New Results on Artificial Plasma Layers

combining the old with the new

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**Invited Presentation
19th Ionospheric
Interactions Workshop
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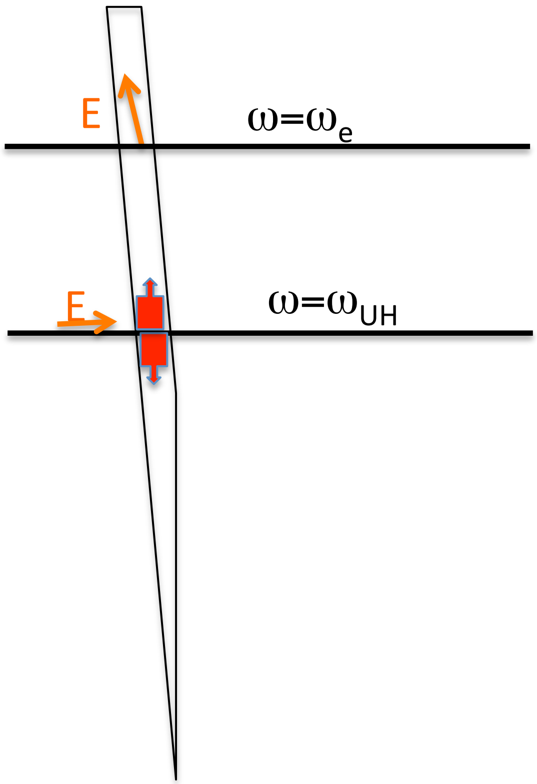
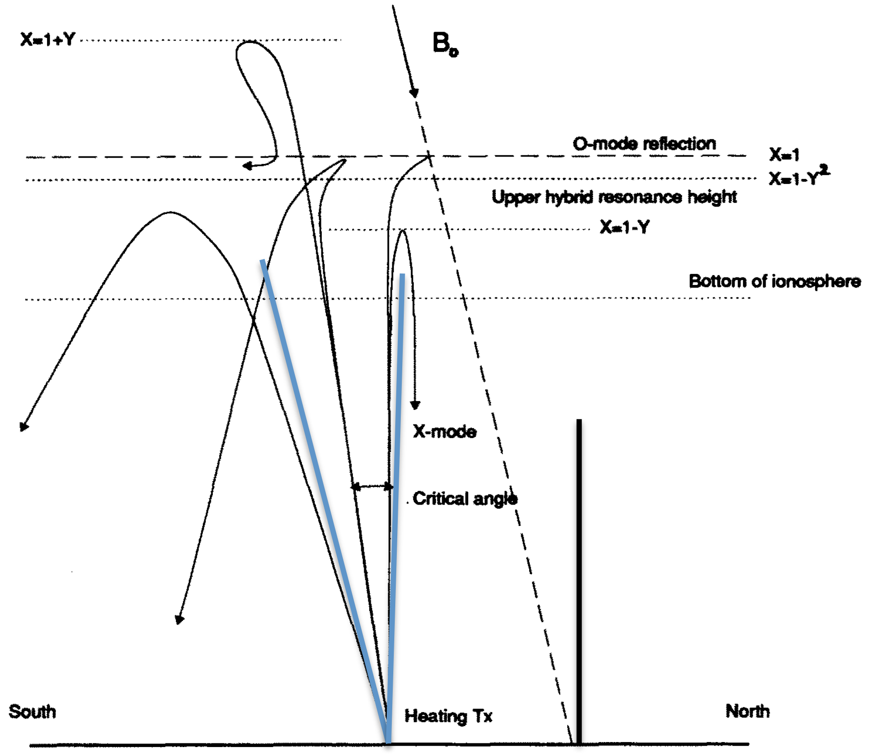
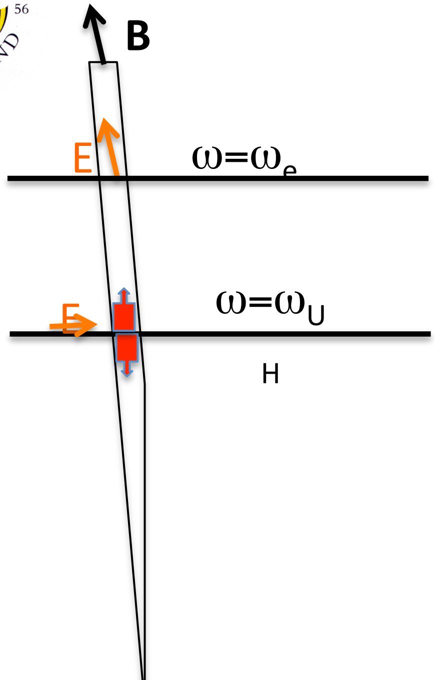
Arecibo, PR**

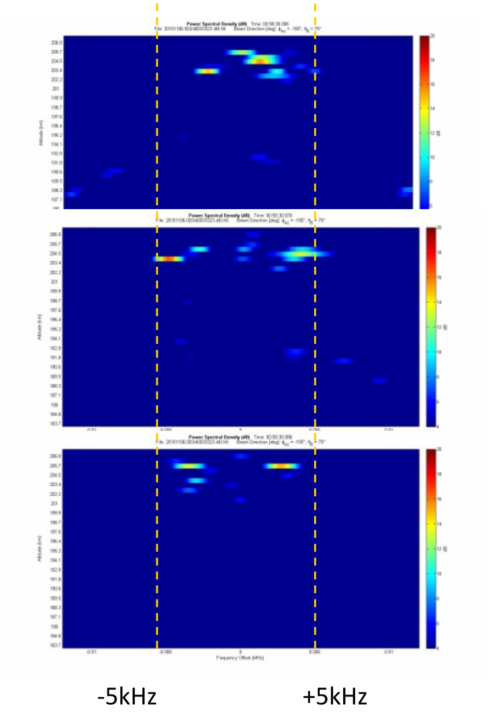
Key Physics Ideas

- Electron acceleration controlled by Langmuir turbulence at the reflection height
- Electron heating controlled by upper hybrid heating including dual resonance
- Field aligned heat transport of heated plasma and energetic electrons




Ray paths for HF radio waves





Multi-time and length scale code (DAIL code suite- Eliasson et al. JGR 2012): (i)El. Accel in SLT, (ii)Transport model for accel. El.,(iii) ionization (iv) Chemistry package (recomb.,excit…)

Input: (i) HF E at 100 km (ii) Ambient density (iii) T_e

Output: (i)Temporal evolution of density and optical emissions (ii) Supra-thermal EDF

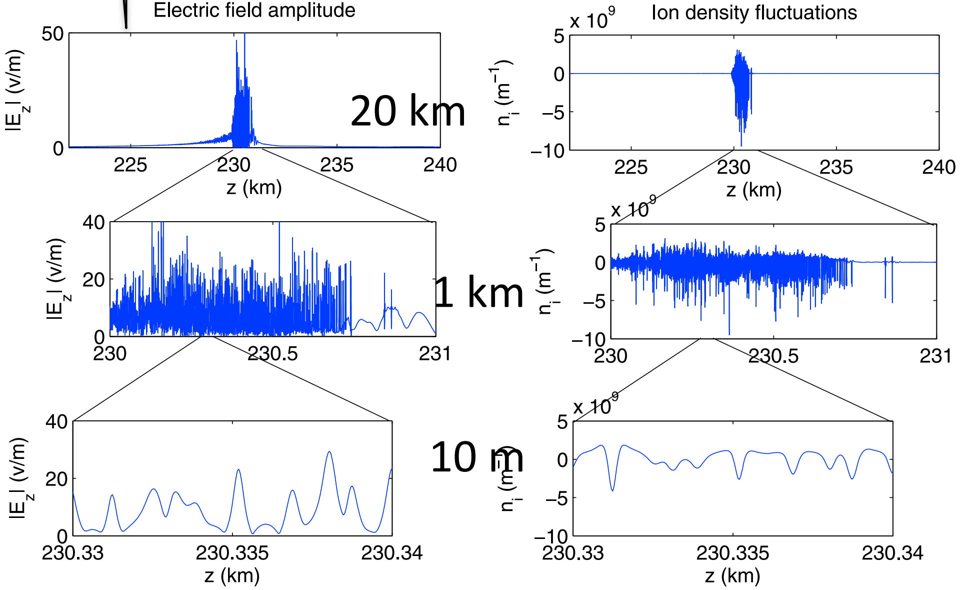
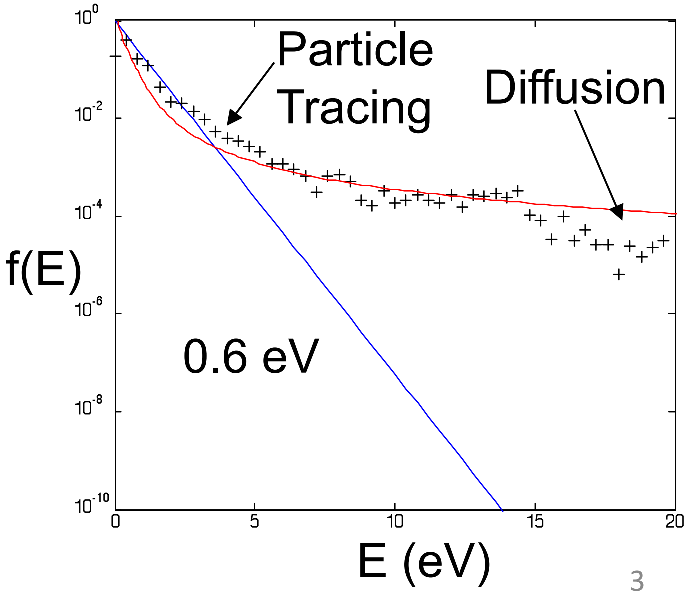
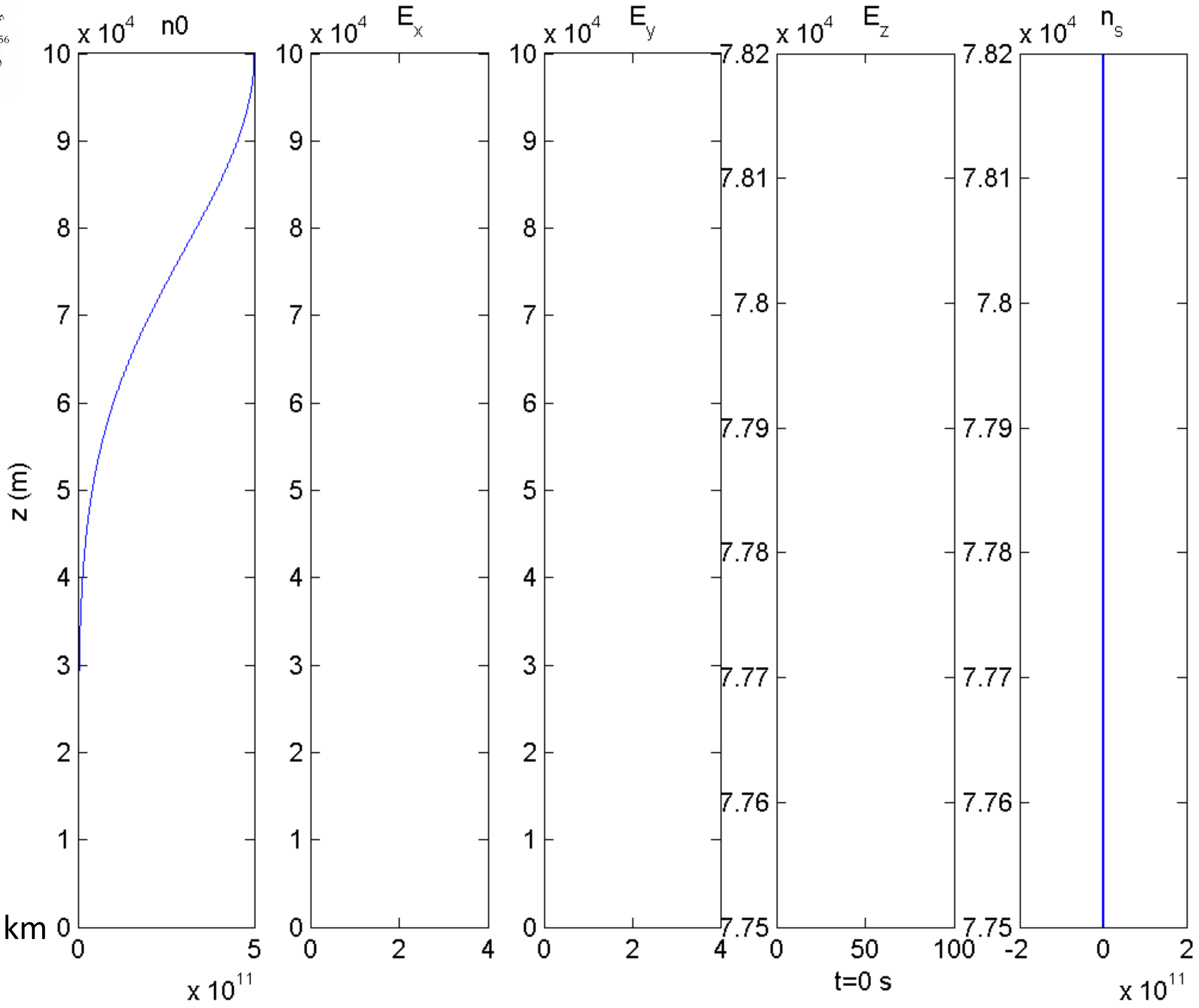


Figure 2. The amplitude of E_z and slowly varying ion density fluctuations n_i at various altitudes, for $E_O = 1.5\text{V/m}$.

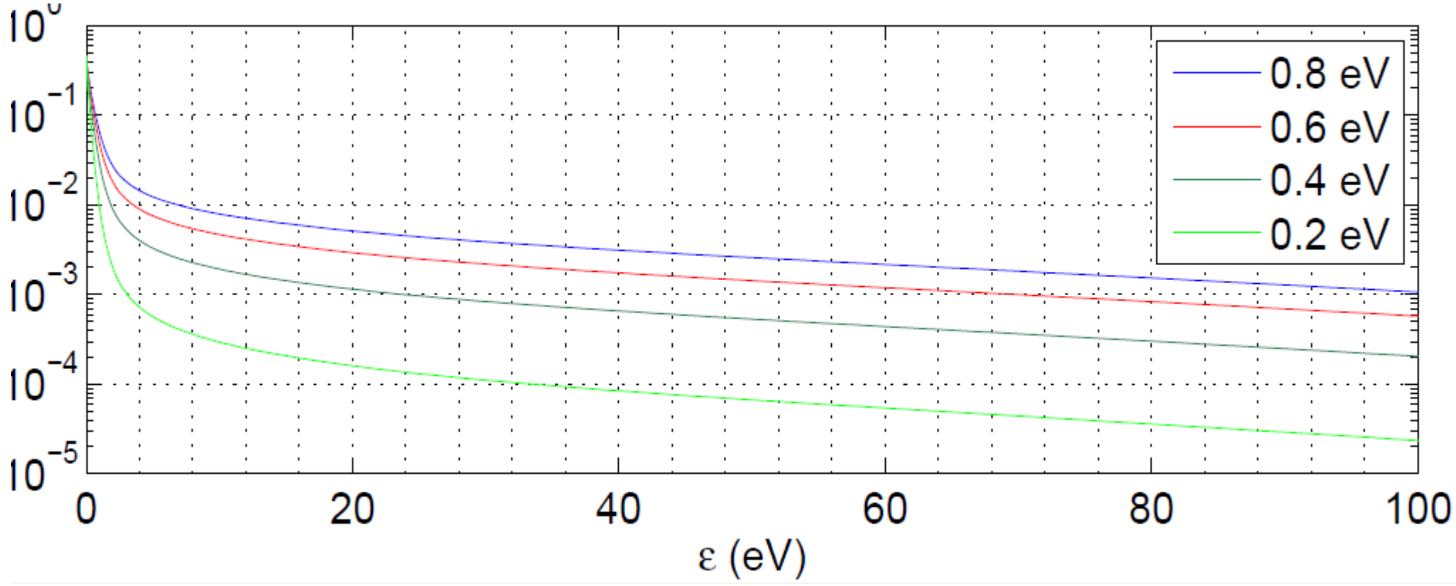


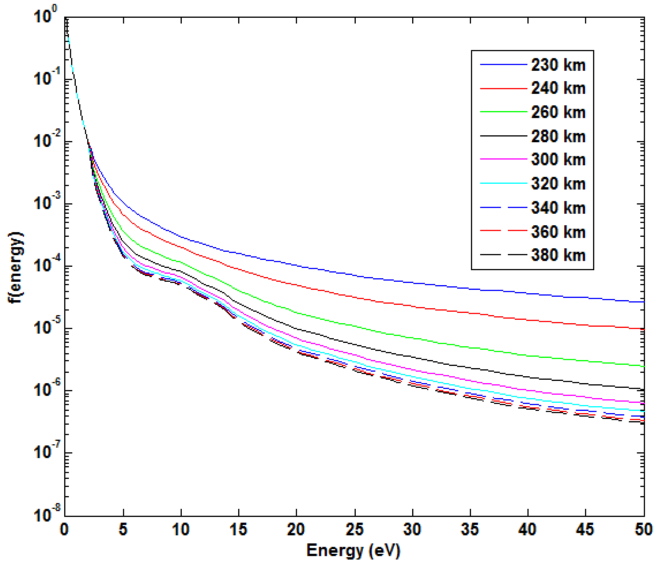

x 10^4 n0
x 10^4 E_x
x 10^4 E_y
x 10^4 E_z
x 10^4 n_s
z (m)
10
9
8
7
6
5
4
3
2
1
0
7.82
7.81
7.8
7.79
7.78
7.77
7.76
7.75
0 5
x 10^11
0 2 4
0 2 4
0 50 100
t=0 s
-2 0 2
x 10^11

100 km

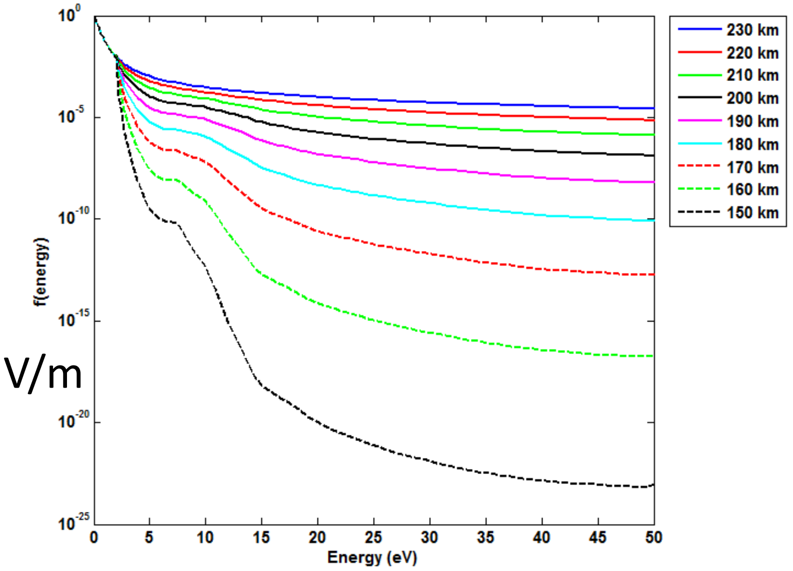
.7 km

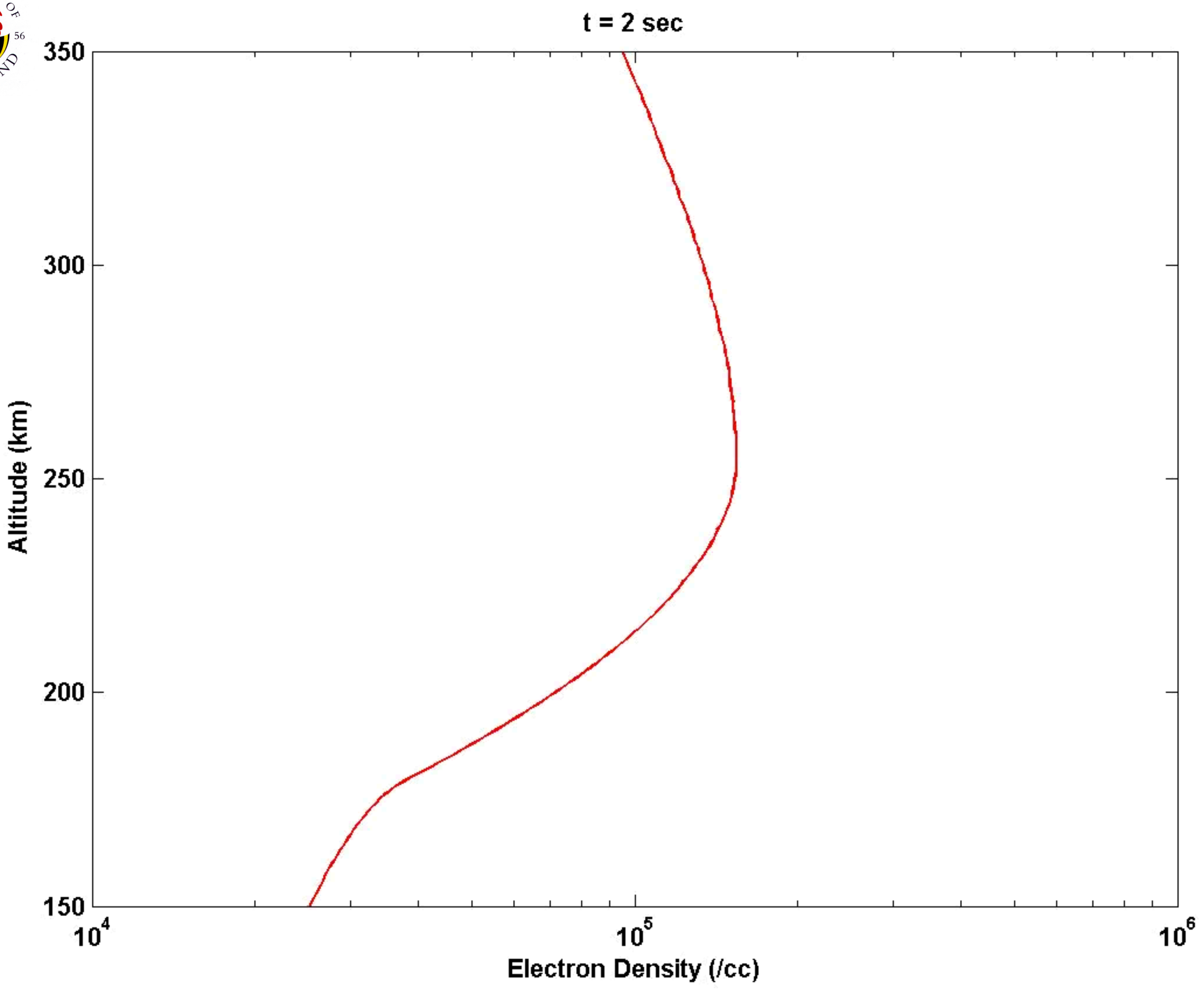
Normalized EDF of supra-thermal electrons for E 1.5 V/m at 100 km

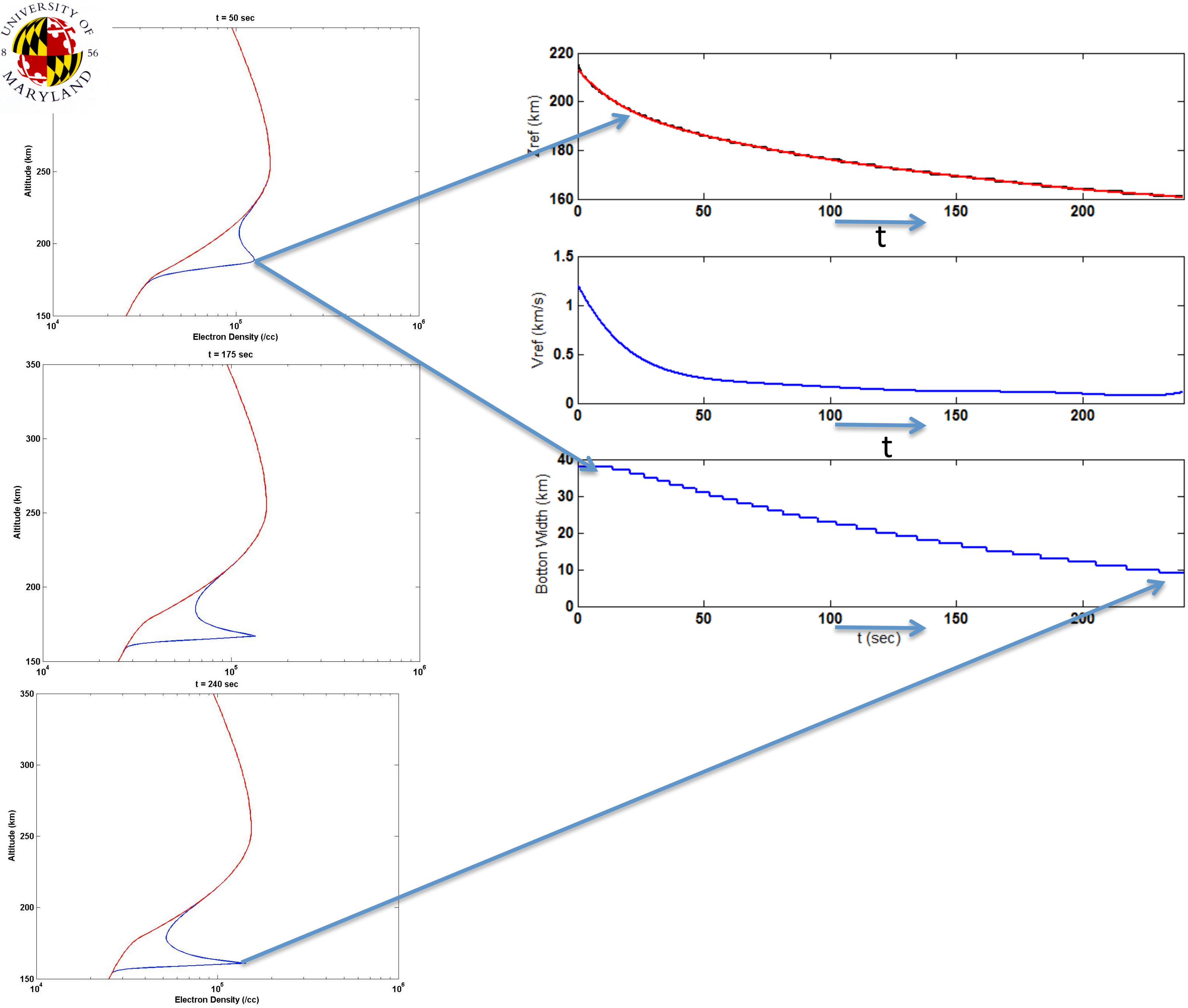




.6 eV, 1.5 V/m




t = 2 sec
350
300
250
200
150
Altitude (km)
10^4
10^5
10^6
Electron Density (/cc)


t = 50 sec
Altitude (km)
250
200
150
10^4
10^5
10^6
Electron Density (/cc)
t = 175 sec
350
300
250
200
150
Altitude (km)
10^4
10^5
10^6
t = 240 sec
350
300
250
200
150
Altitude (km)
10^4
10^5
10^6
Electron Density (/cc)
Zref (km)
220
200
180
160
0
50
100
150
200
t
Vref (km/s)
1.5
1
0.5
0
0
50
100
150
200
t
Botton Width (km)
40
30
20
10
0
0
50
100
150
200
t (sec)

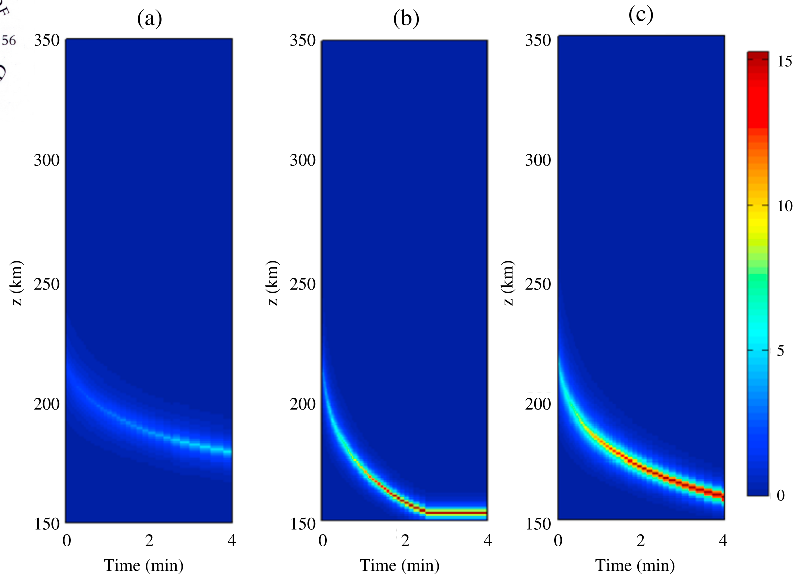
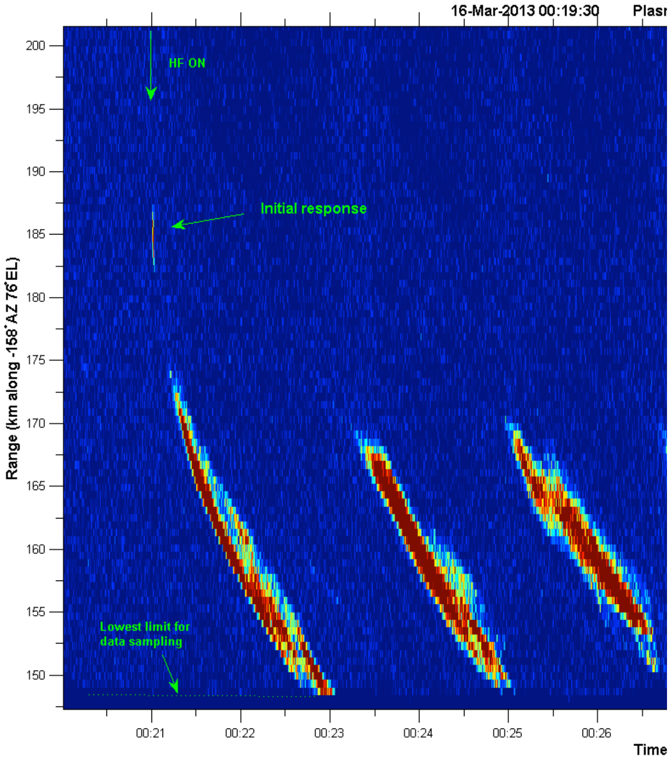
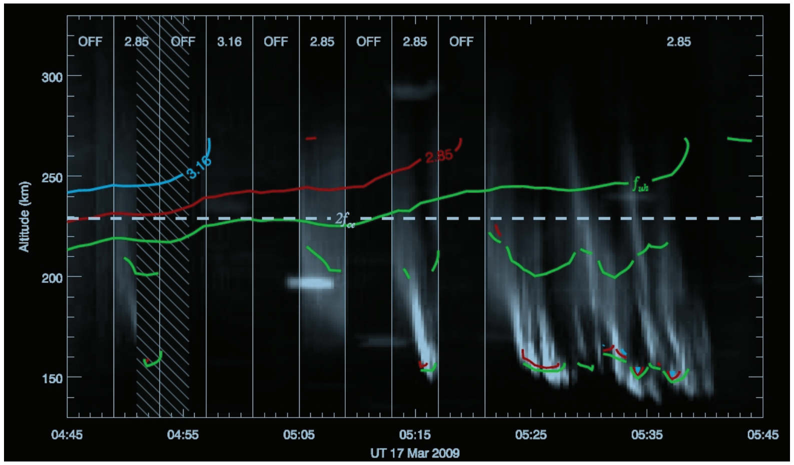


Figure 13. Green line emission as derived from simulation for different input wave amplitude and initial electron thermal energy: (a) $E_0 = 1$ V/m, $T_e = 0.4$ eV, (b) $E_0 = 1.5$ V/m, $T_e = 0.4$ eV, and (c) $E_0 = 1$ V/m, $T_e = 0.6$ eV.

Plasma Line

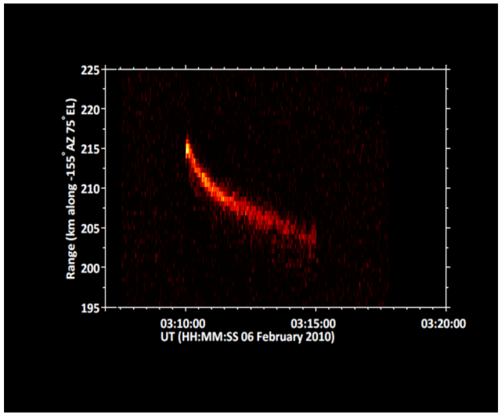




T. Pedersen et al. 2010

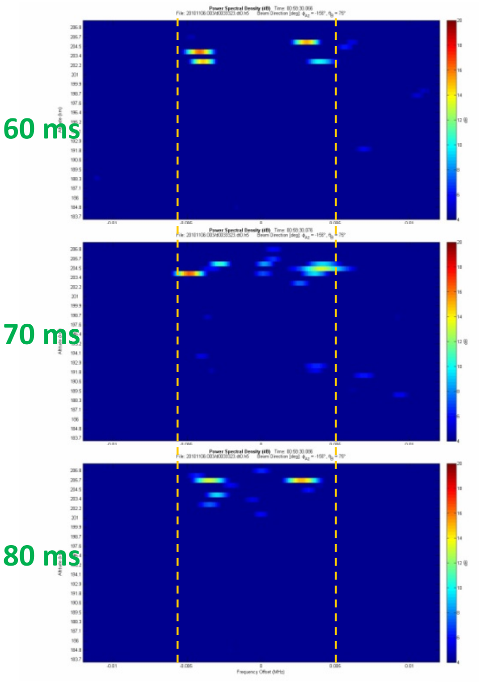
<u>Descending ion-line and plasma line structures observed with UHF radar during heating</u>.

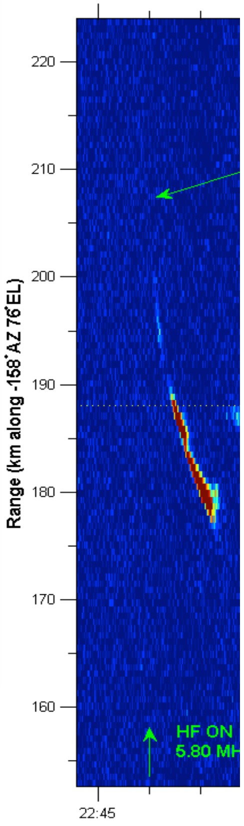
Watkins

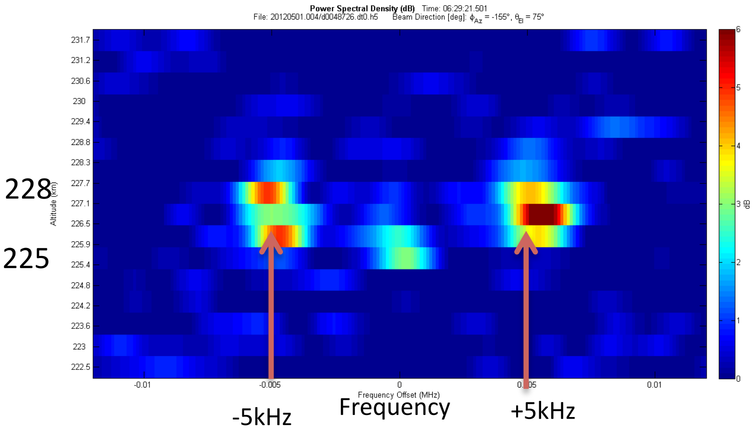


Ion Line

HYPOTHESIS: Hot plasma .5-.6 eV with supra - thermal tails creates enhanced IA and electron plasma waves locally – IA and plasma waves are damped within few meters





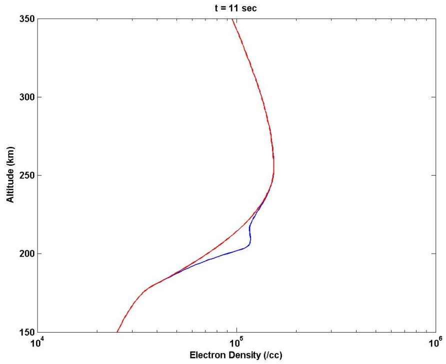


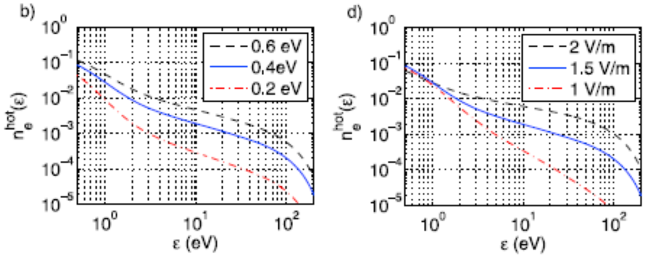
Ion Sound

$$\Delta\omega \approx kC_s = 2k_o C_s$$

$$C_s = \sqrt{\frac{\gamma T_e}{M}}$$

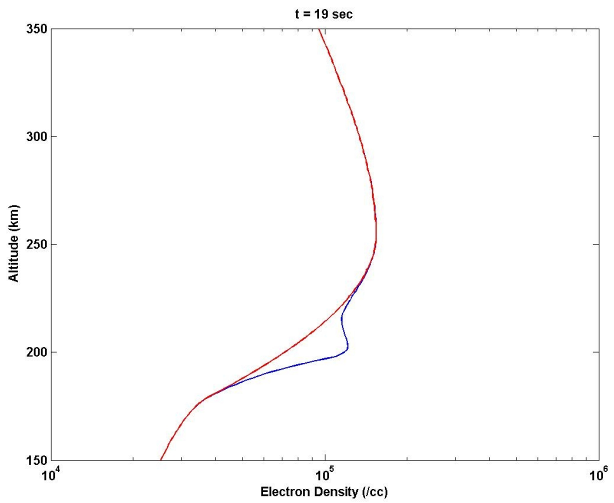
$$T_e \approx .65(M_{eff}/20\gamma)(\Delta f/5kHz)eV$$

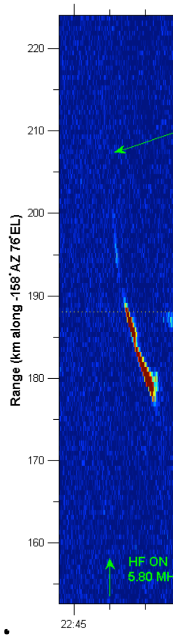


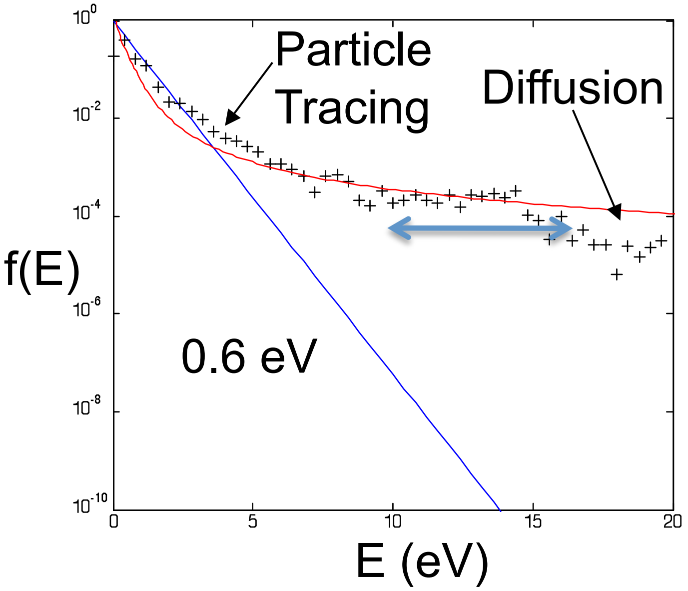


B. Watkins Measurements

PLASMA LINE ENHANCEMENT







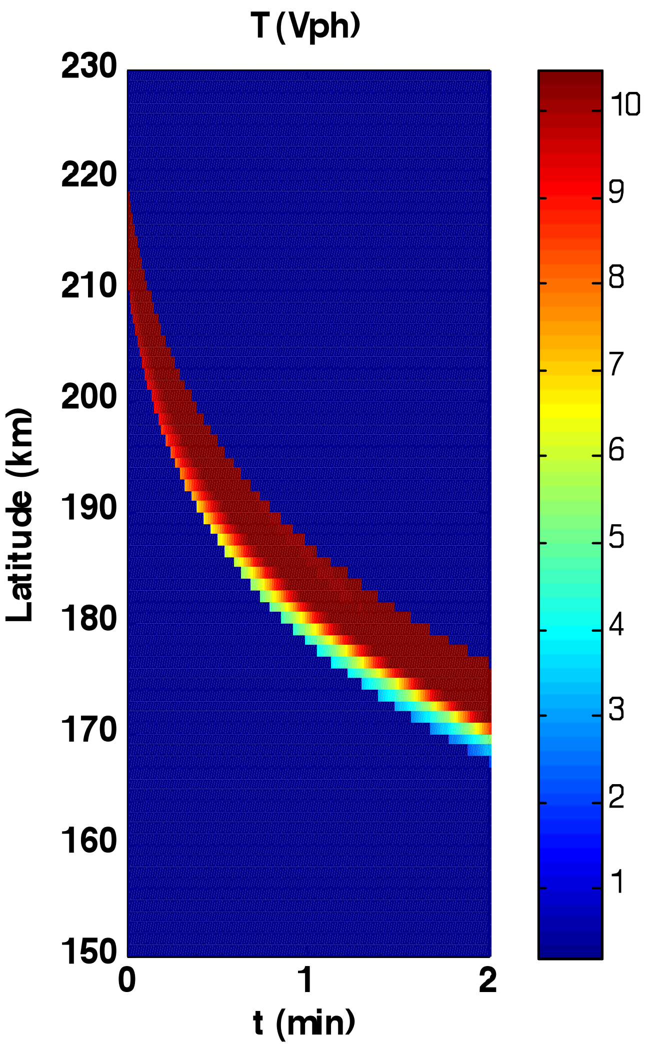
Enhancement due supra-thermal tails. Similar to Arecibo enhancement by photoelectrons but much stronger. The ionizing wave includes large T_e/T_i plasma and hot electron tails. Enhancement stops at low altitude when collisional damping dominates over Landau.

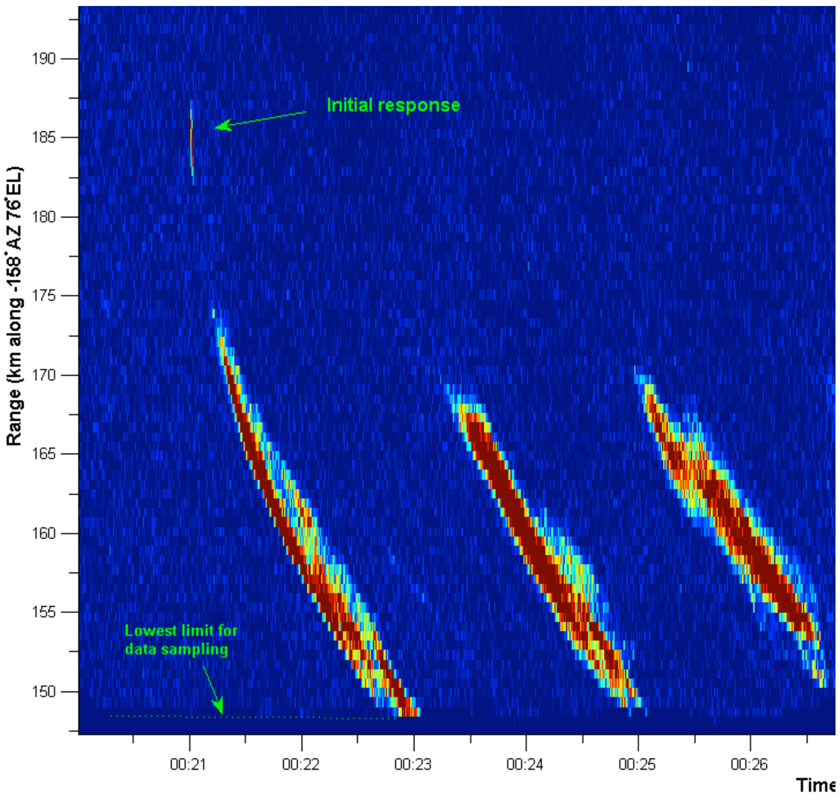
$$\frac{< E^2 >}{8\pi} \approx \frac{8ne^2}{\omega_e} \int_{k_1}^{k_2} dkk \frac{F_T(\omega_e/k)}{\left|F_e^{'}(\omega_e/k)\right|}$$

$$R \prec \frac{V_T^2/V_e^2}{/n(V_E/\alpha V_e)} \rightarrow (\lambda_R/\lambda_D)^2$$

$$\text{if } \nu < \omega_e u_{ph}^2 F'(u_{ph})$$

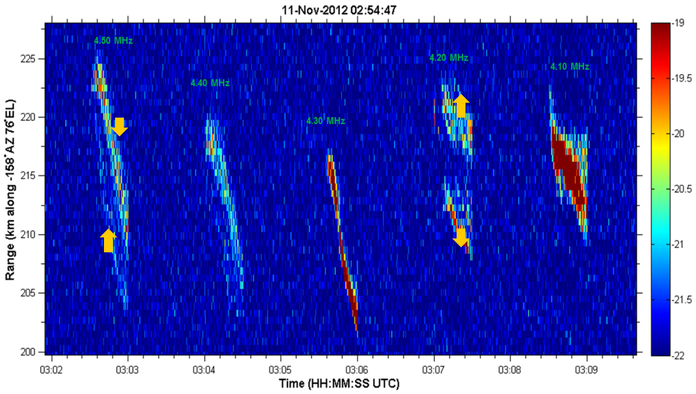
Classic signature of non-equilibrium plasma with supra-thermal tails

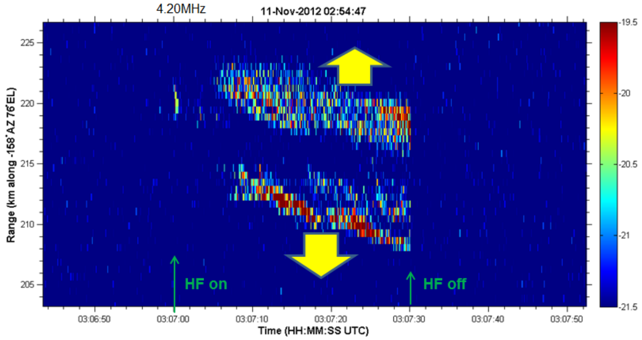

T (Vph)
Latitude (km)
230
220
210
200
190
180
170
160
150
0
1
2
t (min)
10
9
8
7
6
5
4
3
2
1

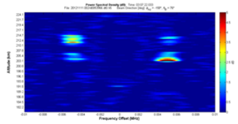

Range (km along -158°AZ 76°EL)
190
185
180
175
170
165
160
155
150
Initial response
Lowest limit for
data sampling
00:21
00:22
00:23
00:24
00:25
00:26
Time

ION LINE PECULIARITIES

B. Watkins

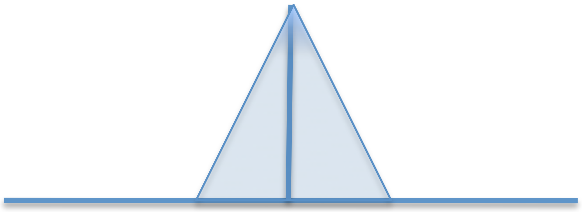


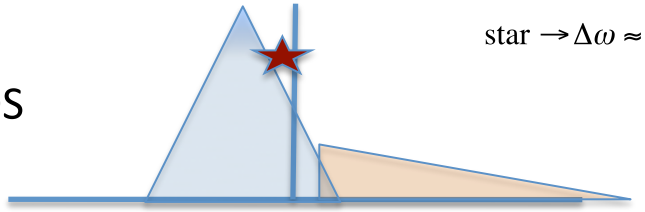




Power-height-time plot of HF-enhanced ion-line signals. Close to 3rd gyro-harmonic signals split into two layers. Doppler spectra (example to left) show strong asymmetries that indicate mainly upward propagating only ion-acoustic waves in the upper layer. The downward layer is associated with primarily downward propagating ion-acoustic waves..

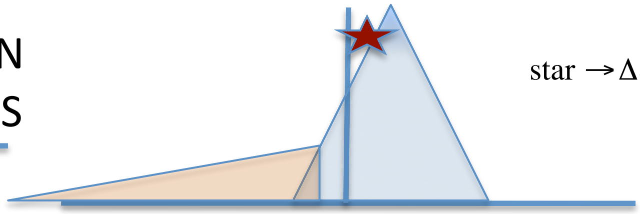
The above spectral asymmetries are interpreted to be the result of electron flow upward and downward from the HF interaction region as indicated by the yellow-colored arrows.





INJECTION
DOWNWARDS

star $\rightarrow \Delta\omega \approx 2k_R c_s$



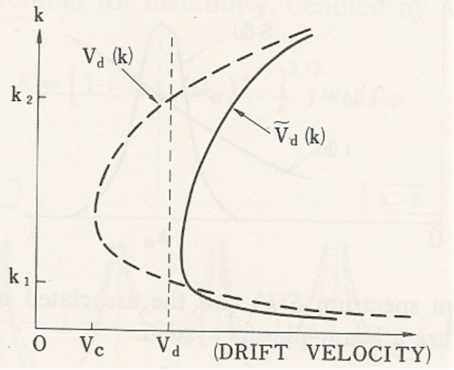
INJECTION
UPWARDS

star $\rightarrow \Delta\omega \approx \text{-}2k_R c_s$

Plasma with drift
γ(k)=0 gives

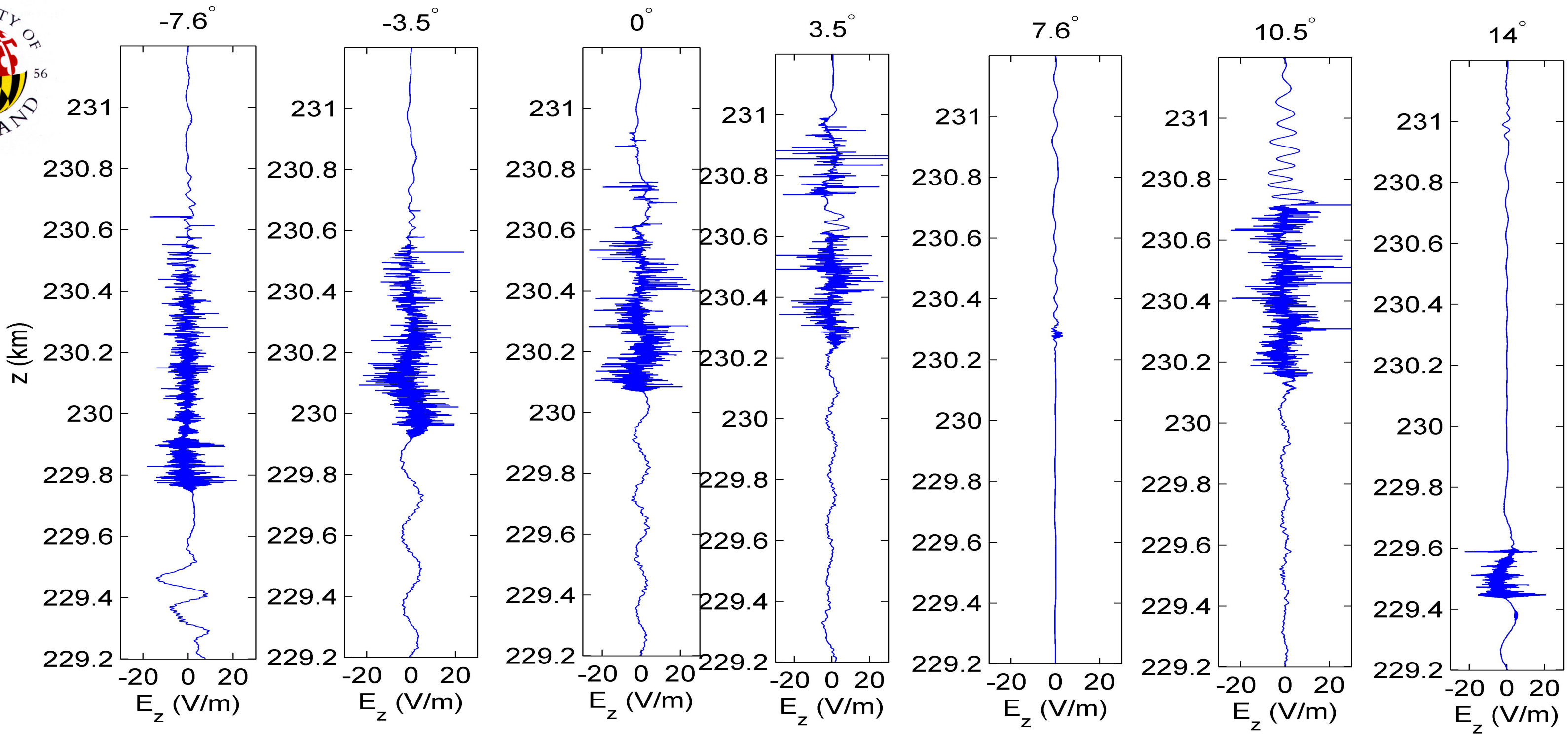
$$V_d(k) = (\omega_k / k) + (ion\ \mathrm{L\ damping})$$

$$S(k) = \frac{1}{2}\frac{\omega_k / k}{V_d(k) - Vd}$$



ONGOING PHYSICS STUDIES FOR INPUT TO DIAL MODEL

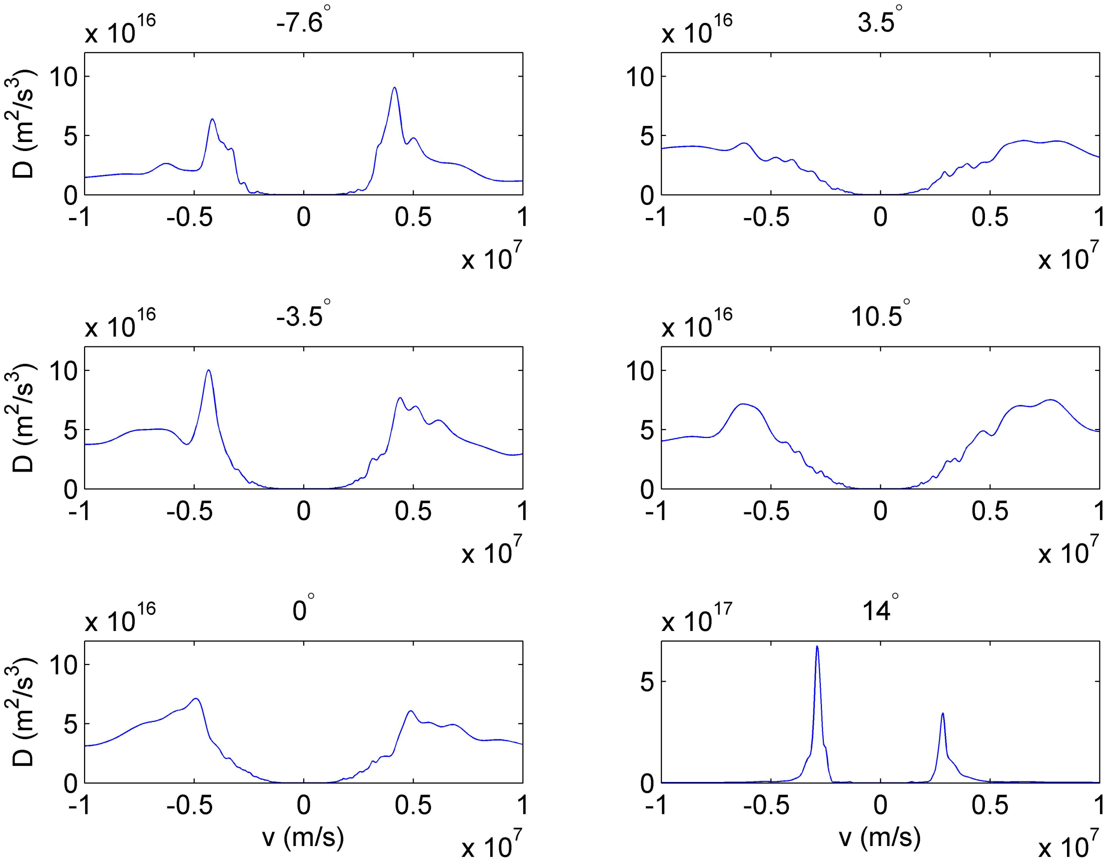
1. MULTI-DIMENSIONAL ISSUES
2. UPPER HYBRID
3. DOUBLE RESONANCE HEATING

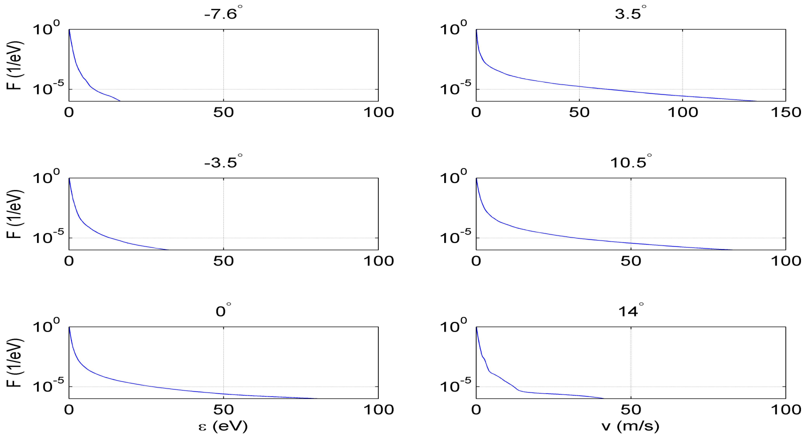


O-mode, 1V/m amplitude, electron temperature 0.4 eV, and different angles of incidence, B field *at 14-◦.* to the vertical line (same parameters as JGR 2012).

E_z amplitude *t=1* ms for different angles of incidence. The case *,7.6-◦.* corresponds roughly to the Spitze angle *,8.1-◦.*. Also at *,−7.6-◦.* there is an accumulation of electrostatic waves due to absorption (called southward process by Mjolhus 1990). The O mode turning point is at z=231.0 km and the upper hybrid resonance layer at z=223.8 km (outside the range of the plots).

Weak turbulence

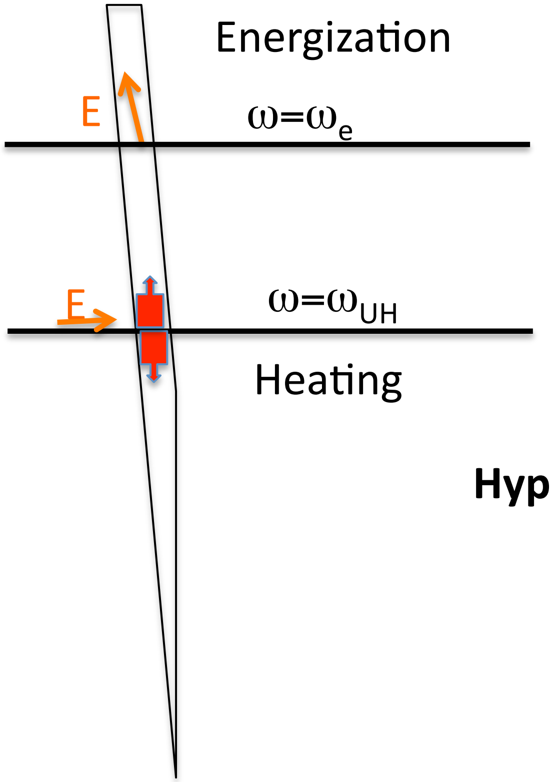


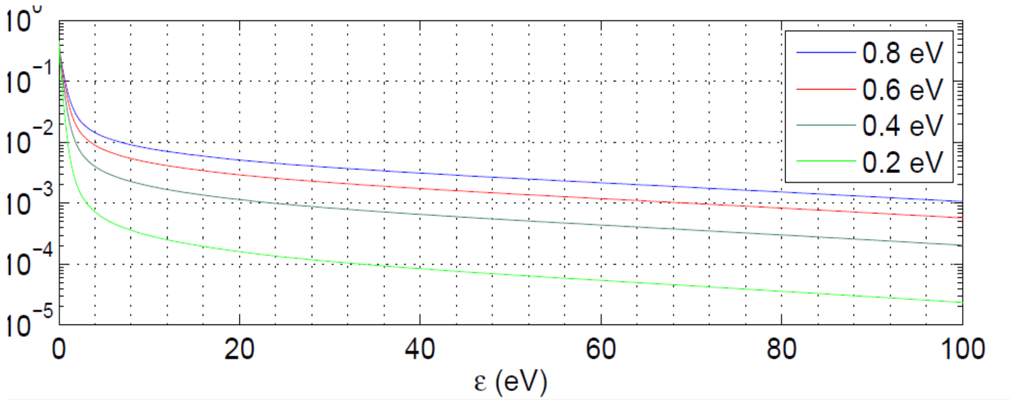


Weak turbulence

UH HEATING AND THE ROLE OF DOUBLE RESONANCE $\omega_{UH}\approx n\Omega_e$

Is it related to ECR acceleration and hoW do we account in the context of ourD AIL model?





The extent of acceleration depends of heating

Hypothesis: UH heating different under double resonance

Next : Two ongoing studies of UH heating

STUDY ELECTRON HEATING DUE AN ES WAVE GIVEN BY $E_x=E_o \sin(kx- \omega t)$

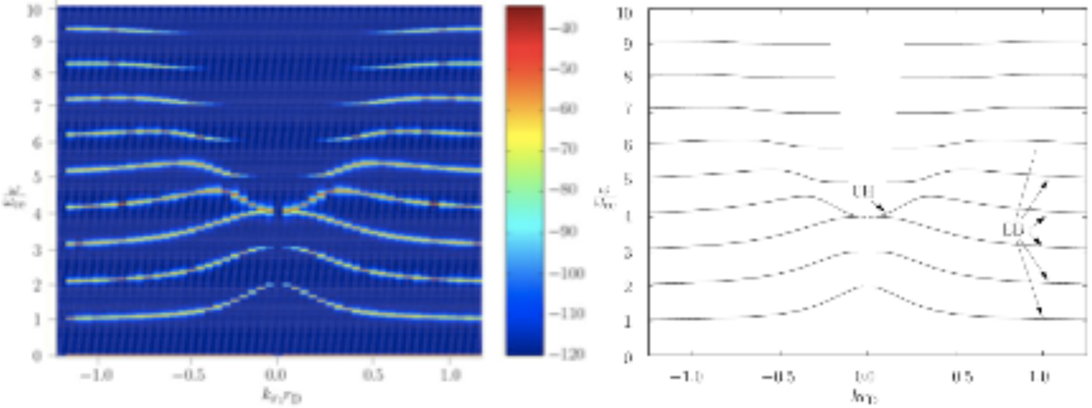


Figure 2: Power spectrum obtained from a Vlasov simulation (left) and theoretical dispersion diagram (right) showing the upper hybrid (UH) branch and several electron-Bernstein (EB) modes at the electron cyclotron harmonics for $\omega_{UH} = 4\omega_{ce}$. The wave energy is concentrated to the eigenmodes of the system. After *Eliasson* (2010).

Stochasticity analysis 10^4 particles

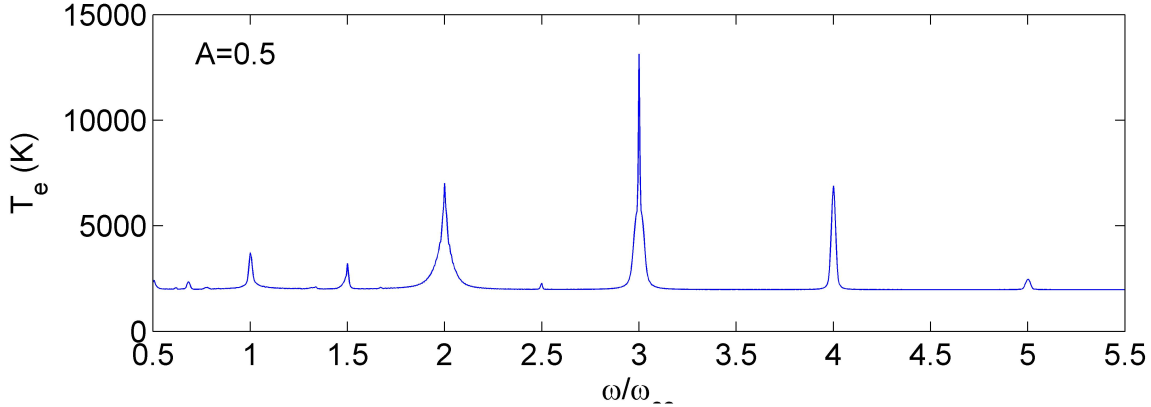
$$m\frac{d\mathbf{v}^j}{dt} = -eE_0\sin(k_x x^j - \omega t)\hat{\mathbf{x}} - e\,\mathbf{v}^j \times B_0\hat{\mathbf{z}}$$

$$\frac{dx^j}{dt} = v_x^j$$

$$\frac{du_x^j}{dt} = -A\sin(u_y^j - \Omega t) - u_y^j$$

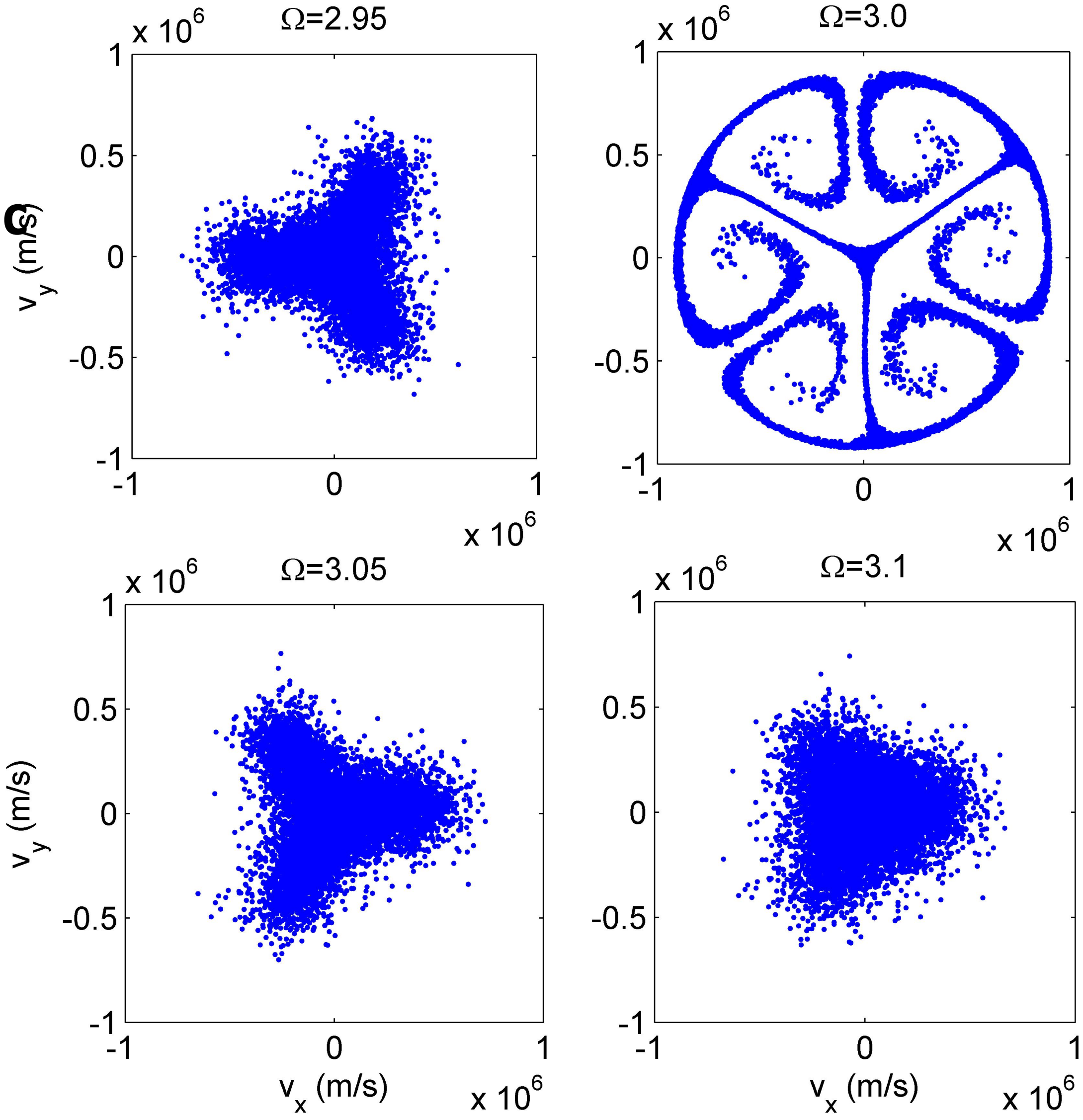
$$\frac{du_y^j}{dt} = u_x^j$$

$A=ek_xE_o/m\Omega_e^2$, $\Omega=\omega/\Omega_e$,
Velocity norm to ω/k, t->$1/\Omega_e$

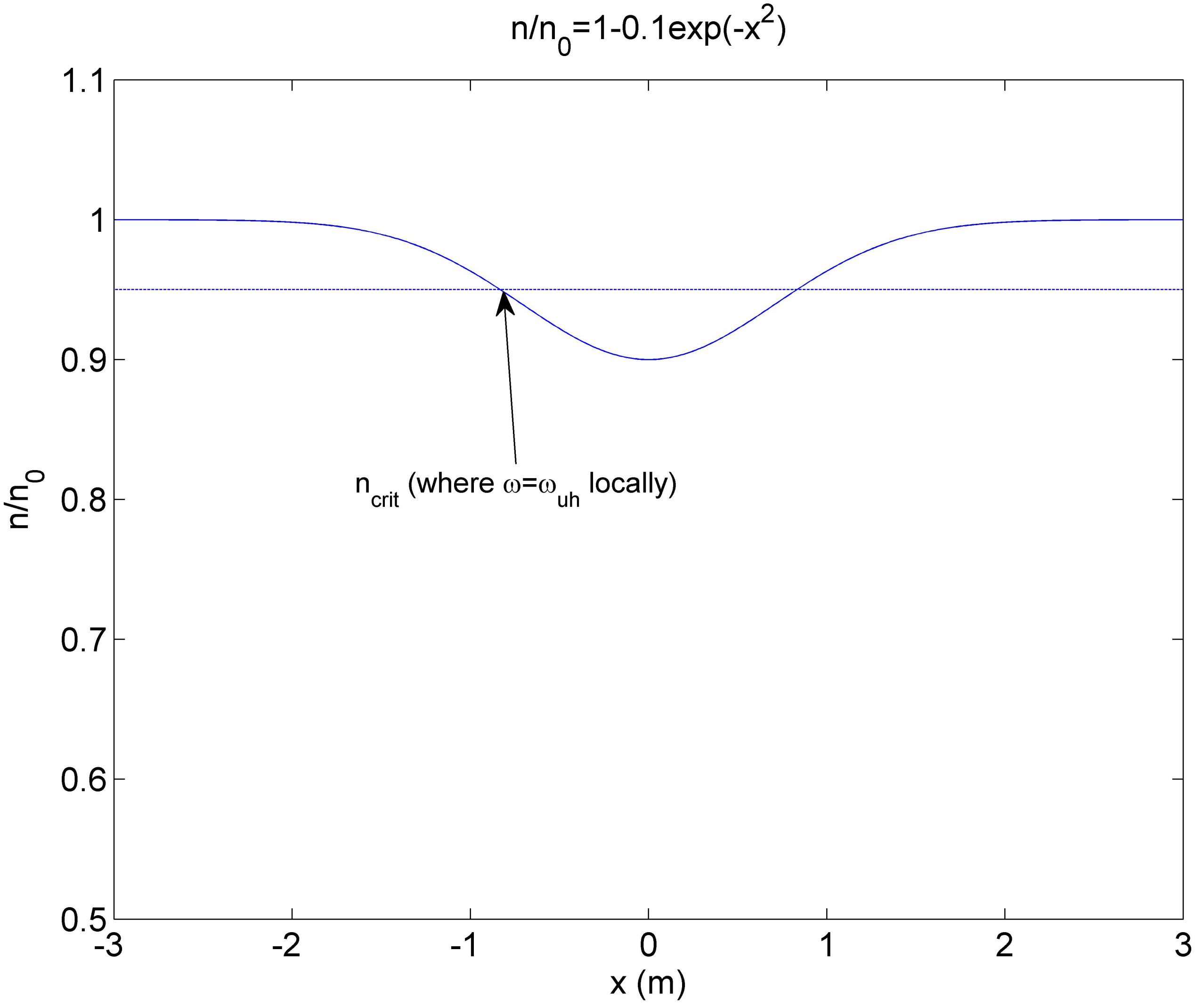


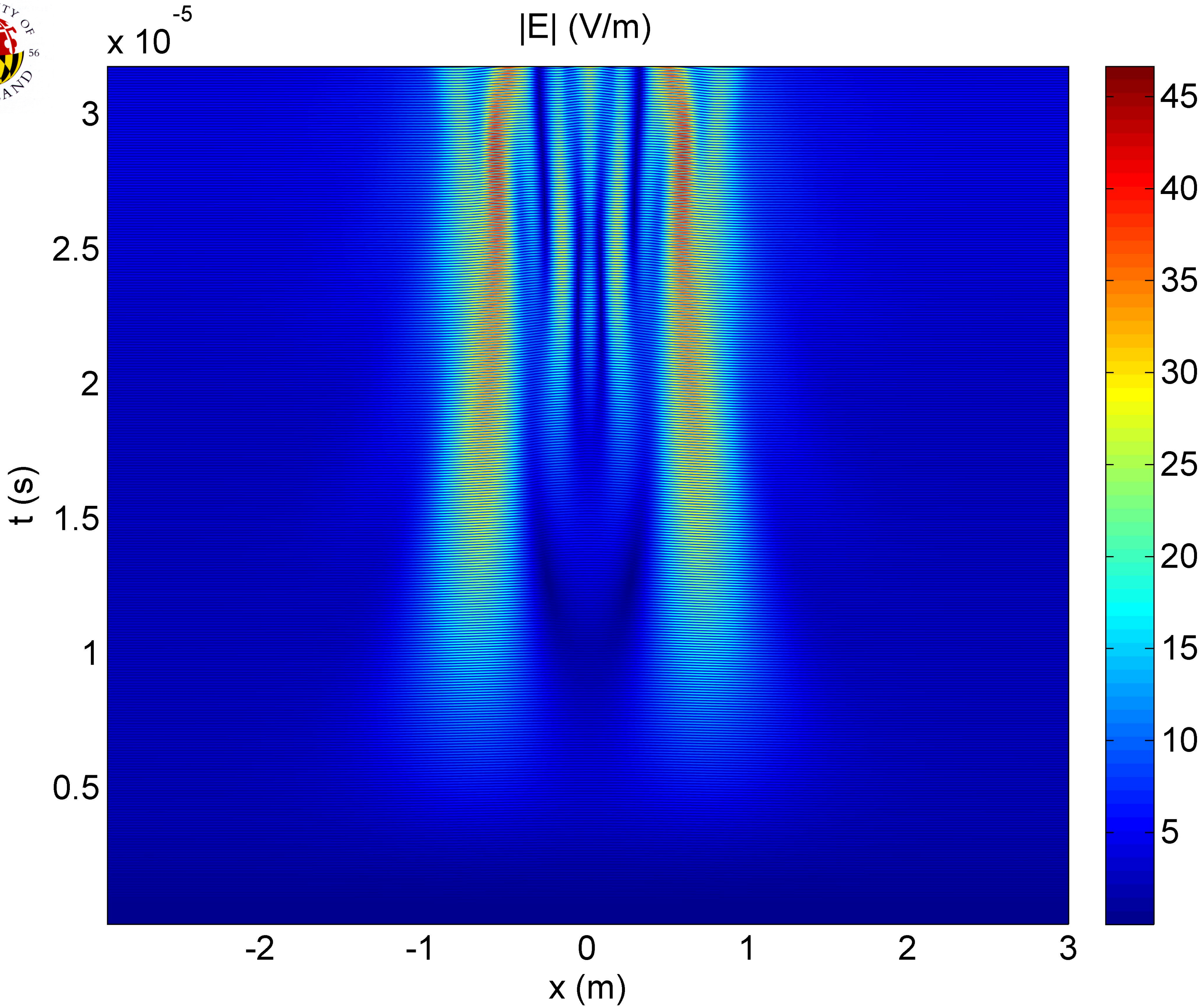
3.5 V/m

Strongly anisotropic Heating

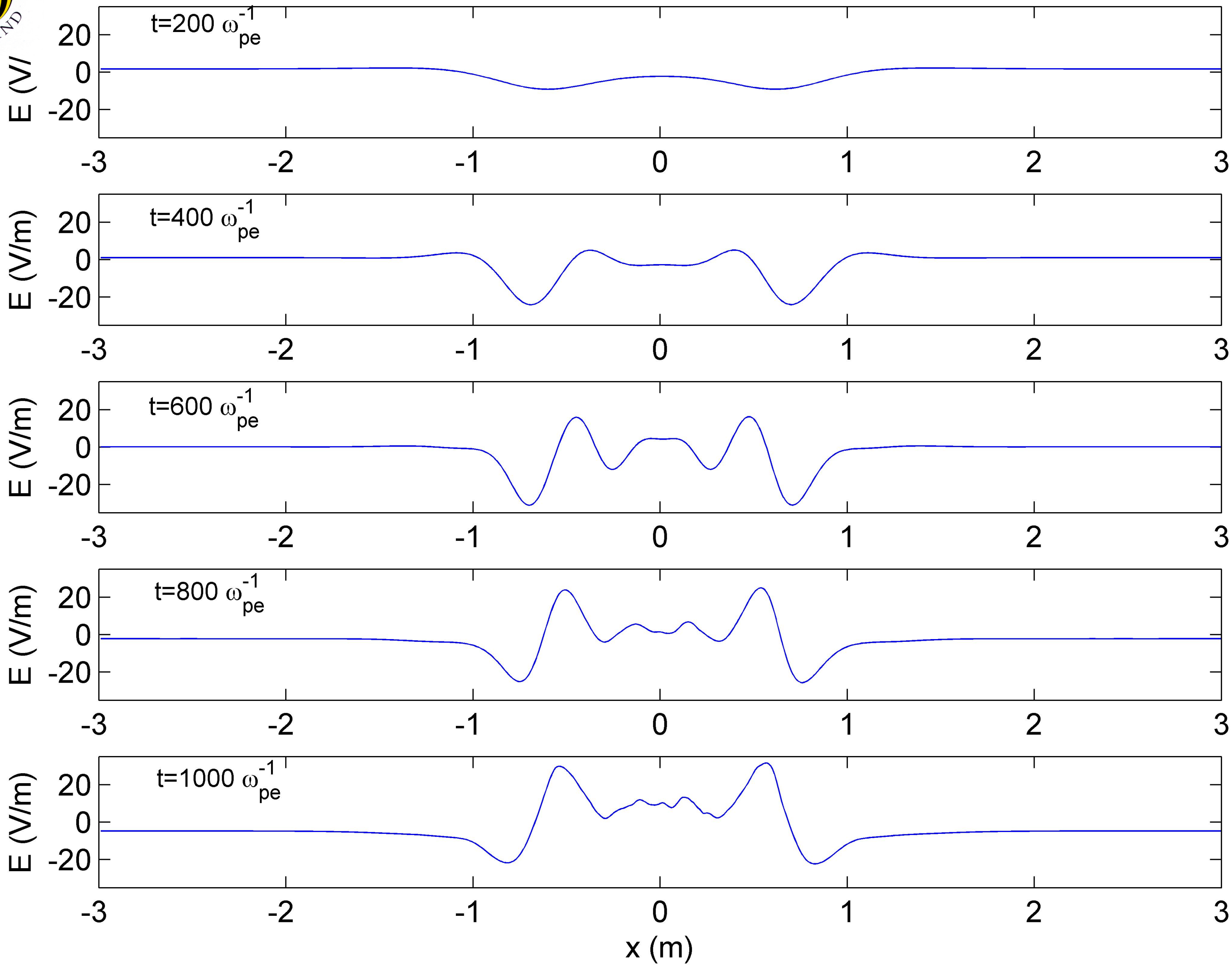


UPPER HYBRID – RESONANCE ABSORPTION



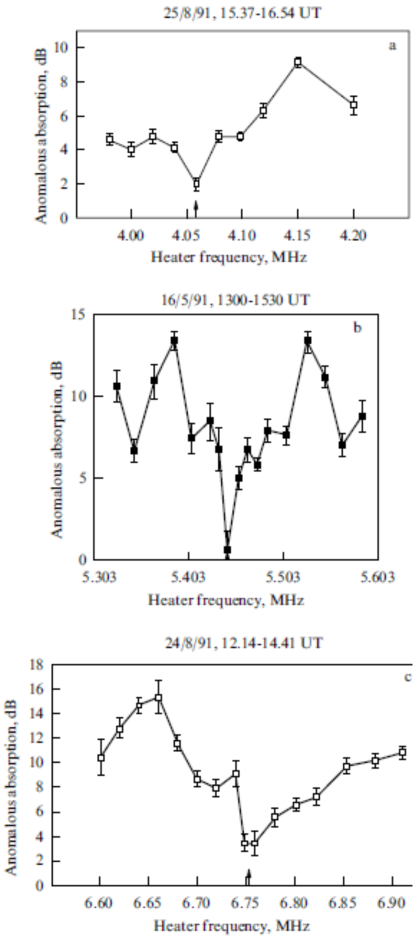

|E| (V/m)
x 10^-5
3
2.5
2
1.5
1
0.5
t (s)
-2
-1
0
1
2
3
x (m)
45
40
35
30
25
20
15
10
5

$\omega_{pe}=31.4\times10^{6}\ \mathrm{s}^{-1}$, $\omega_{ce}=0.248\omega_{pe}$, $\omega_{UH}=1.030\omega_{pe}$, $\omega=1.004\omega_{pe}$

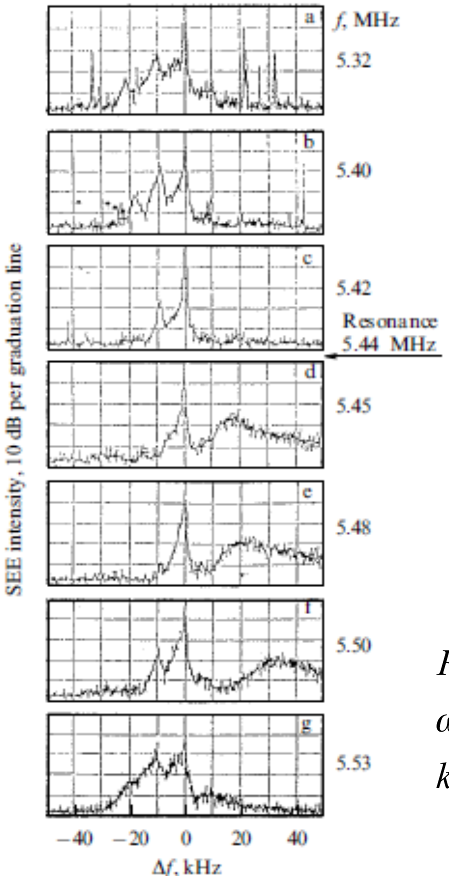


Suoer-Short Striations

Effects associated with $\omega \approx \omega_{uh}(z) \approx n\Omega_e$



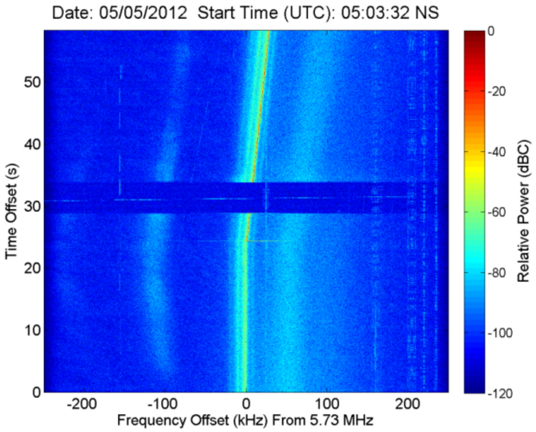
Suppression of anomalous absorption



BUM

Generation of short scale FAI
Super-Short-Striations (SSS)

Gurevich Physics-Uspekhi, 2007



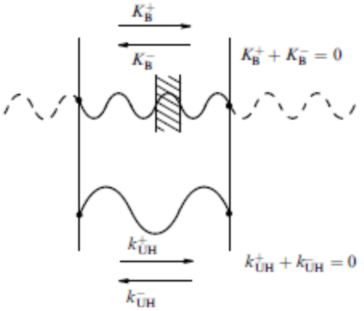
Paul's BUM

Need for four wave interaction – Pump, UH, EB, IA.

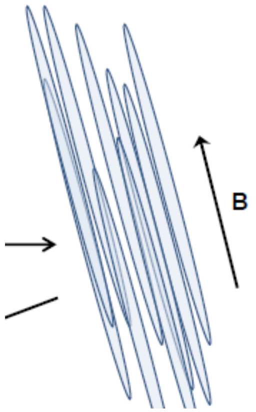
$$Pump(\omega, k_o = 0), UH(\omega_1, k_1), EB(\omega_2, k_2), IA(\omega_s, k)$$

$$\omega_1 + \omega_s = \omega = \omega_2 - \omega_s, \rightarrow \omega_2 > \omega$$

$$k_1 + k = 0 = k_2 - k, \rightarrow k = k_2 \approx O(1/r_e)$$



Raising MUF to GHz



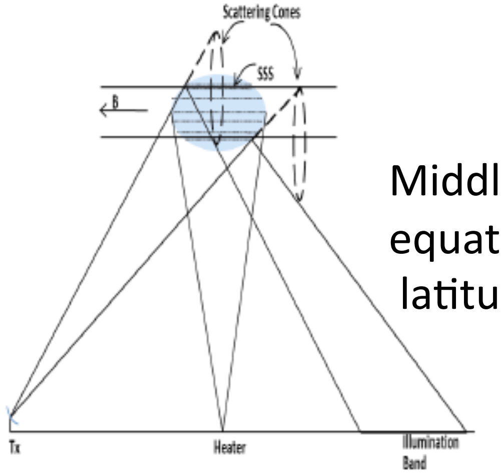
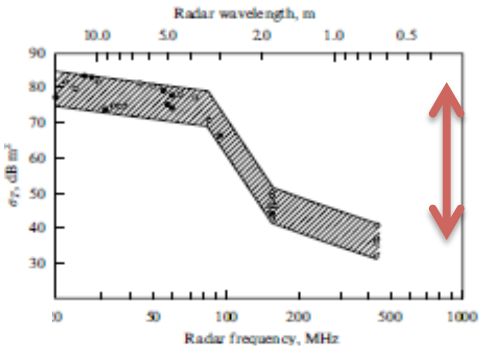


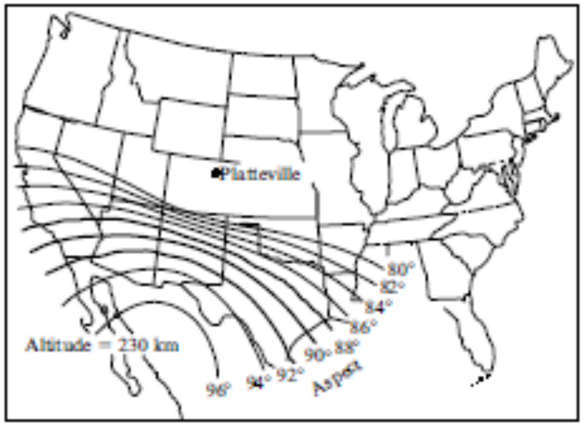
Fig. 1: Schematic of SSS FAS system at GHz.

Middle or equatorial latitude

Platteville FAS:



Potential answer from physics of ion cloud formation



FAS Concept- Aspect scattering. RF transmitted from Tx along the 90^{0} line are orthogonal to FAI and will be observed everywhere at the 90^{0} line. Tx located in the 92^{0} line observed at 88^{0} and vice versa