Modeling small-scale plasma density irregularities associated with Equatorial spread F

Y. S. Dimant, Y. Tambouret and M. M. Oppenheim

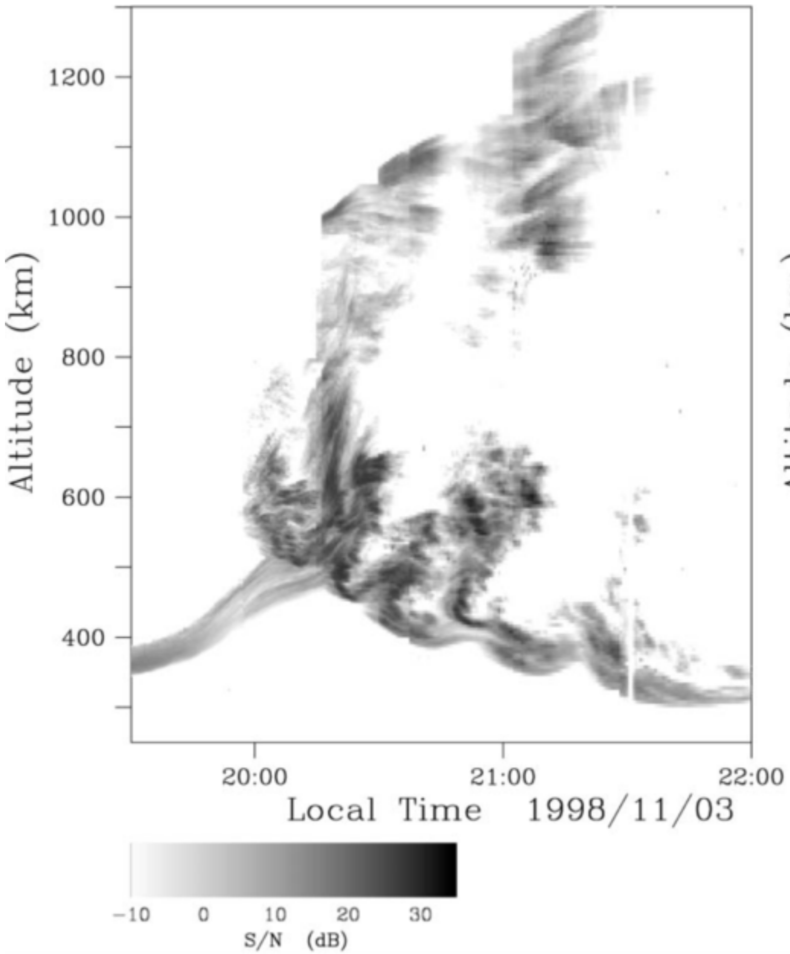
Center for Space Physics, Boston University

CEDAR 2012 (Santa Fe, New Mexico) Workshop:
"Thermosphere-ionosphere coupling and the development of irregularities"
June 26, Tuesday (1:30-3:30 PM) - Anasazi N

Outline

- Background
- PIC simulations
- Simple theory

Equatorial Spread F



Hysell D. L., J. Atmos. Solar-Terr. Phys, 62, 1037 (2000)

- Large-scale phenomenon (plasma bubble)
- Observed by radars (e.g. Jicamarca, 50 MHz)
- What causes such meter-scale irregularities?
- Two possibilities:

  Local instability

  Nonlinear cascading

We explore the possibility that large-scale bubble gradients/electric fields generate small-scale waves via local instability

Typical Simulation Parameters

Common System Parameters

Parameters		Value
$B_0 \cdot \hat{z}$	(G)	2.500e-05
n processors		64
L	m	7.68

Case → Parameters ↓	1	2	3
$\delta x, \delta y (m)$	0.120	0.085	0.060
δt (s)	3.00e-6	2.13e-6	1.50e-6
Nx	512	768	1024
Ny	256	512	512
T (K)	1000	500	250
$r_{Larmor,i}(m)$	4.73	3.35	2.37
$r_{Larmor,e}(m)$	0.280	0.198	0.140

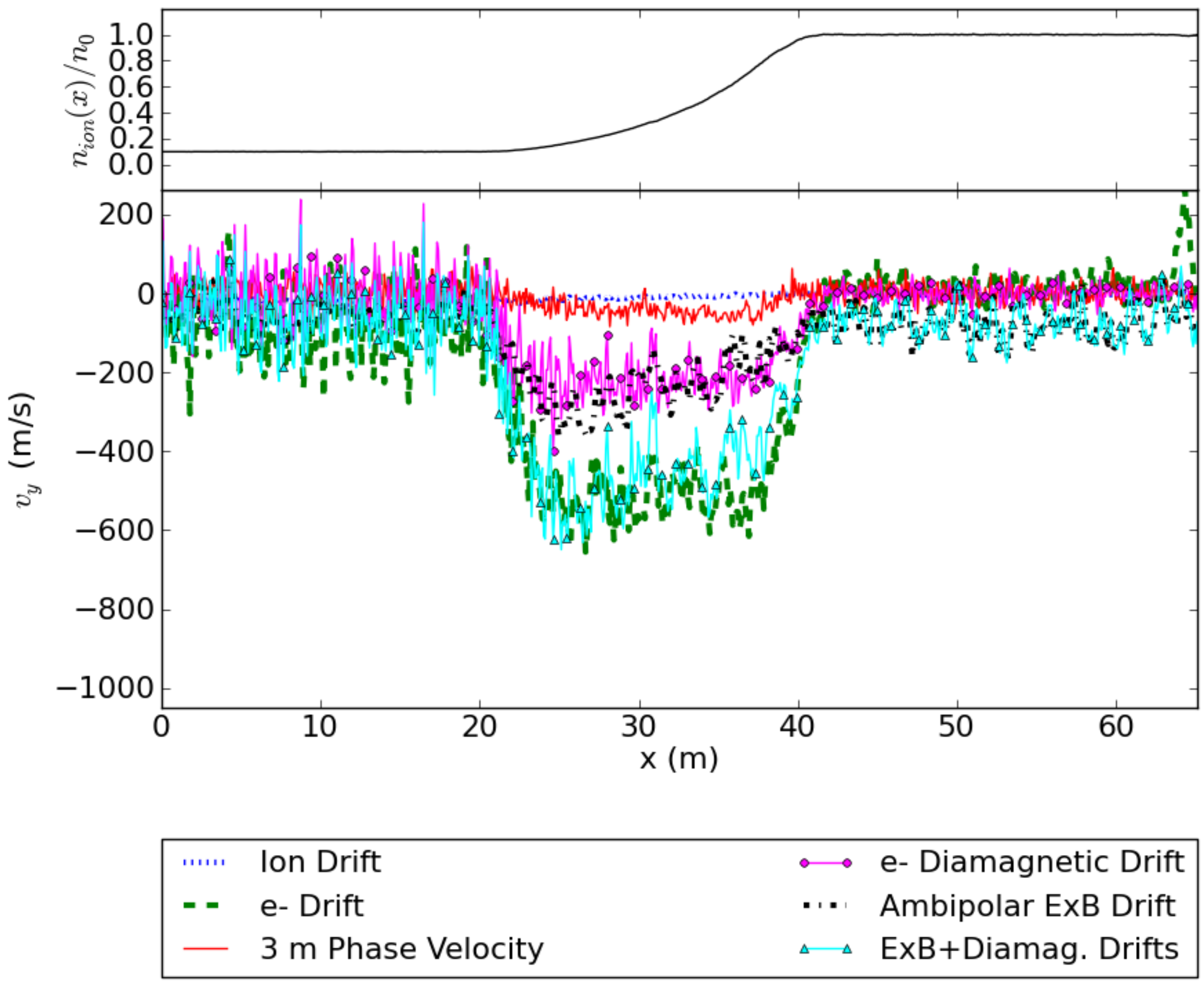
Common Particle Parameters

Parameters		Value
m_e	(kg)	9.100e-29
m_i	(kg)	2.600e-26
q	(C)	1.602e-19
n_0	$(\frac{1}{m^3})$	3.078e+08
Max $N_{particle,e}$/Cell		100
Max $N_{particle,i}$/Cell		200
ν_n	(1/s)	0.000e+00

Large electron mass for numerical efficiency

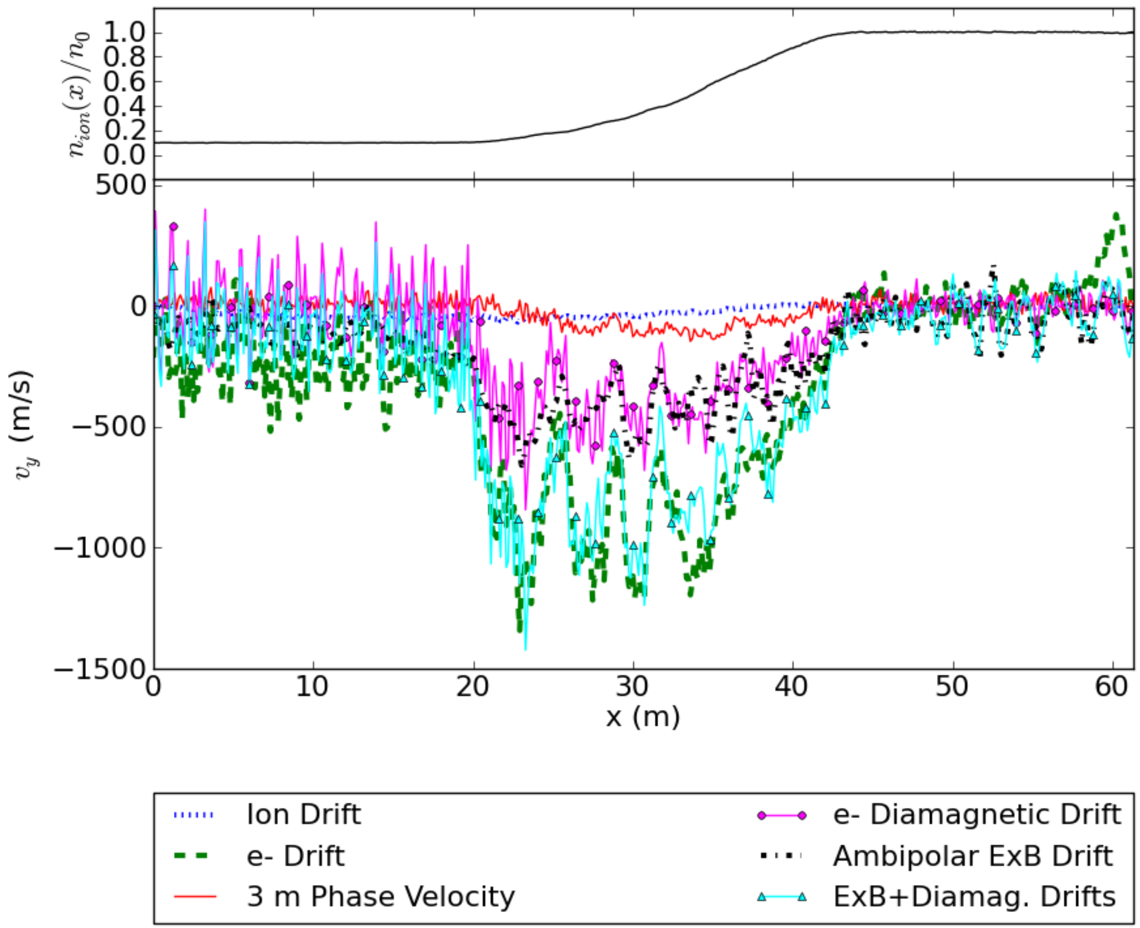
Density is smaller than F-region value

PIC Simulations: Particle Drifts



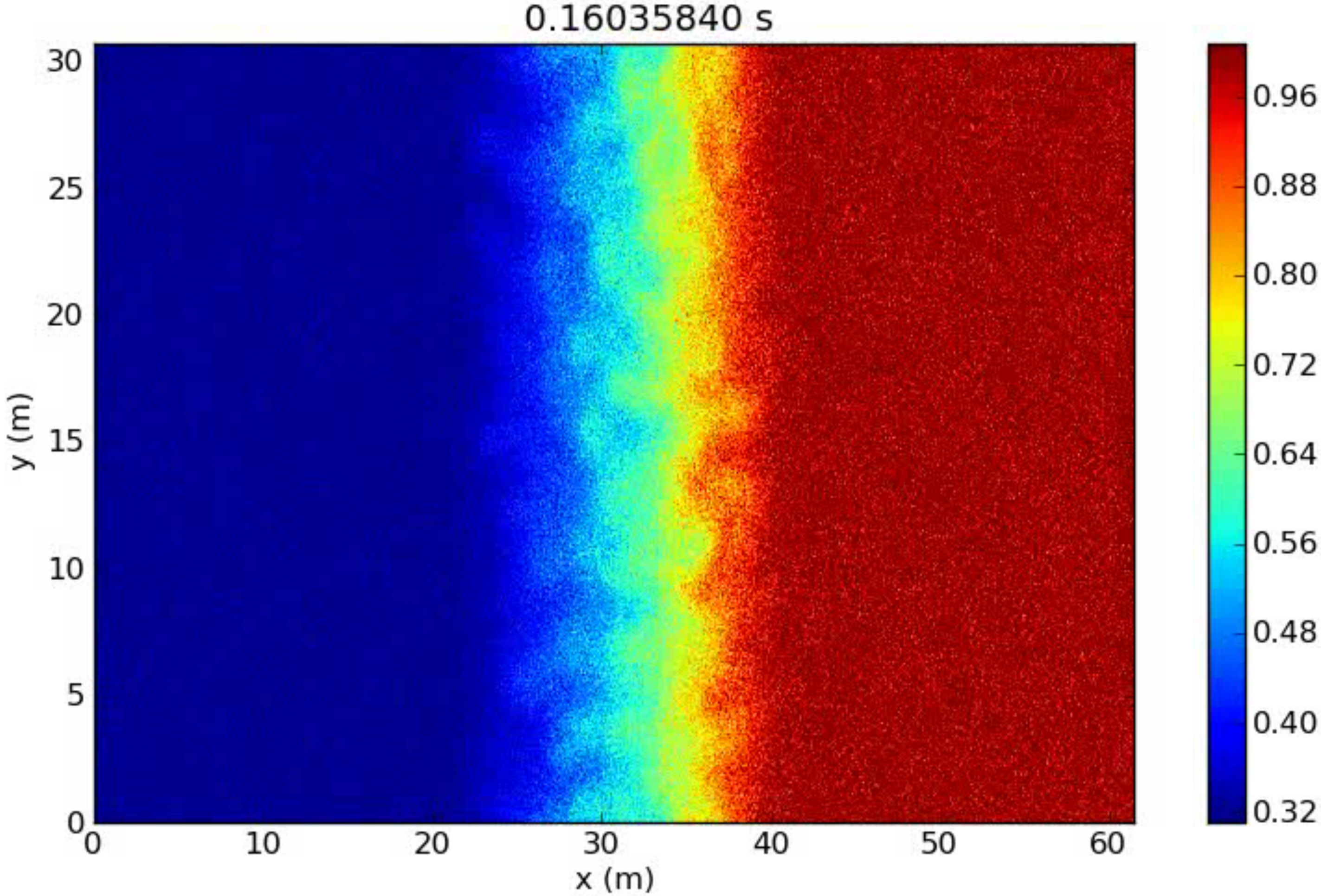
T = 500K

PIC Simulations: Drift Waves



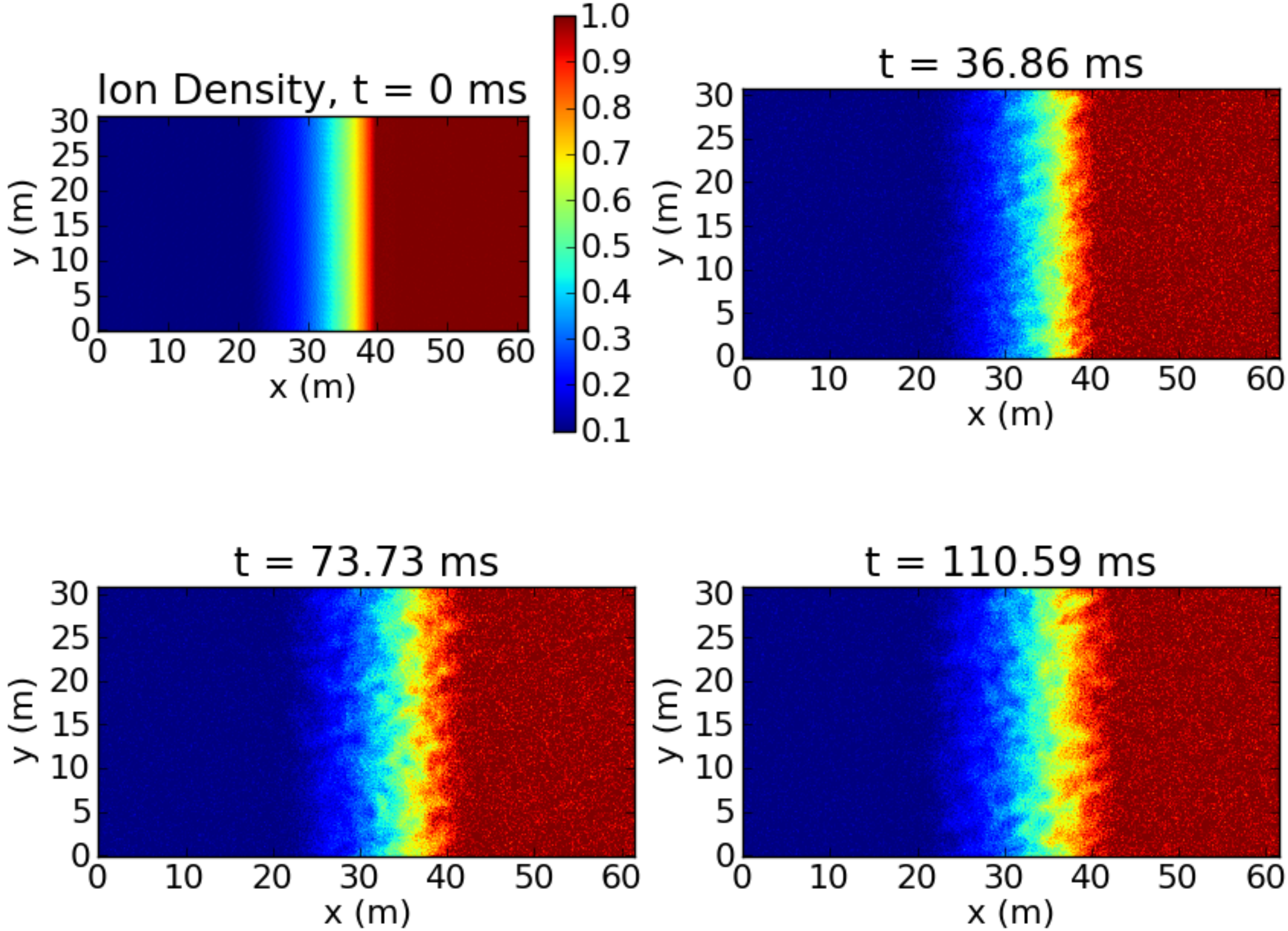
T = 1000K

$n_1(x,y)/n_{peak}$

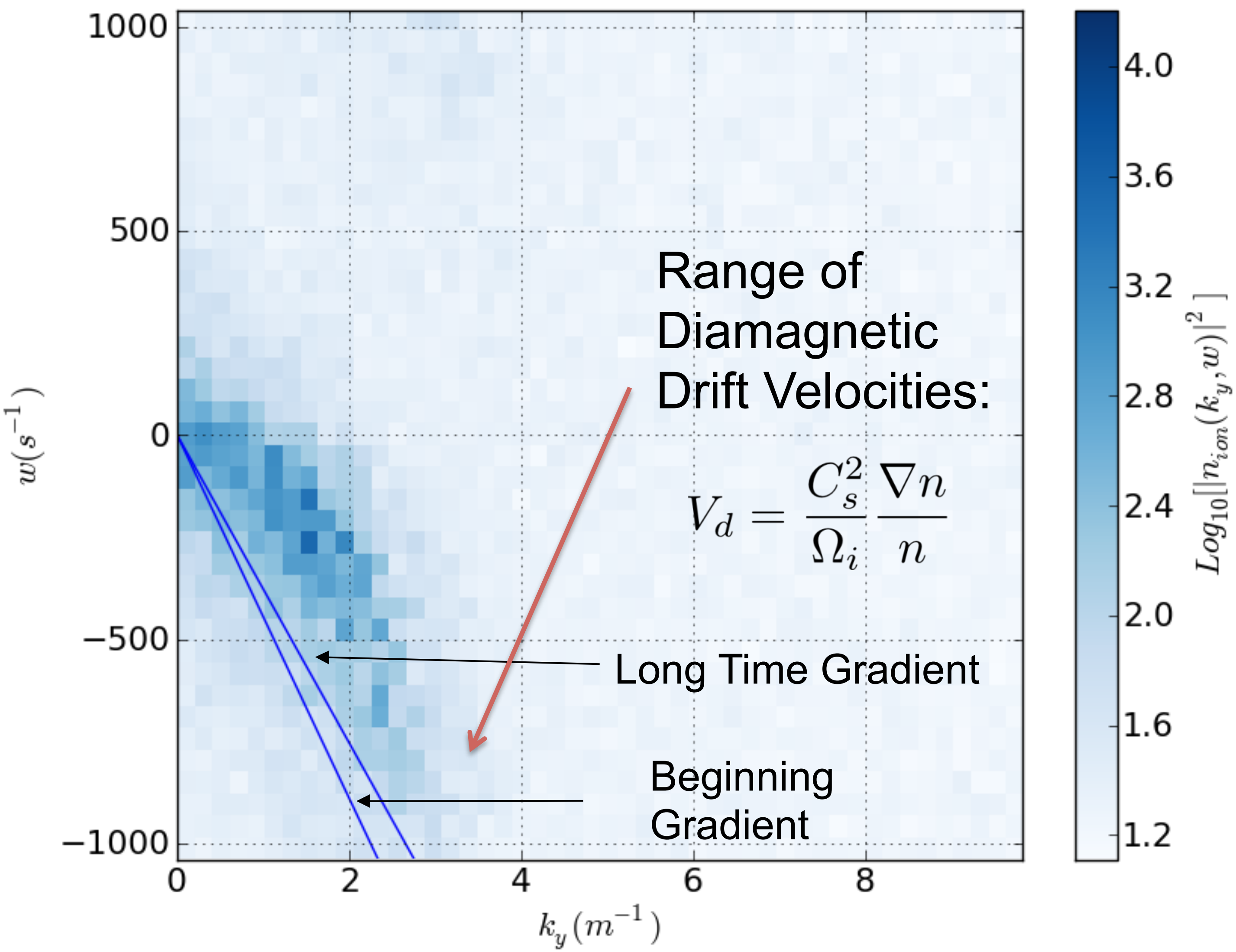


Run Title: '1000K
Run on: 02/16/12

Density Profiles



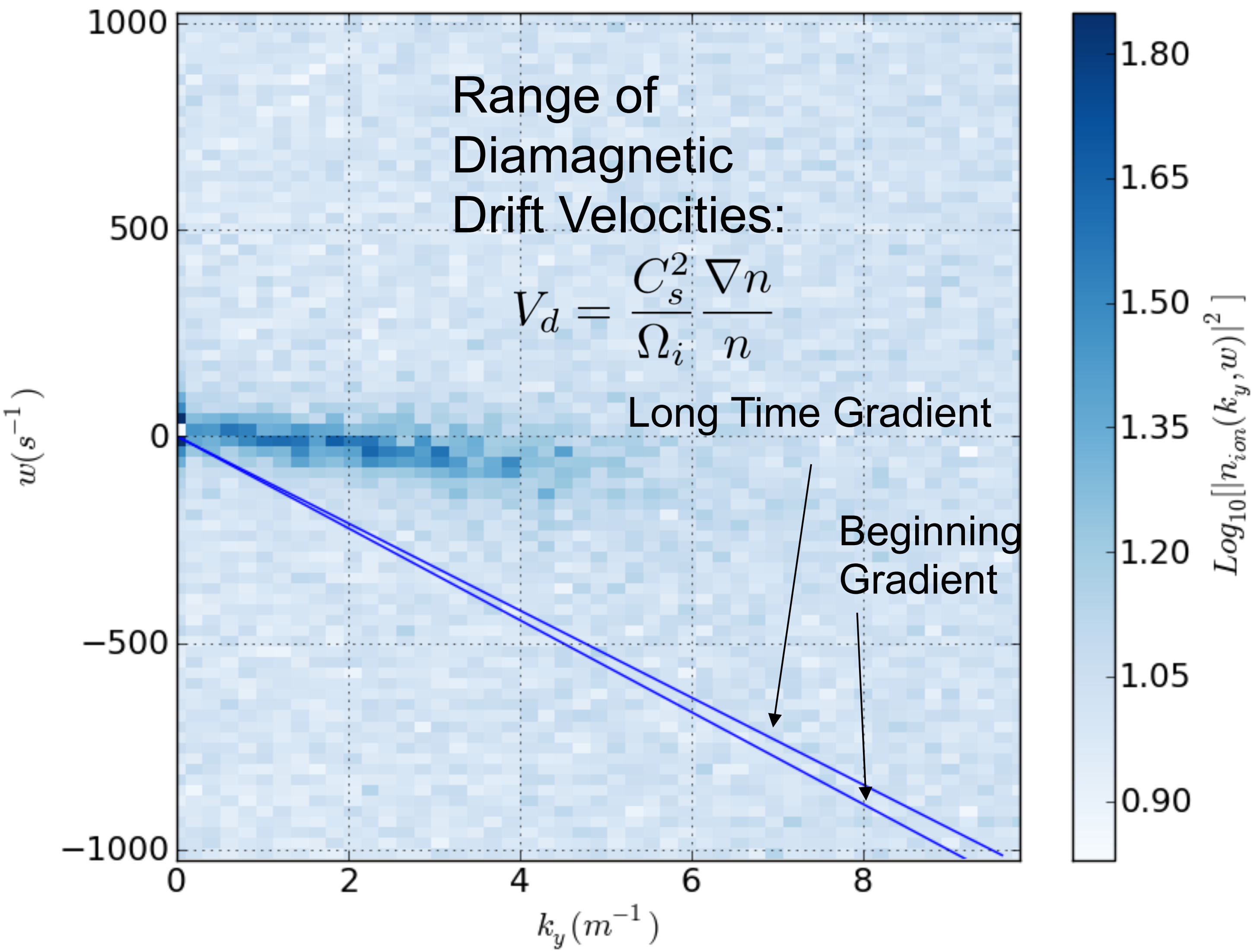
Density Spectra



T = 1000K

Lower-hybrid waves (2600 s^{-1}) were not excited in simulation.

2D Case 3 (T = 250K): Density Spectra



T = 250K

Simplified Linear Theory

- Two-fluid (vs. kinetic) model: $\omega / k << v_{Ti}, \quad \rho_i << L$
- Electrostatic, quasi-neutral perturbations: $(k\lambda_D)^2 << 1$
- Local wave approximation: $\kappa \equiv kL >> 1$
- Collisionless plasma, inertialess electrons

Strictly neutral perturbations: $\delta n_e = \delta n_i \propto \exp\left[i\left(\vec{k} \cdot \vec{r} - \omega t\right)\right]$

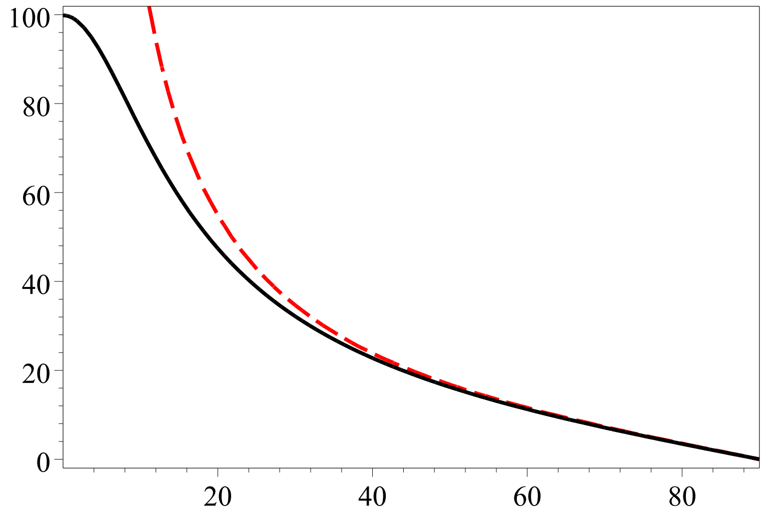
$$\omega = \frac{\Omega_i\left(-k^2 L + ik_x\right)}{k_y} = \frac{\Omega_i\left(-\kappa + i\cos\theta\right)}{\sin\theta}, \qquad k_x \parallel \nabla n_0$$

Weakly non-neutral: $|\delta n_e - \delta n_i| << |\delta n_e|, \quad \varepsilon \equiv \frac{\Omega_i}{\omega_{Pi}} \approx 0.014\left(\frac{10^3\,\text{cm}^{-3}}{n_0}\right)$

$$\omega = \omega_{Pi}\left(\frac{\sin\theta}{2\kappa\varepsilon} - \sqrt{\left(\frac{\sin\theta}{2\kappa\varepsilon}\right)^2 + 1 + \varepsilon^2 - \frac{i\cos\theta}{\kappa}}\right)$$

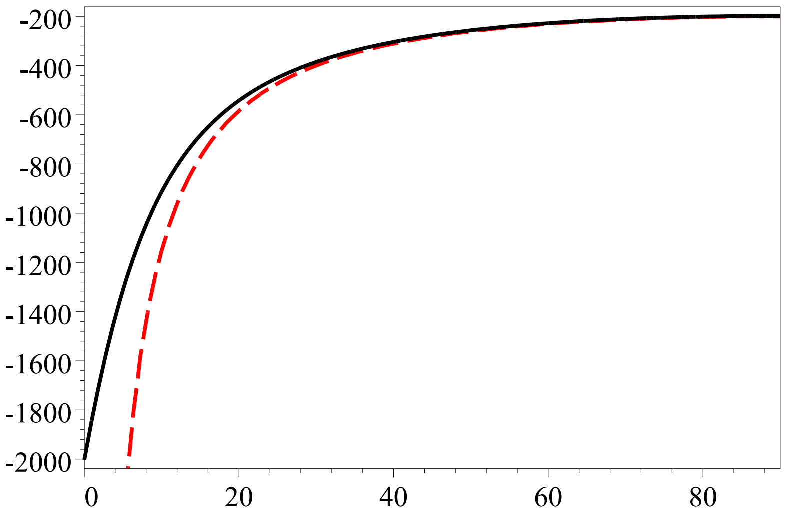
Linear Theory: $\varepsilon = 0.01$, k = 10

Growth rate (s^{-1})



Flow angle (degrees)

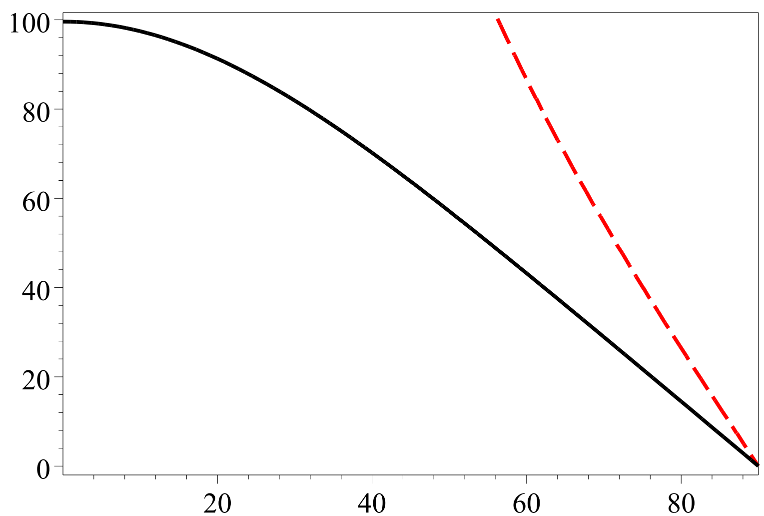
Real frequency (s^{-1})



Flow angle (degrees)

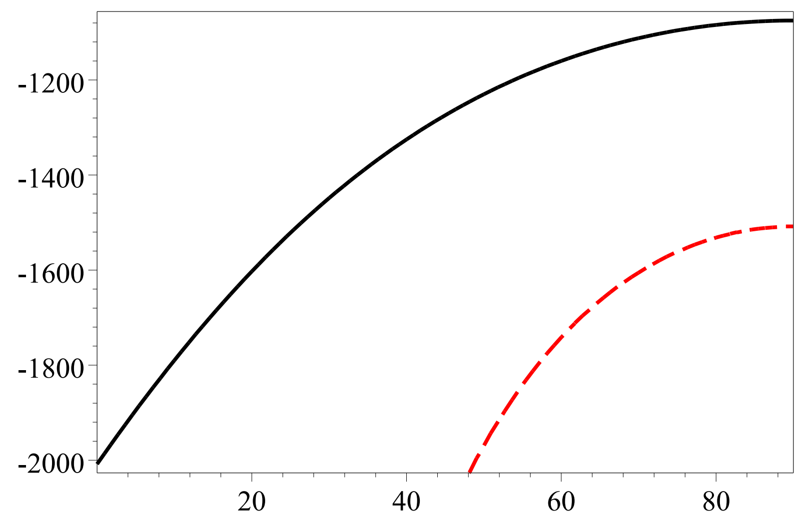
Linear Theory: $\varepsilon = 0.075$, k $= 10$

Growth rate (s^{-1})



Flow angle (degrees)

Real frequency (s^{-1})



Flow angle (degrees)

Conclusions

- First 2-D PIC simulations of a local nighttime F-region plasma density gradient are performed.
- Meter-size electron density irregularities show up that might be responsible for observed spread-F radar echoes.
- Simple analysis supports linear instability driven by local density gradient and E-field.
- *Work in progress!*