Three-Dimensional Effects, or the Lack Thereof, in Asymmetric Collisionless Magnetic Reconnection

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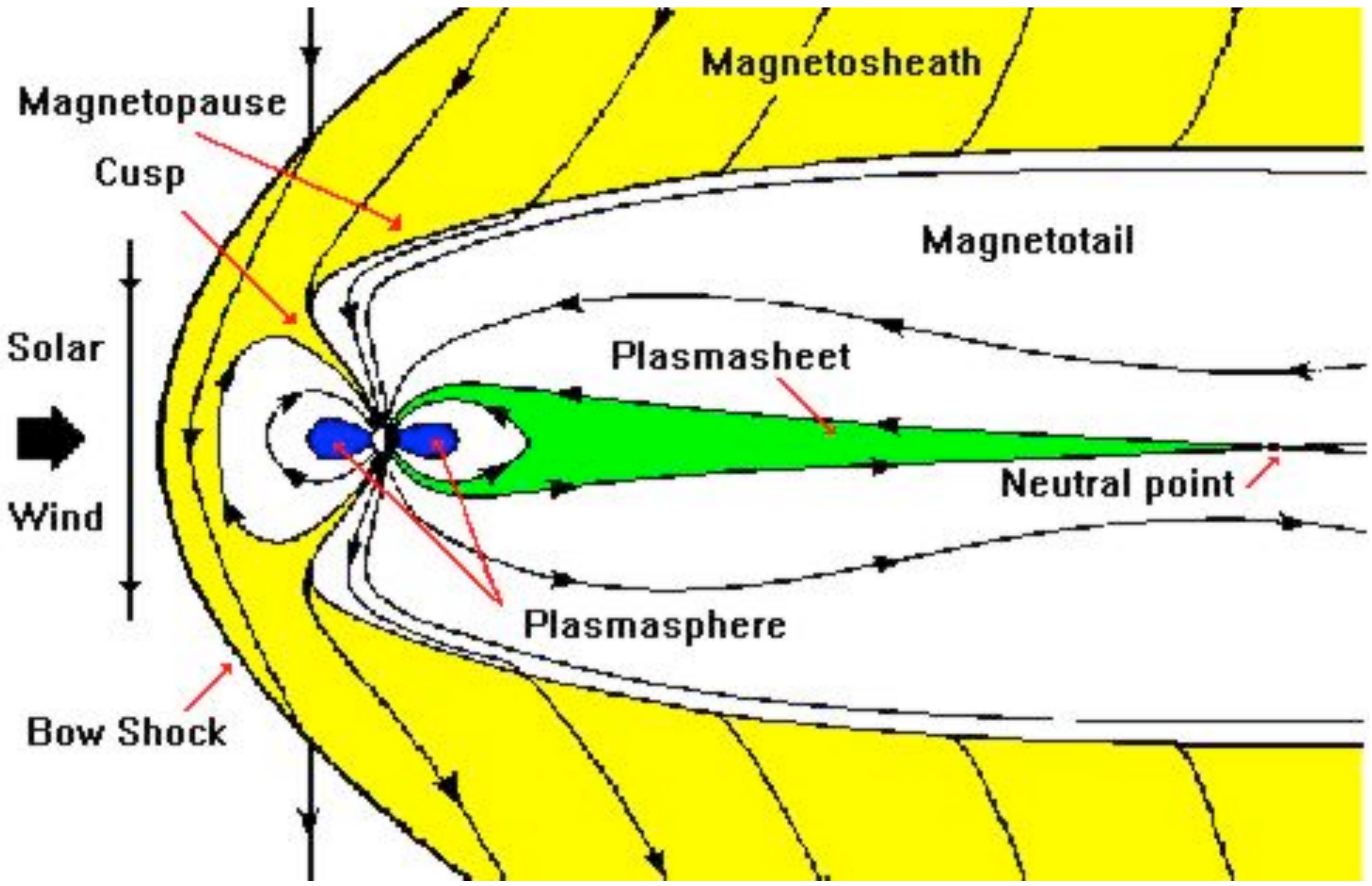
Reconnection in the Earth's Magnetosphere

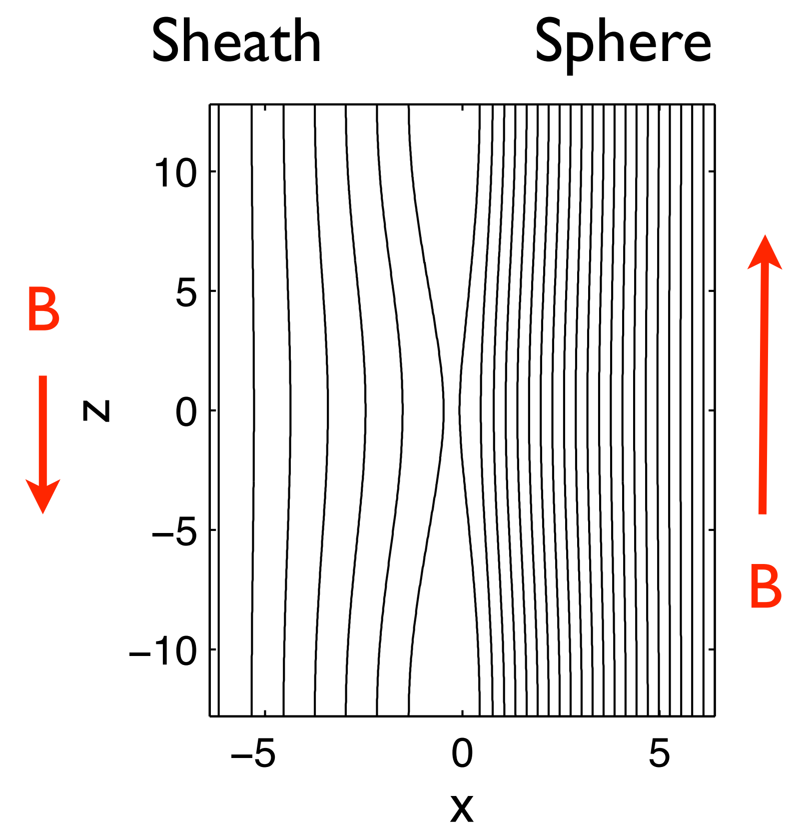


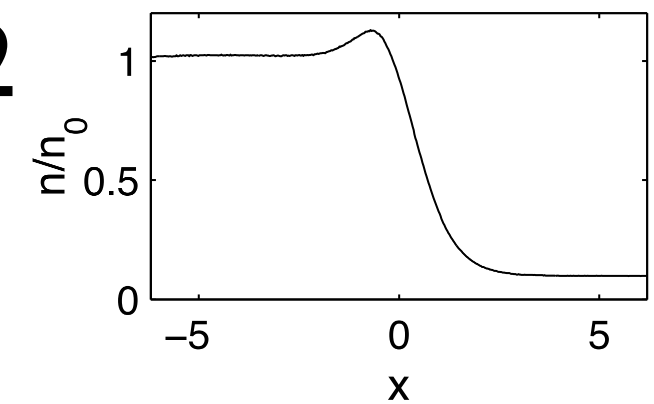
I. Magnetotail: Conditions across current sheet nearly symmetric.
II. Dayside Magnetopause: Strong gradients in magnetic field, plasma density, and temperature across current sheet. Asymmetric reconnection.

3D PIC Simulations:

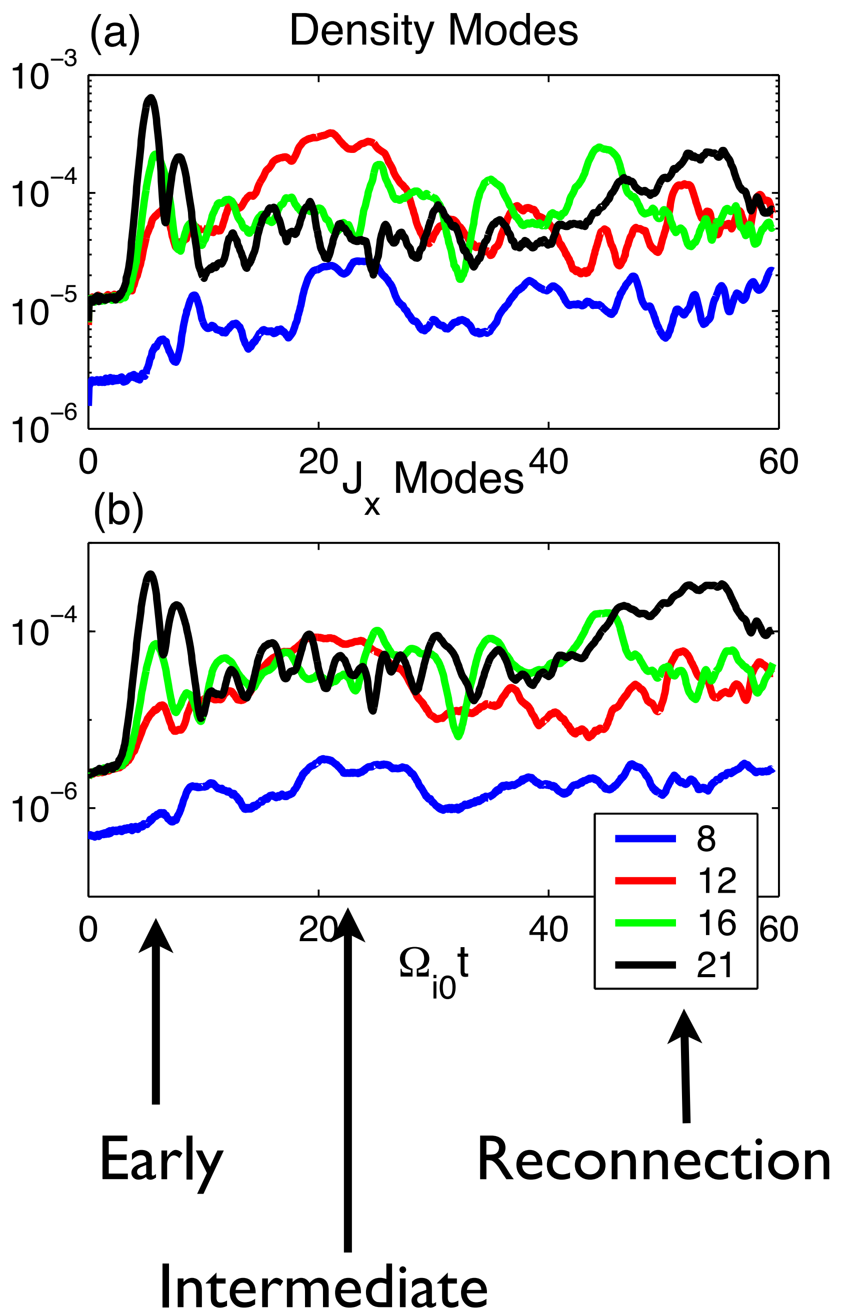
- x: conducting or driven BC
  (sech^2(z/L) E_y field)
- y: periodic
- z: open

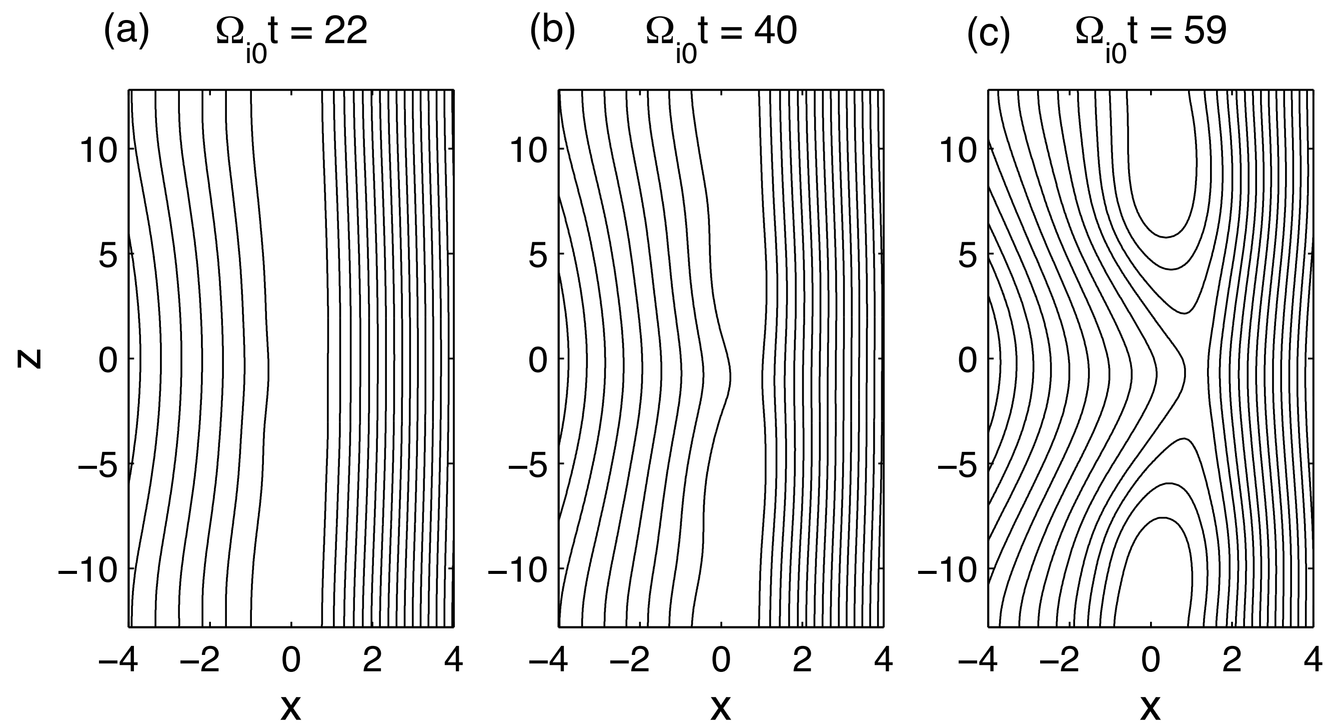
  Remove particles, inject thermal Maxwellian with initial T_i, T_e; $T_i/T_e = 2$
- $m_i/m_e = 200$ in 3D,
- Half thickness: $\lambda = 1.0\ c/\omega_{pi}$
- No Guide Field
- Reference Alfven speed based on B_0 and n_0: $c/v_A = 20$
- Unit electric field $v_A B_0$ typically 20-30 mV/m
- System size 25.6 c/ω_{pi} X 12.8 c/ω_{pi} X 25.6 c/ω_{pi}





Overview of Time Development

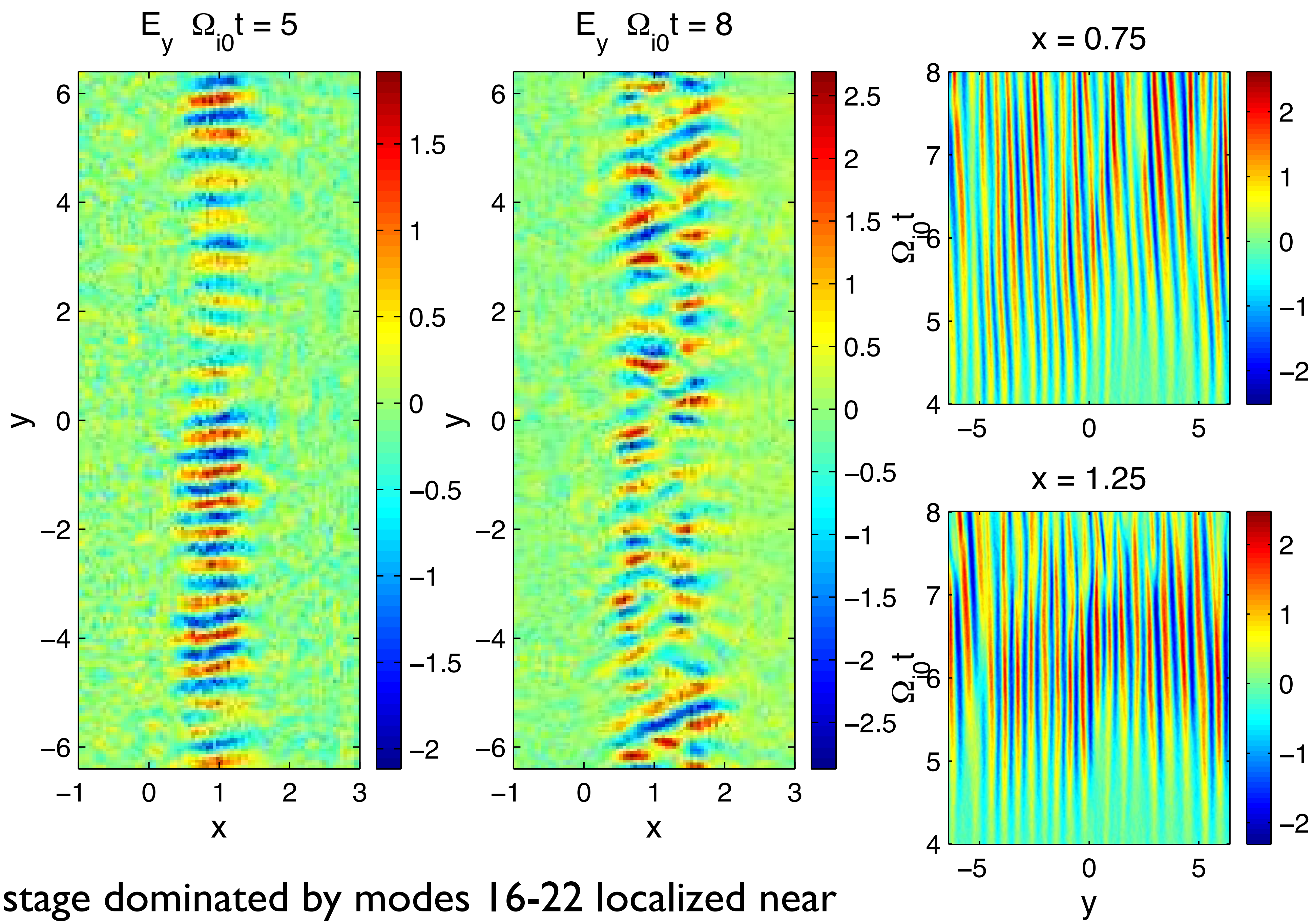




Mode 21: $k_y \rho_e = 0.52$

Mode 12: $k_y (\rho_e \rho_i)^{1/2} = 1.1$

Early Time



Early stage dominated by modes 16-22 localized near peak of density gradient. Then structures start to break up, in part due to differential in drift velocities.

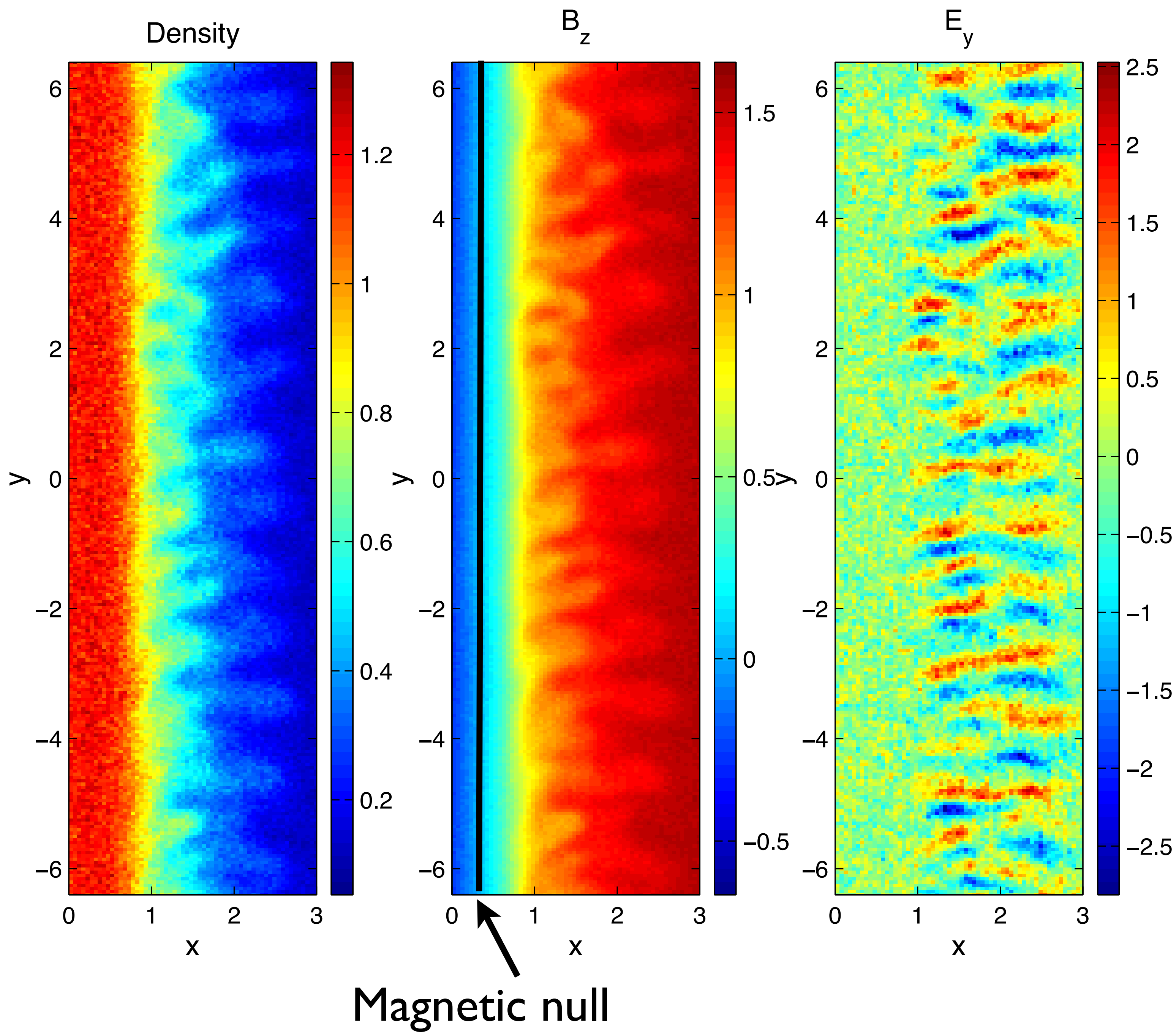
Intermediate Time ($\Omega_{i0}t = 22$)

Quasi-coherent structures of intense E_y fields extending over several d_i, significant contributions from modes 12-22.

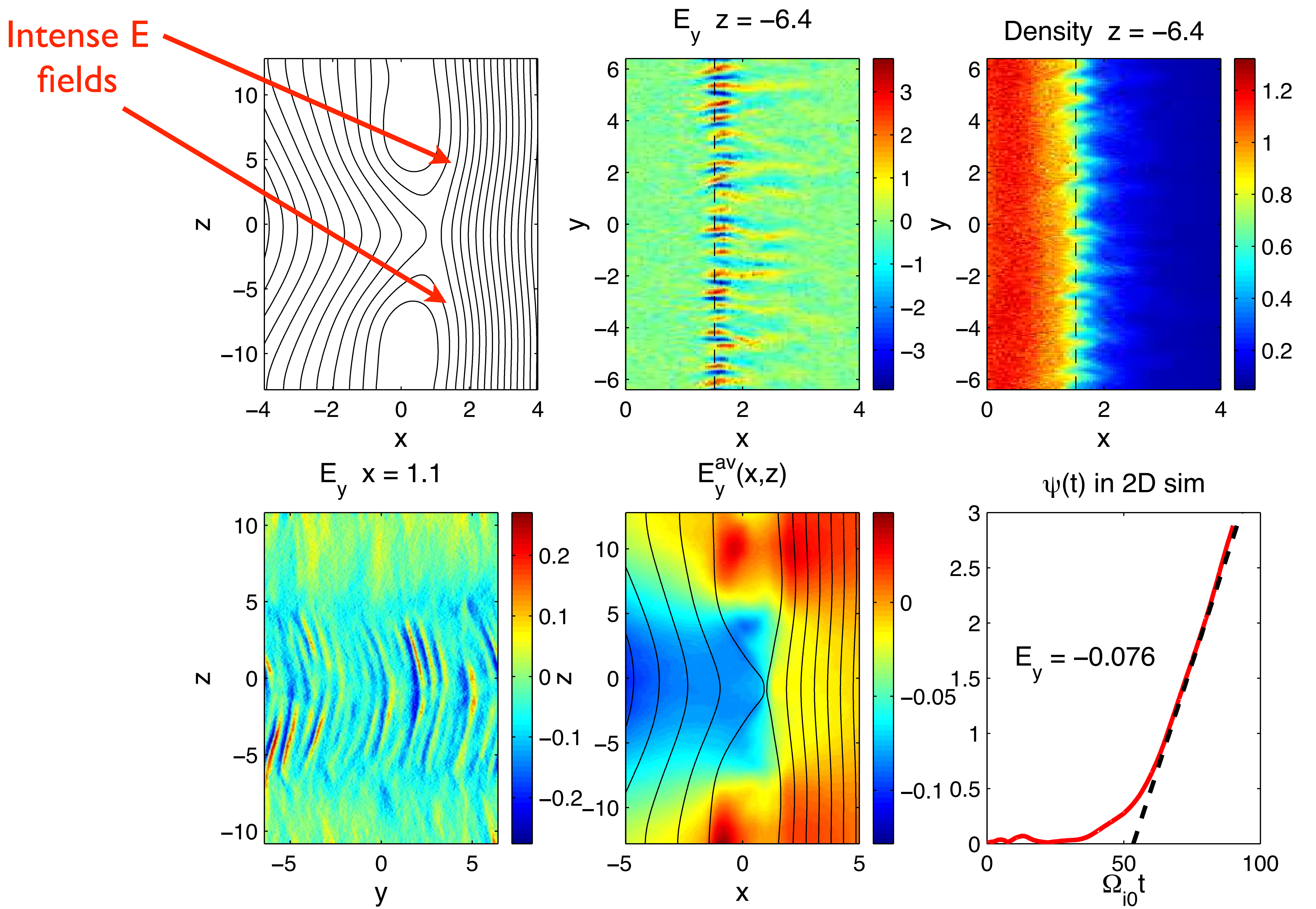
Modes saturate with $e\Phi/T_e \sim 1$; density and B_z are rippled but not strongly modified on average.

Modes are restricted away from the magnetic field null position.

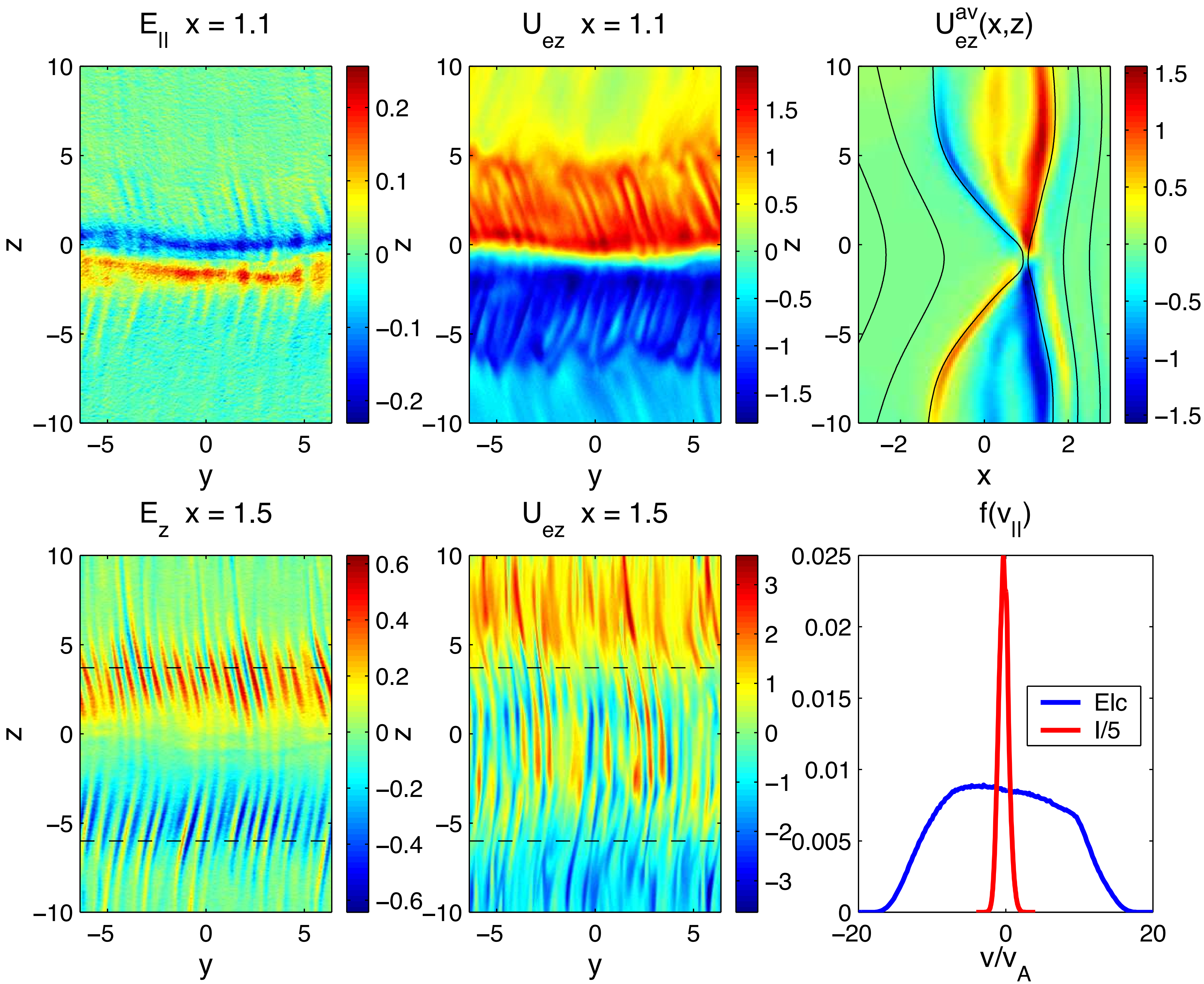
Modes occur for all z, consistent with $\mathbf{k} \cdot \mathbf{B} = 0$.



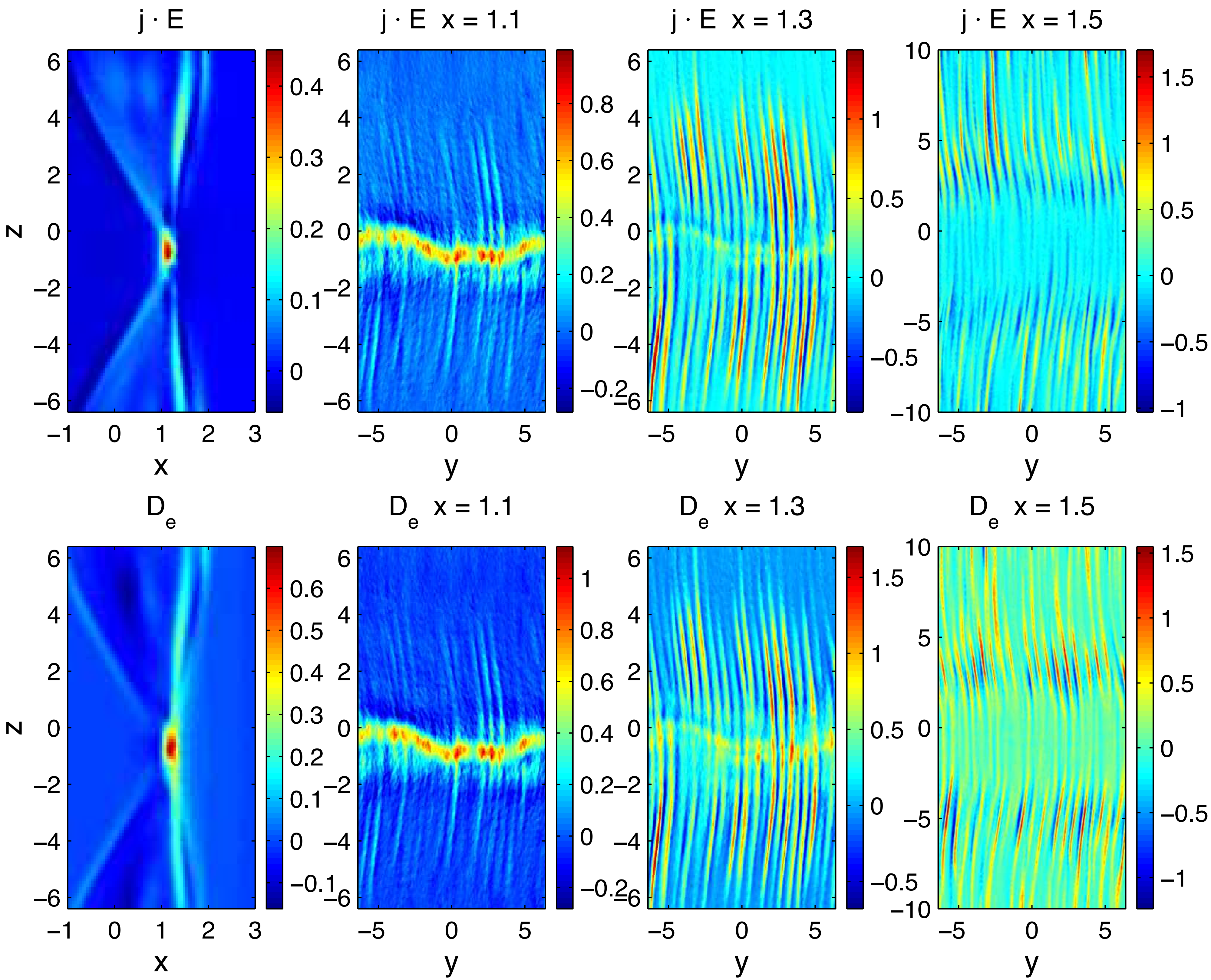
Reconnection Stage $\Omega_{i0}t = 56$



Average reconnection rate is not modified from standard 2D result. Intense E fields do not appear to play important role in reconnection dynamics.



$E_{||}$ x = 1.1
U_{ez} x = 1.1
$U_{ez}^{av}(x,z)$
E_z x = 1.5
U_{ez} x = 1.5
$f(v_{||})$
z
y
x
v/v_A
Elc
I/5



D_e: Lorentz invariant dissipation in electron rest frame (Zenitani et al., 2011)

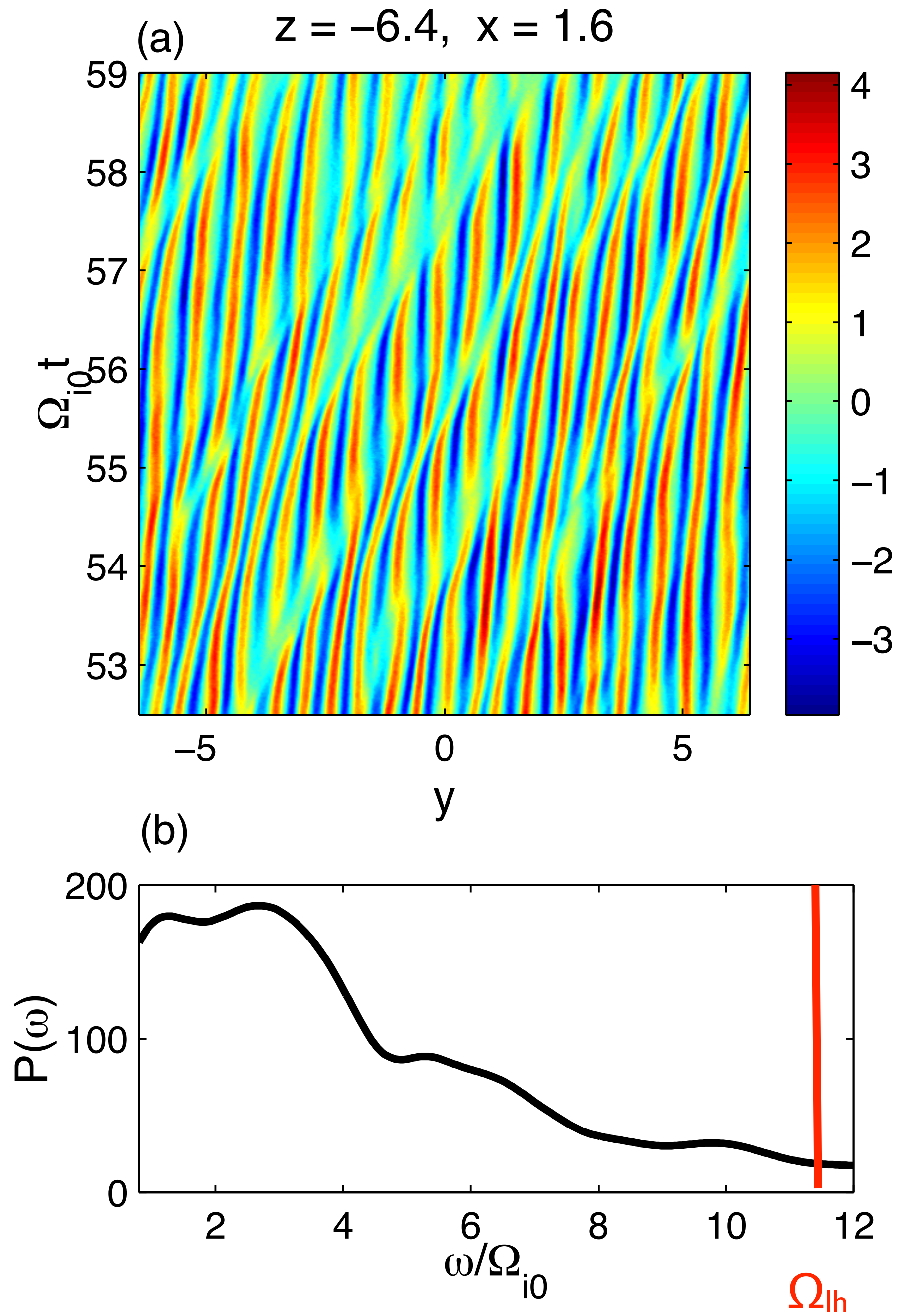
Frequency Spectrum

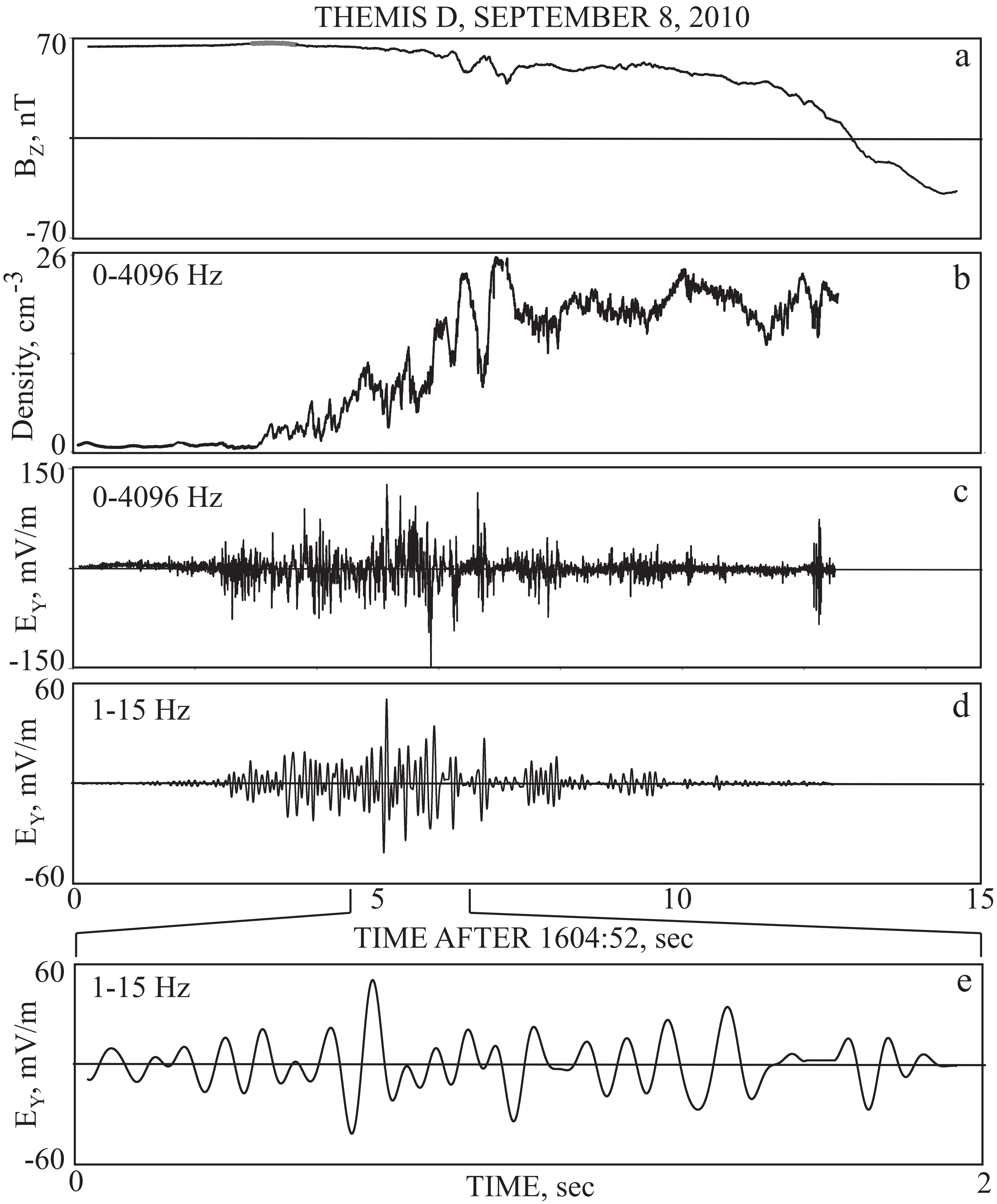
Electric field structures drift dawnward at $\approx 0.2\ v_A$, wavelength = 0.61 d_i, giving apparent frequency of 2.1 Ω_{i0}

Power spectrum shows peaks at 2.7 Ω_{i0} and 5.3 Ω_{i0}.

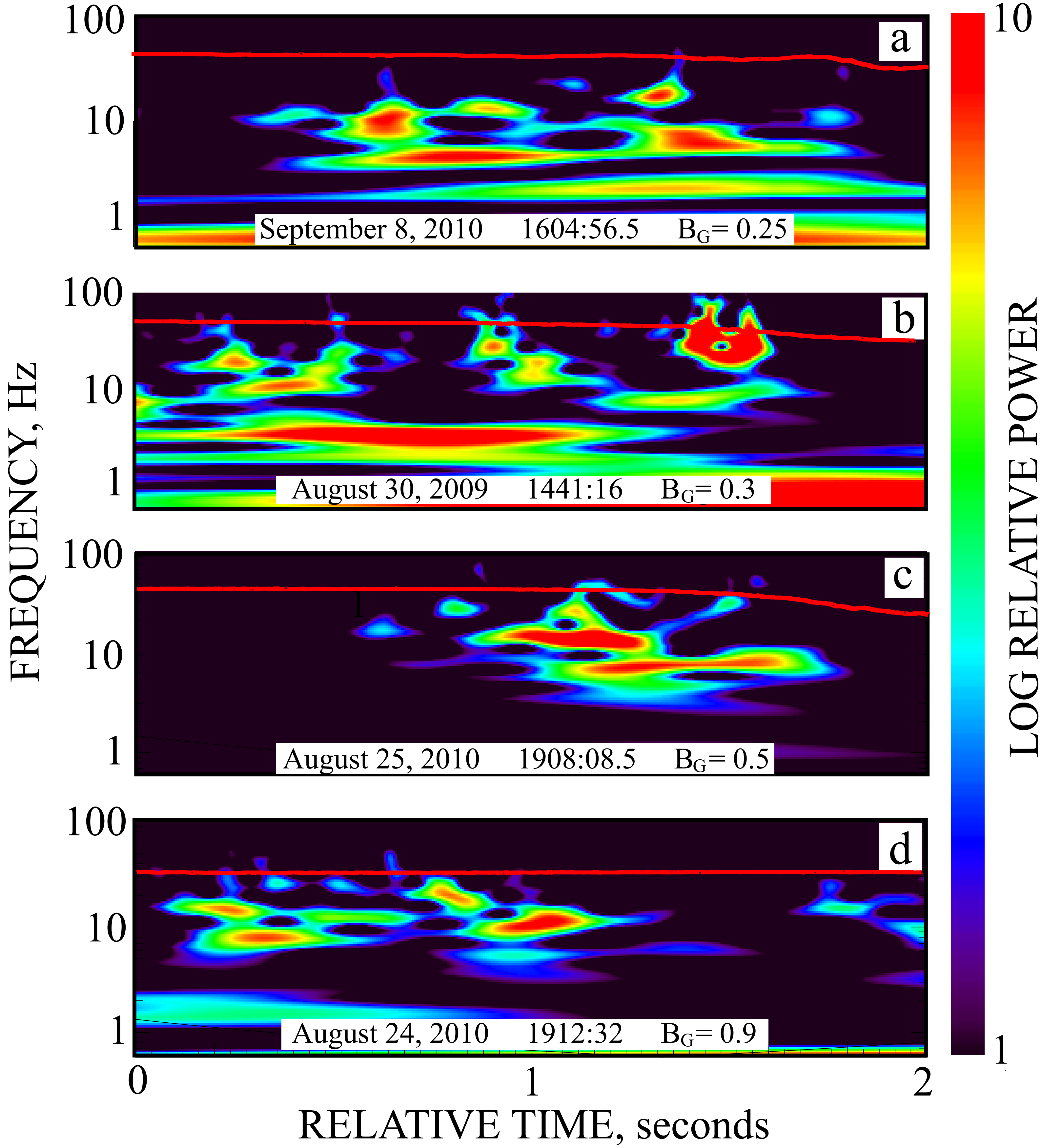
The frequency and wavenumber appear to scale inversely with ρ_e. Thus for true electron mass of $m_p/1836$, expect a frequency 3.0 times as large or 8 and 16 Ω_{i0} (8 and 16Hz with proton cyclotron frequency of 1 Hz).

Compare with THEMIS observations at the subsolar magnetopause.





THEMIS D, SEPTEMBER 8, 2010
70
-70
B_Z, nT
a
26
0
Density, cm^{-3}
0-4096 Hz
b
150
-150
E_Y, mV/m
0-4096 Hz
c
60
-60
E_Y, mV/m
1-15 Hz
d
0
5
10
15
TIME AFTER 1604:52, sec
60
-60
E_Y, mV/m
1-15 Hz
e
0
2
TIME, sec


a
September 8, 2010 1604:56.5 B_G= 0.25
b
August 30, 2009 1441:16 B_G= 0.3
c
August 25, 2010 1908:08.5 B_G= 0.5
d
August 24, 2010 1912:32 B_G= 0.9
100
10
1
FREQUENCY, Hz
0
1
2
RELATIVE TIME, seconds
10
1
LOG RELATIVE POWER

SUMMARY

- Intense (~50-100 mV/m) electric field modes exist on magnetospheric edge of magnetopause current sheet.
- Consistent with LHDI - trapped in the density gradient region and satisfy $\mathbf{k} \cdot \mathbf{B} = 0$. Frequency ~ 20% - 40% of lower hybrid frequency.
- The modes are persistent, but there can be significant fluctuations in frequency.
- Modes saturate, do not do much to alter the density profile.
- Modes remain coherent, do not evolve into turbulence.
- Modes do not appear to directly impact the reconnection process, and they are not a source of anomalous resistivity.
- Existence of ~100 mV/m E fields on magnetospheric side of reconnecting magneto-pauses confirmed by THEMIS observations.
- Observations suggest that the modes persist in the presence of a moderate guide field; such a field would only alter the orientation of the $\mathbf{k} \cdot \mathbf{B} = 0$ surface.