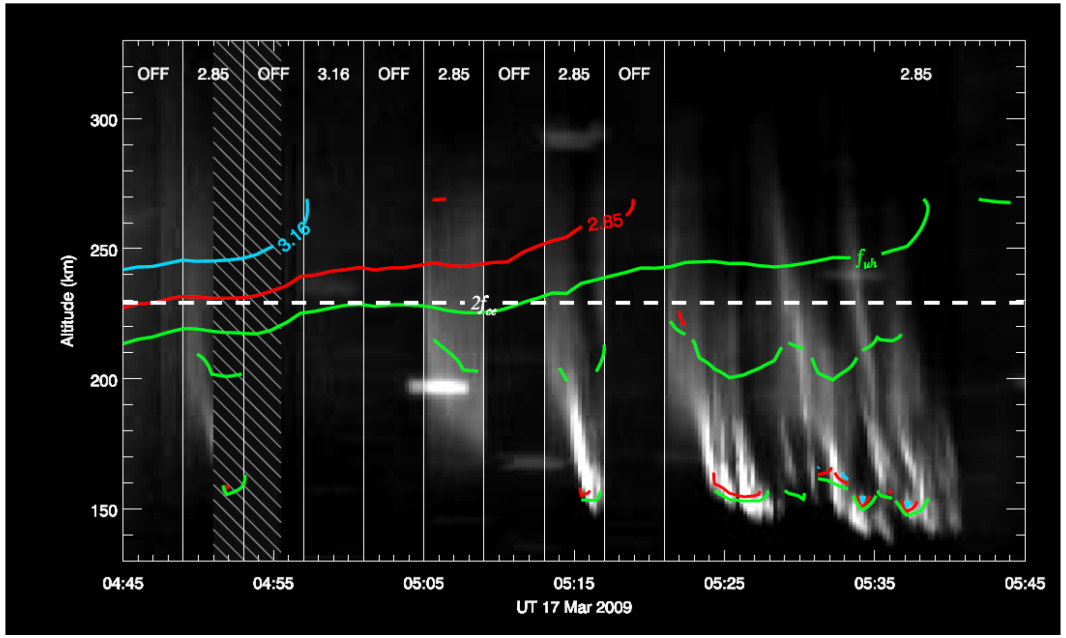
Background – Descending Layers

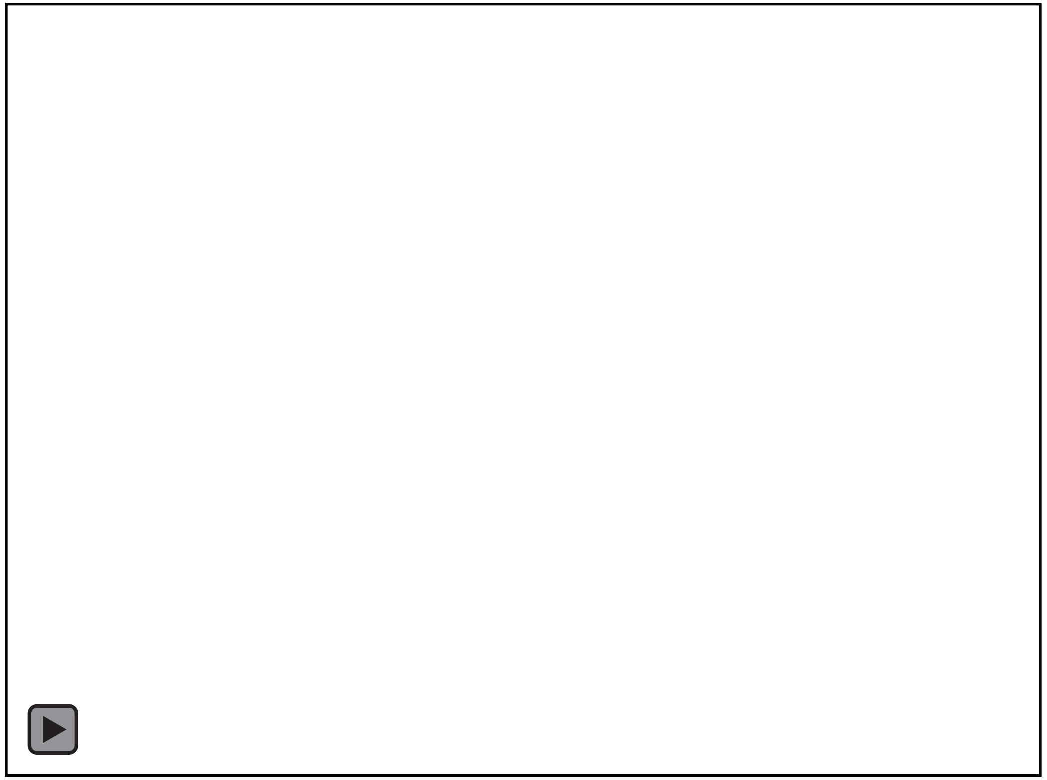
- Plasma density increases with altitude
  - HF waves encounter resonances
  - Ex. $\omega_0 = \omega_{UH}$; $\omega_0 = \omega_{pe}$
  - Upper hybrid resonance and Langmuir resonance.
- O-mode turning point corresponds with Langmuir resonance
- Electromagnetic pump mode converts to electrostatic Langmuir waves, create Langmuir turbulence.
- Langmuir turbulence
  - Accelerate hot electrons, suprathermal
  - Cool electrons oscillate
- Suprathermal electrons stream out, ionize neutrals
- At plasma density, pump is reflected, layer descends



Pedersen et al. – GRL 2010
doi:10.1029/2009GL041895

Background – Descending Layers

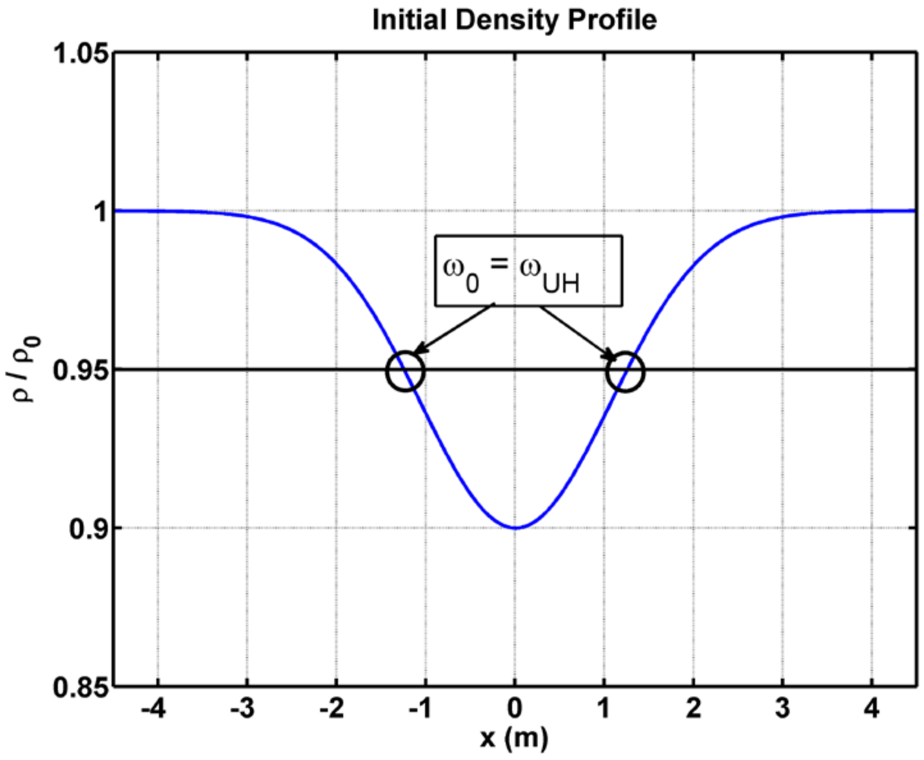
- Eliasson et al (2012) studied this process with a multi-scale numeric model
- Explains the Langmuir turbulence, but is not self-consistent
- Initial electron temperature is a free parameter
- But Langmuir turbulence is only efficient if the electrons are already hot, ~ 4000K
- Candidates for thermal heating, upper hybrid and lower hybrid turbulence.
- Our work: Develop a model/simulation that makes this process self-consistent.



Eliasson et al. – JGR Space 2012
doi: 10.1029/2012JA018105

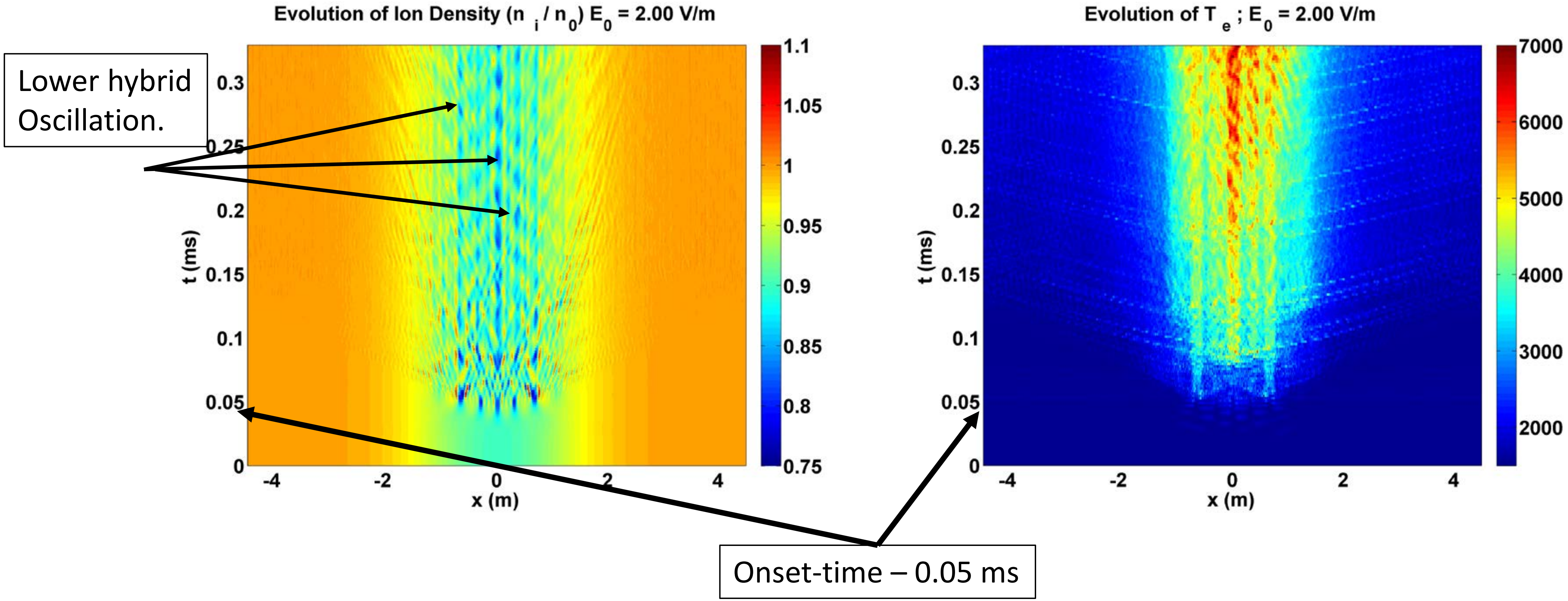
Simulation

Parameter	Value	Parameter	Value
n_0	$1.27 \times 10^{11}\ \mathrm{m}^{-3}$	ω_{pe}	$2.009 \times 10^7\ \mathrm{s}^{-1} = 3.197$ MHz
B_0	5.17×10^{-5}T	ω_{ce}	$9.092 \times 10^6\ \mathrm{s}^{-1} = 1.447$ MHz
E_0	2.0 V/m	ω_0	$21.59 \times 10^6\ \mathrm{s}^{-1} = 3.436$ MHz
T_{e0}	1500 K	v_{Te0}	$1.508 \times 10^5\ \frac{\mathrm{m}}{\mathrm{s}}$
T_{i0}	1000 K	ω_{LH}	$194.8 \times 10^3\ \mathrm{s}^{-1} = 31$ kHz

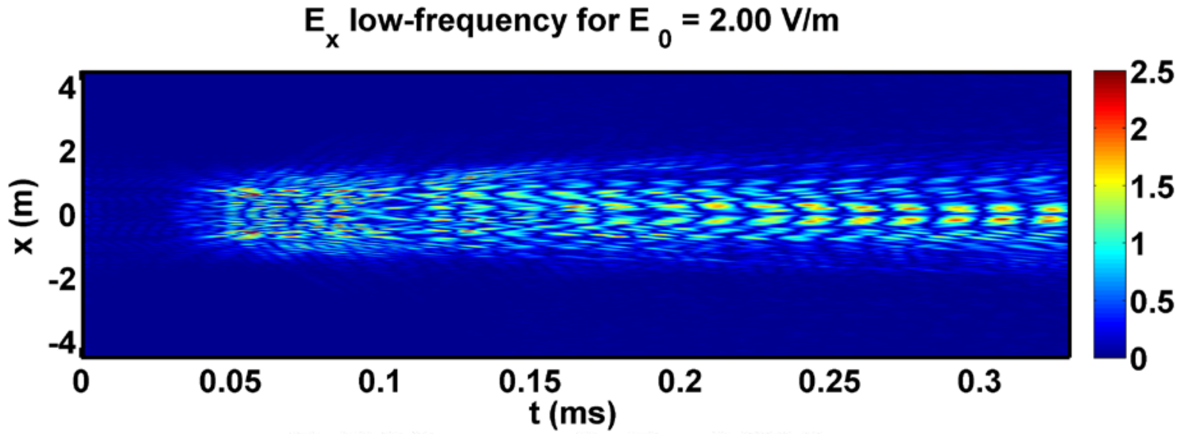


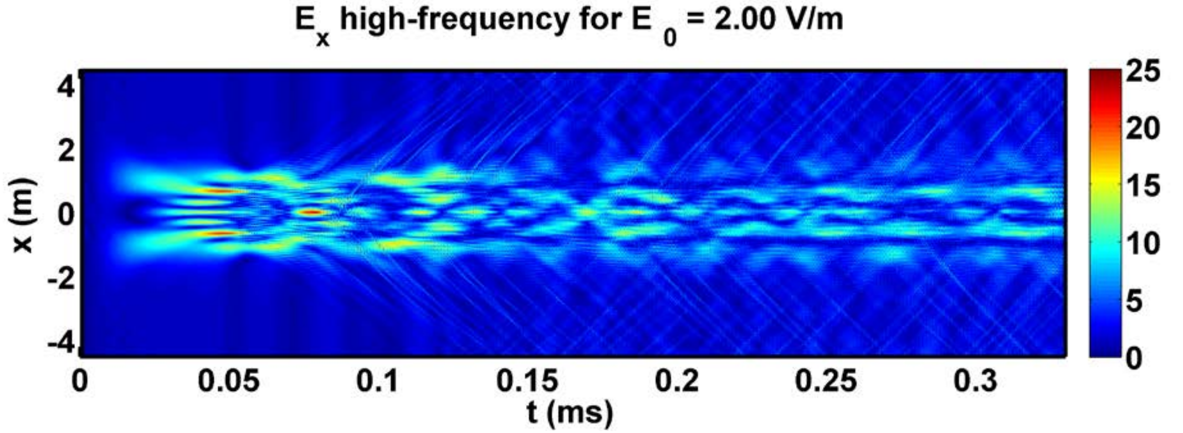
- 600 spatial over 9m, 84000 time steps over ~300μs
- ~1.5 cm / x_grid, ~3.6 ns / t_grid

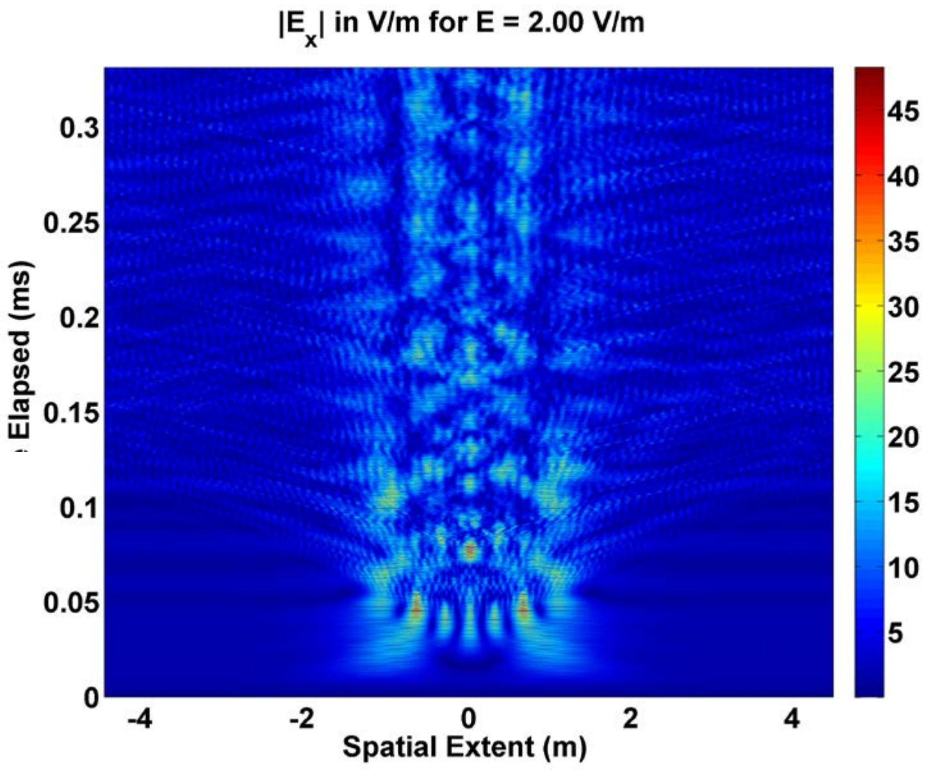
Simulation – Results – Ion Density



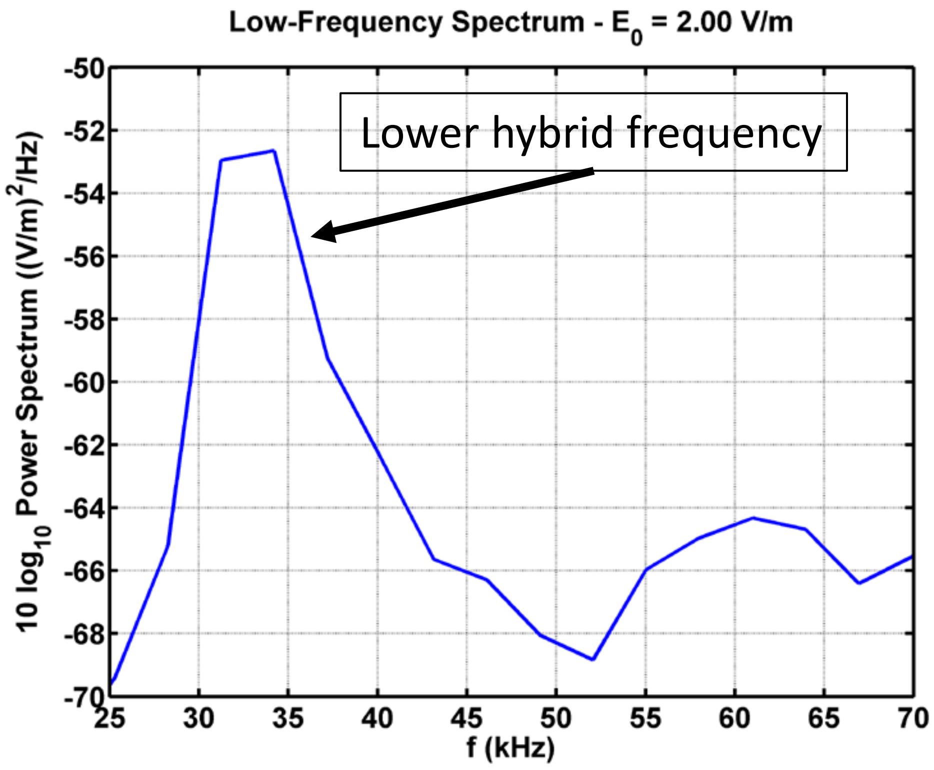
Simulation – Results – Wave Modes

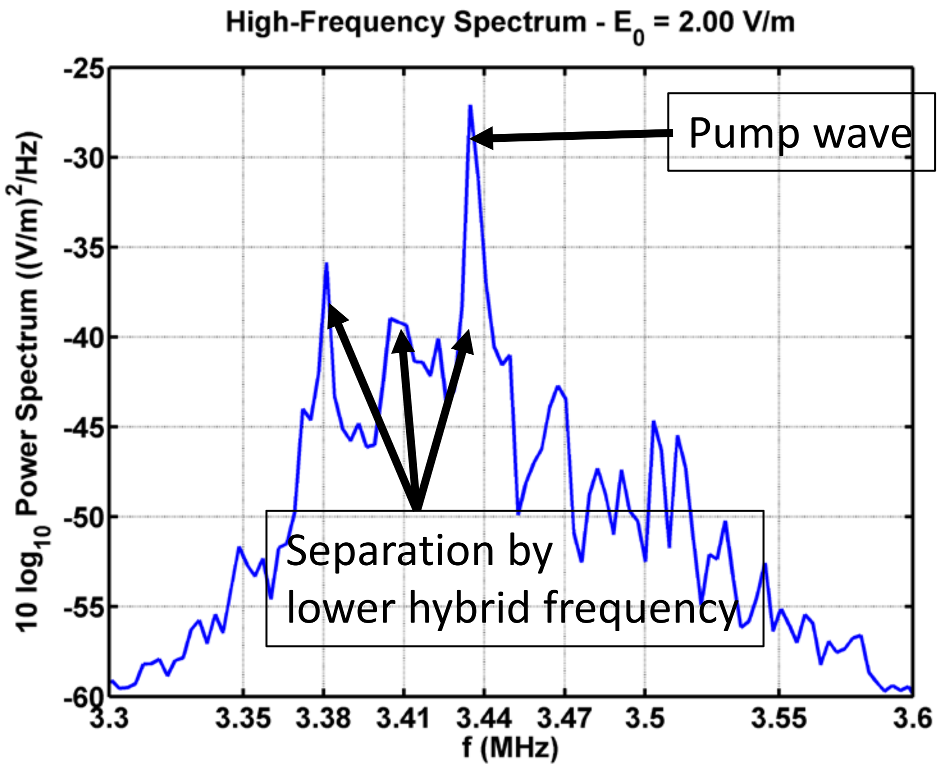




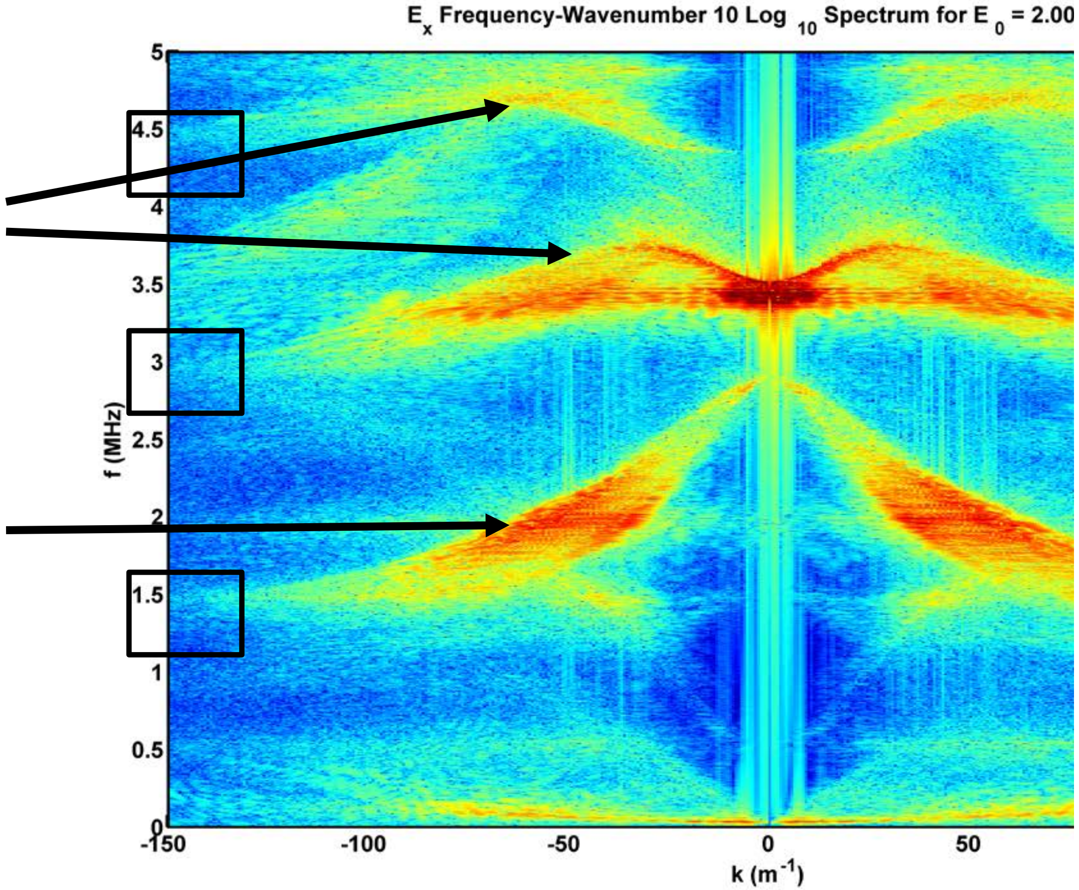


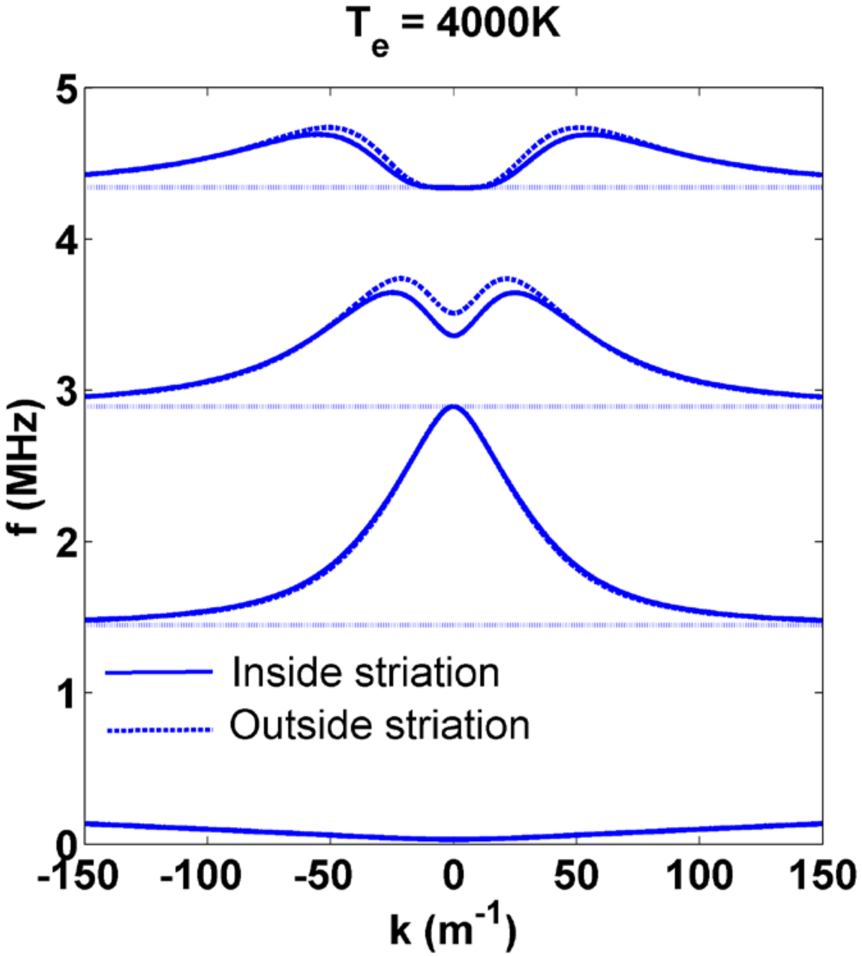
Simulation – Results – Wave Modes



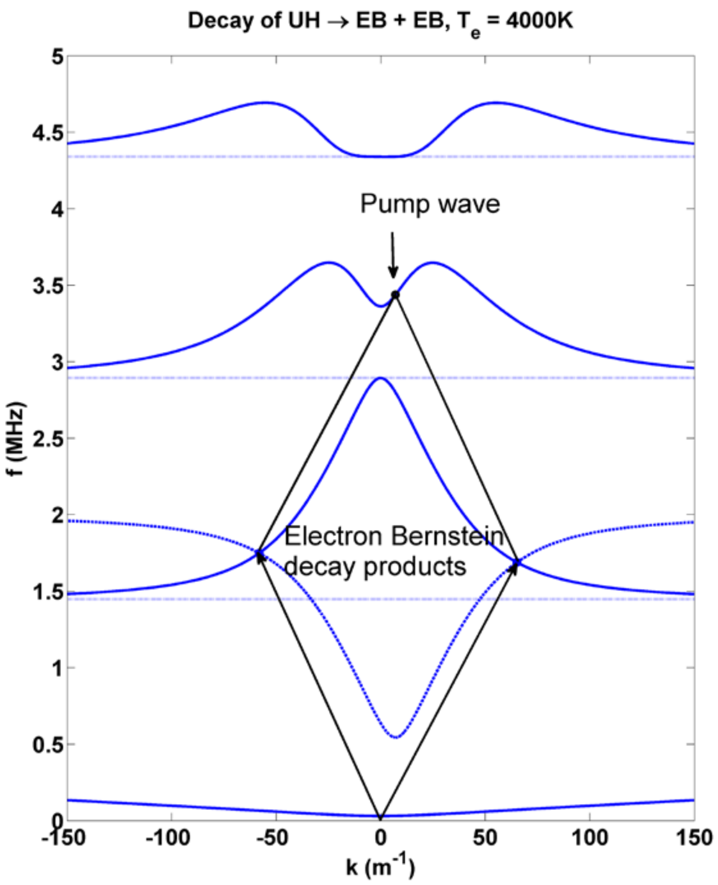


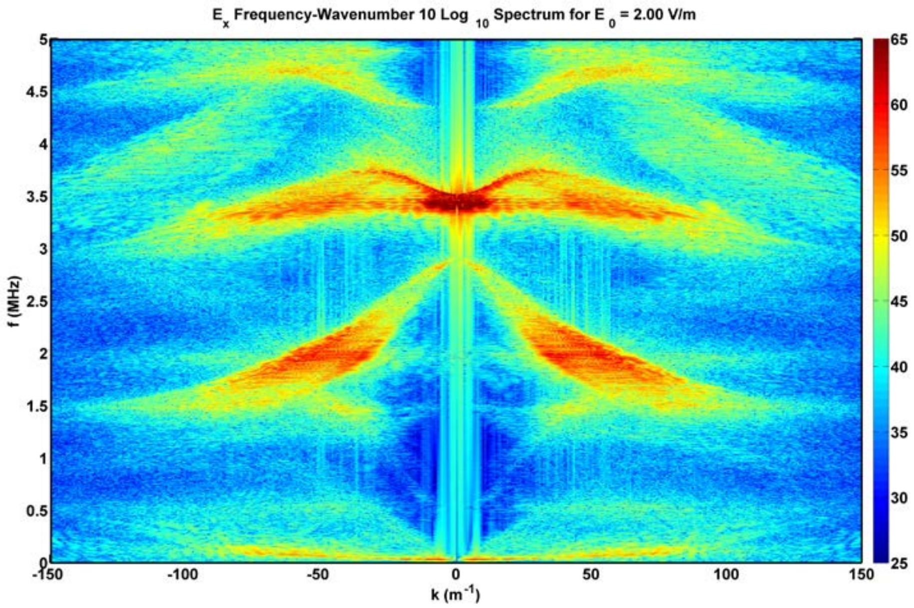
Simulation – Results – Wave Modes

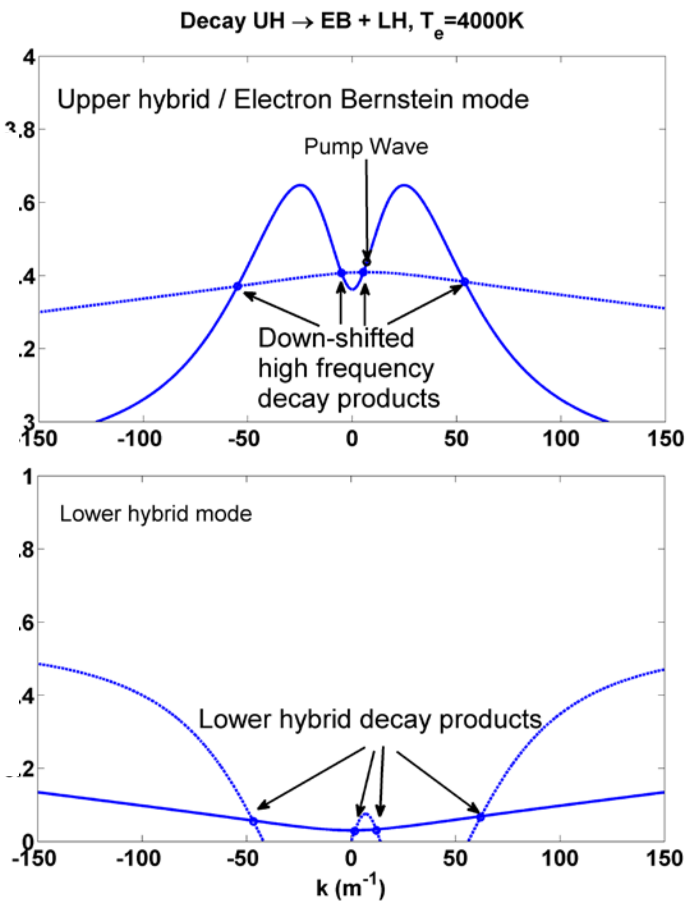




Analysis – Decay Modes

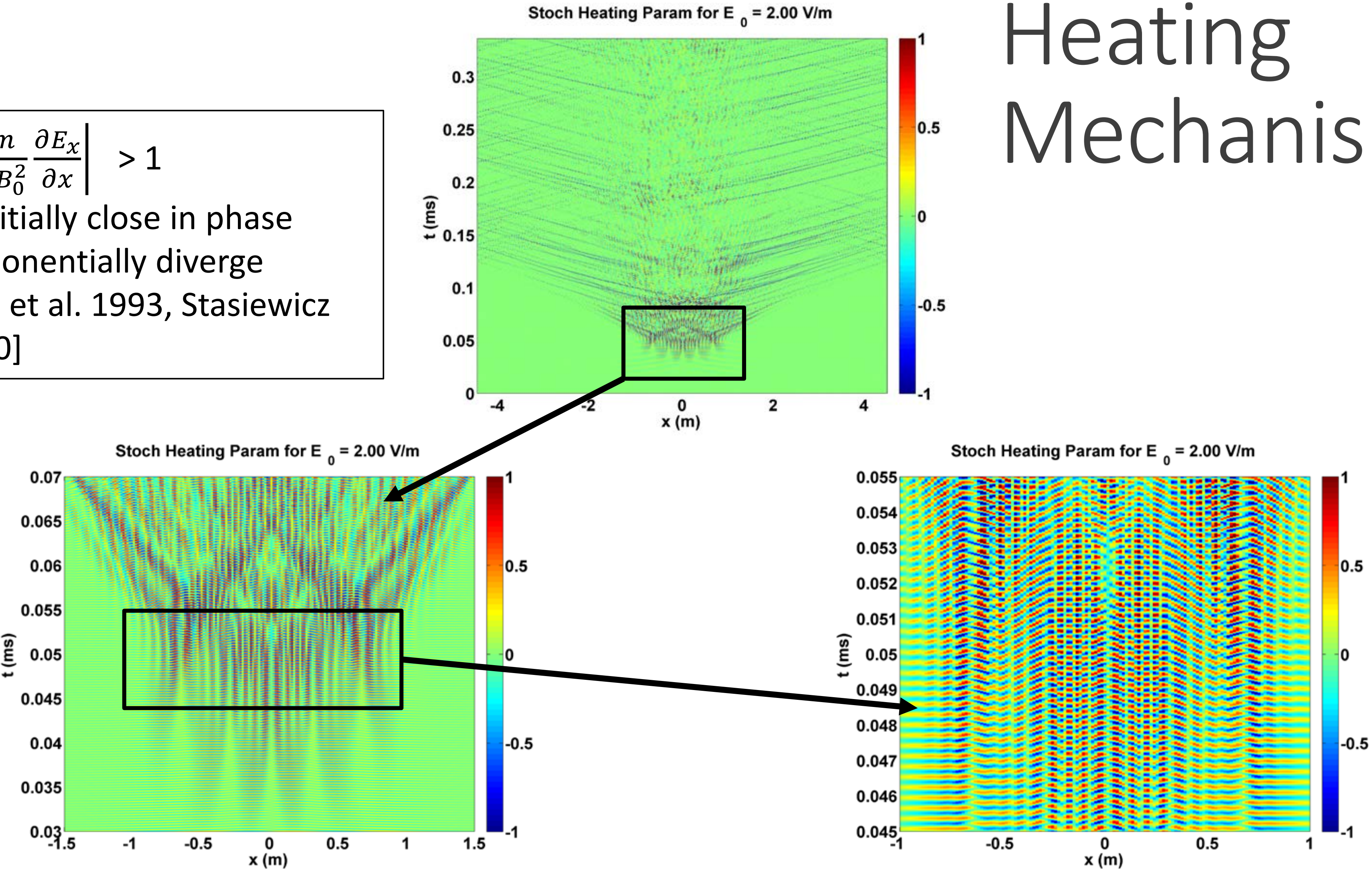




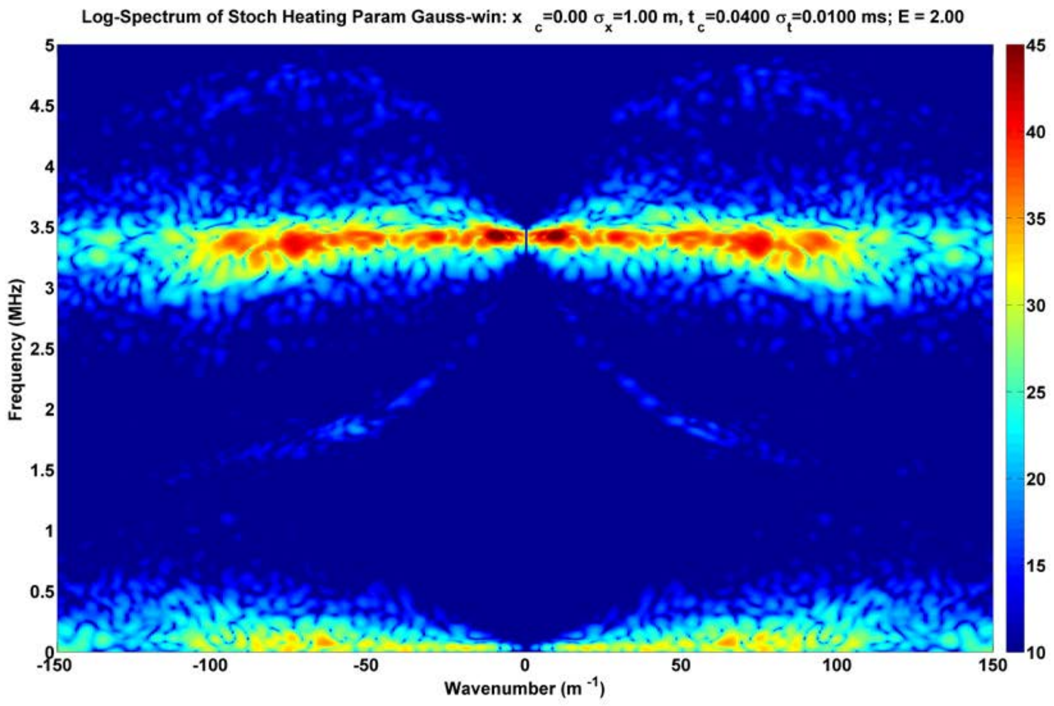


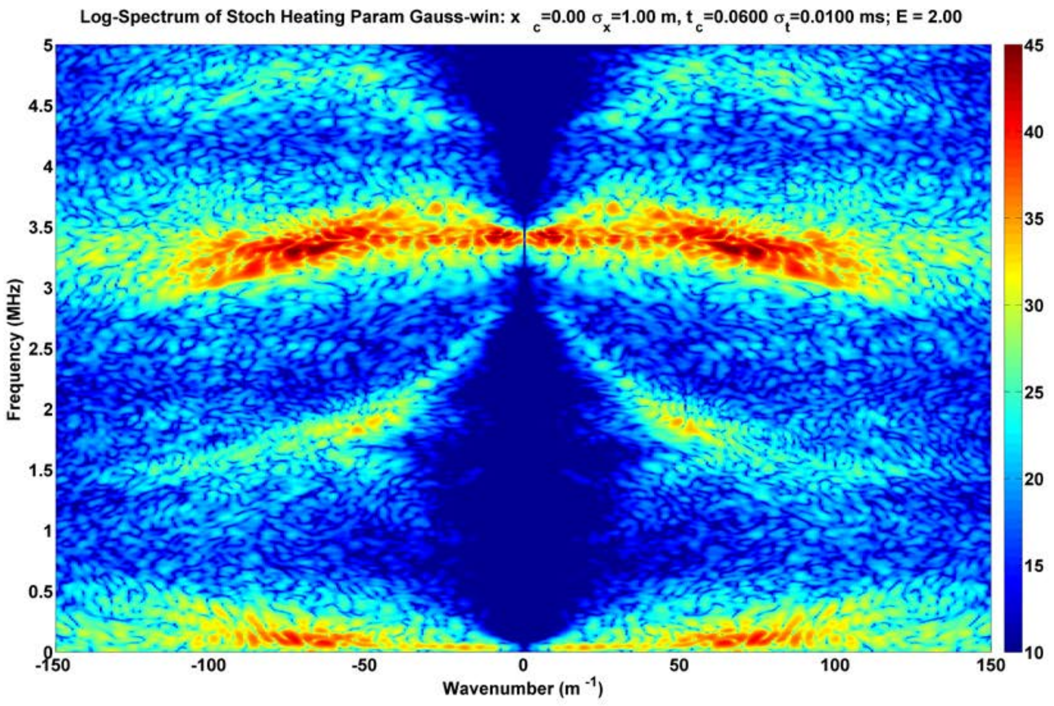
Analysis – Heating Mechanism

- $|A| = \left|\frac{m}{qB_0^2}\frac{\partial E_x}{\partial x}\right| > 1$
- Orbits initially close in phase space exponentially diverge
- [Balikhin et al. 1993, Stasiewicz et al. 2000]



Analysis – Heating Mechanism



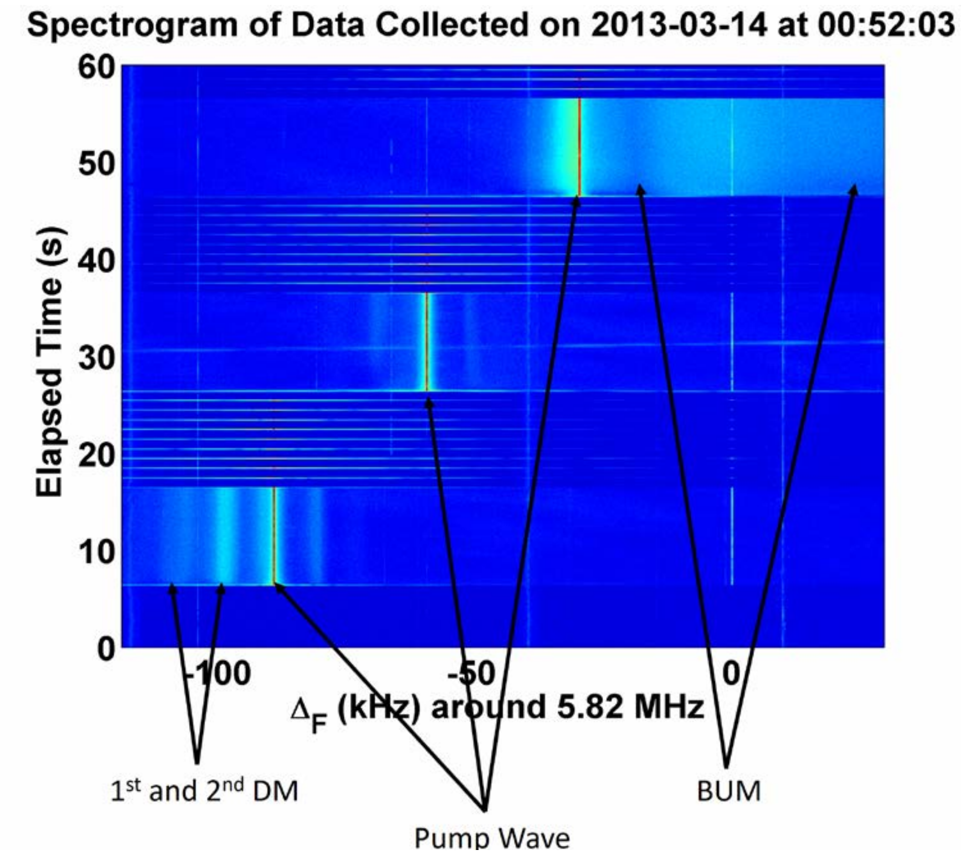


Summary

- Our simulations shows bulk, collisionless, heating of electrons in striations
- Pump waves mode-convert to upper hybrid waves trapped in the striation
  - These convert to upper hybrid and lower hybrid pairs that condense to small wavenumbers
  - Also decay to two different branches of electron Bernstein waves. N = 1, 2
- Threshold for Stochasticisty
  - Electron Bernstein Waves exceed thresholds for stochasticity.
  - Threshold breaking corresponds to characteristic onset-time
  - Primary source of collisionless heating.
  - Main contribution from the N=2 branch (upper hybrid converts to electron Bernstein wave + lower hybrid)
- Bulk temperatures consistent with those required by theories of descending layer formation.

Future Work

- Simulation done at UH resonance
- $\omega_0 = \omega_{UH}$
- Far from other resonances, intentionally
- At HAARP,
  - Experiments at double resonance
  - $\omega_0 = \omega_{UH} = N\,\omega_{ce}\ with\ N = 1, 2, 3, 4 \ldots$
  - DM – evidence of 3-wave; upper hybrid decays to upper hybrid + lower hybrid.
  - BUM – 4-wave (!) interaction that includes electron Bernstein waves.
  - BUM – super-small striations (cm scale)



Najmi et al 2014 JGR - Space