Electron Acceleration in magnetic reconnection with multiple magnetic islands

Naoki Bessho
Li-Jen Chen
Amitava Bhattachargee

Center for Integrated Computation and Analysis of Reconnection and Turbulence (CICART)

University of New Hampshire

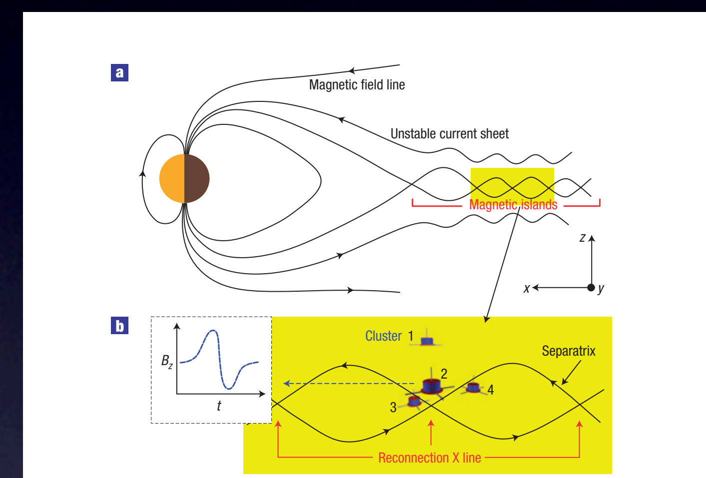
Electron Acceleration in magnetic reconnection

Solar Flares

Up to 50% of released magnetic energy can go to kinetic energy of high energy electrons. (Lin et al., 2003, Holman et al. 2003)

Earth's magnetotail

High energy electrons are observed in
X-lines (Oieroset et al. 2002)
downstream region (Imada et al. 2007)
magnetic islands (Chen et al. 2007)



Chen et al. 2007

Energetic electrons up to 100keV are observed in magnetic islands

High energy electrons
core magnetic fields
electron densities

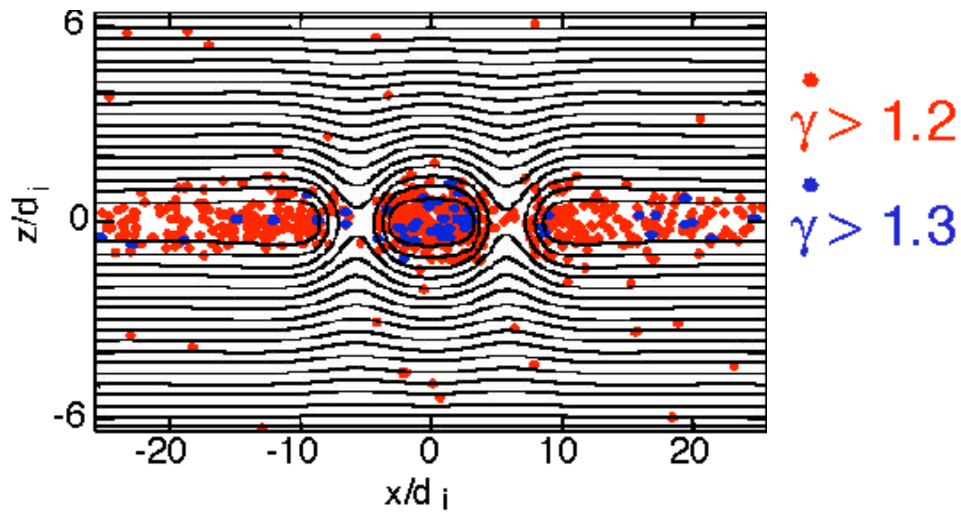
2D PIC simulations

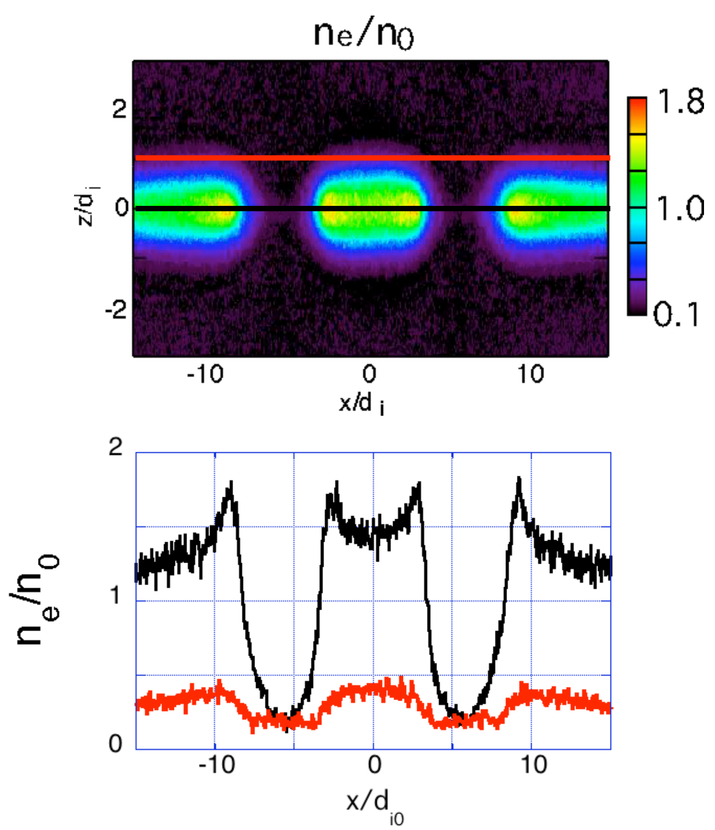
Electron energization in a magnetic island

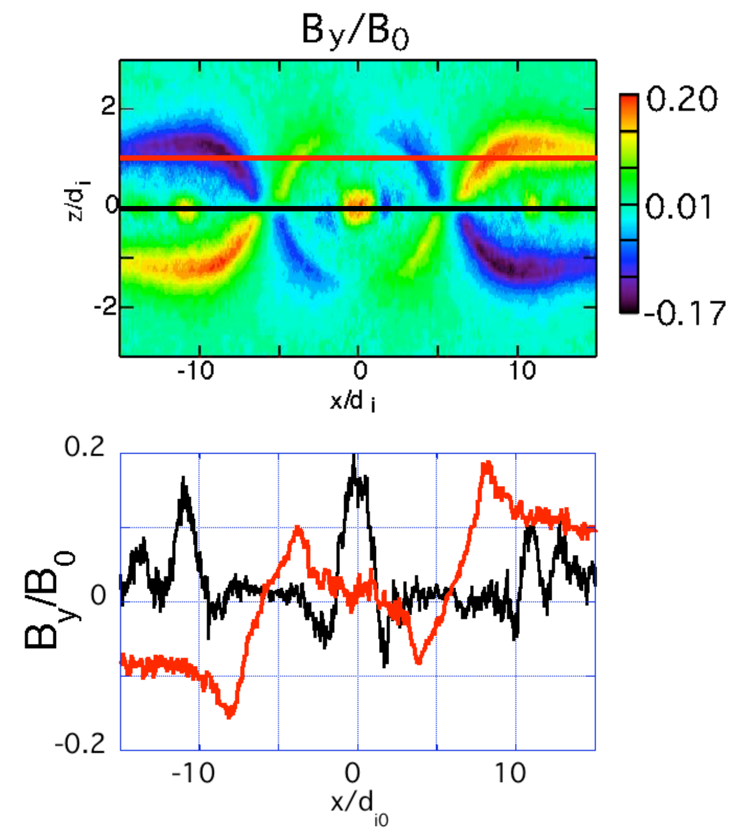
Harris sheet (width 0.5 d_i) with two X-lines

m_i/m_e=100, v_A/c=1/20, T_i/T_e=5

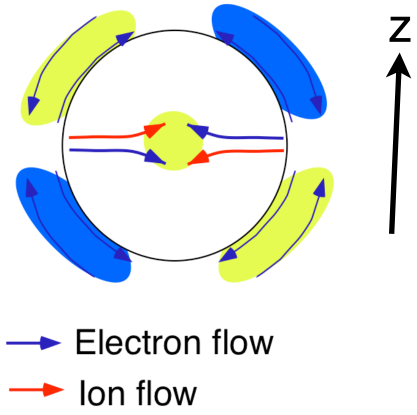
small guide field B_y=0.01B_0





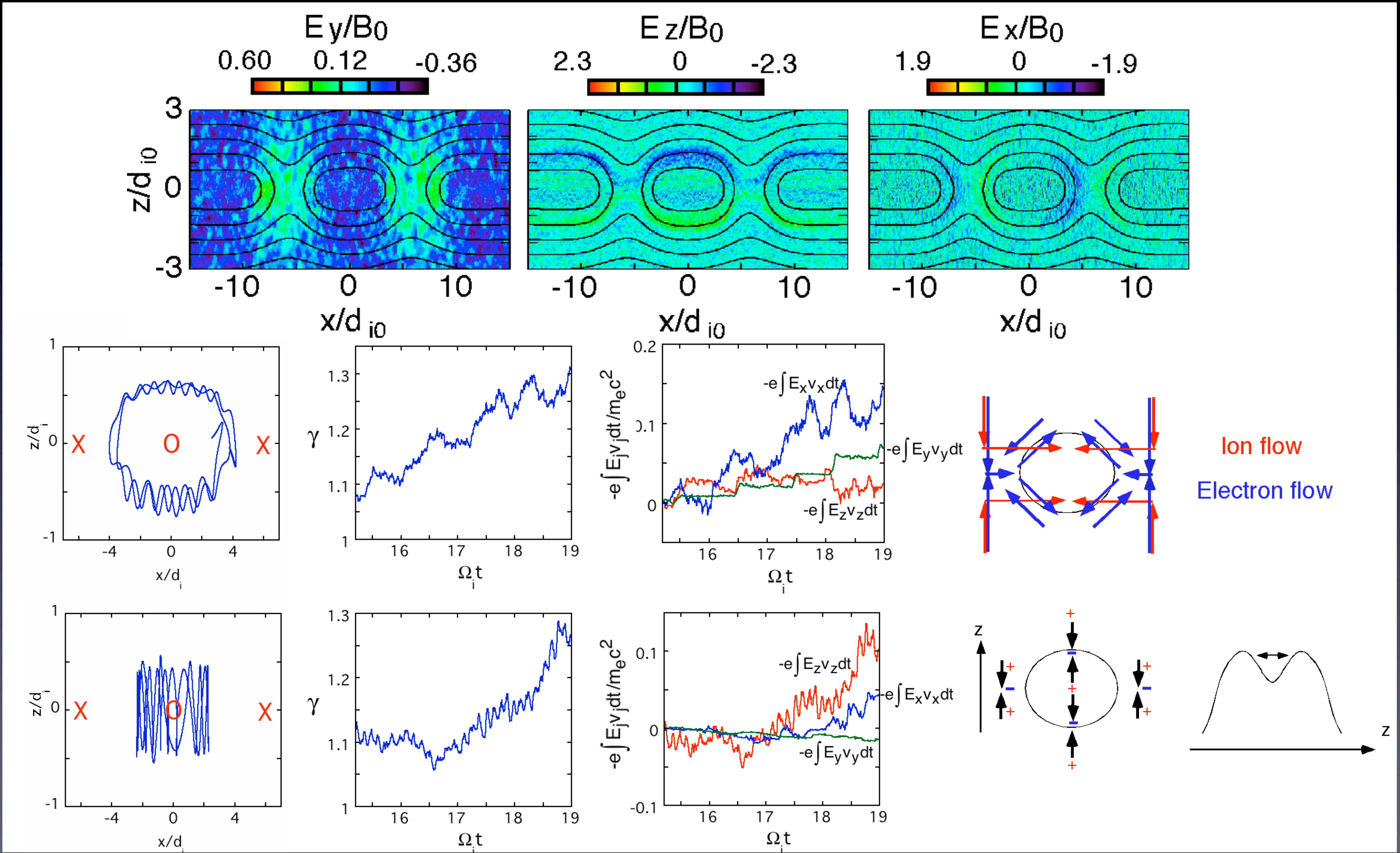


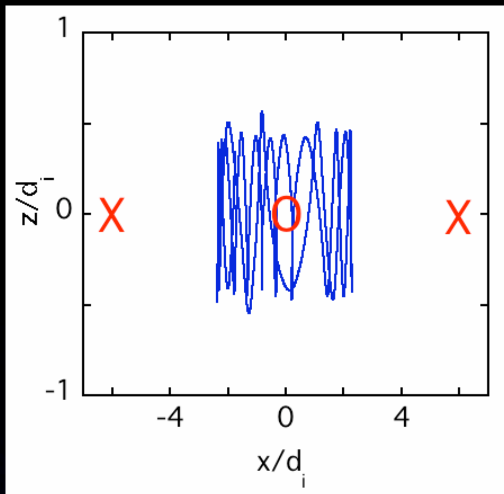
$$F_z \sim q v_x B_y / c$$

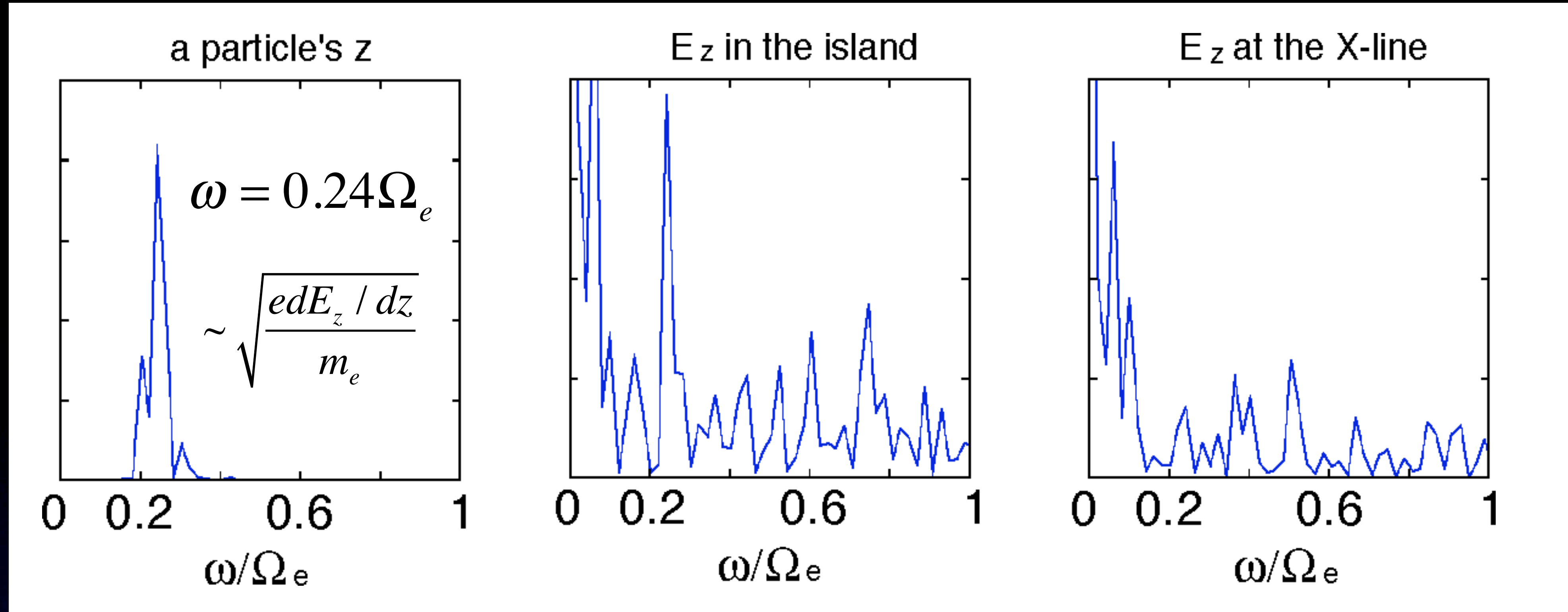


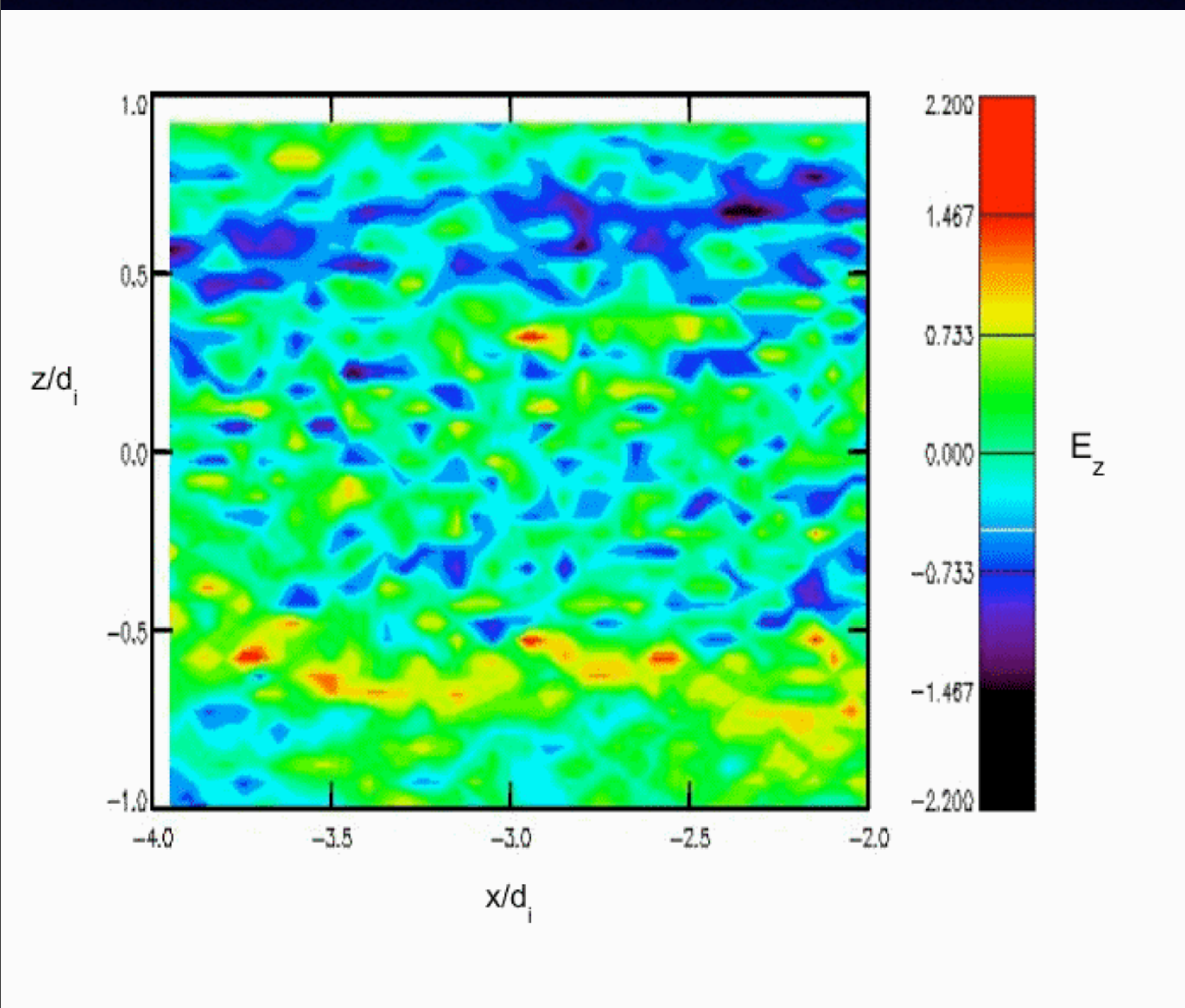
Energization mechanism in magnetic islands

1. acceleration by the out-of plane electric field E_y
2. acceleration by the in-plane electric field E_x and E_z









$$m_e \frac{d^2z}{dt^2} = -eE_z - \frac{e}{c}(v_x B_y - v_y B_x)$$

$$\sim -e\frac{dE_z}{dz} z$$

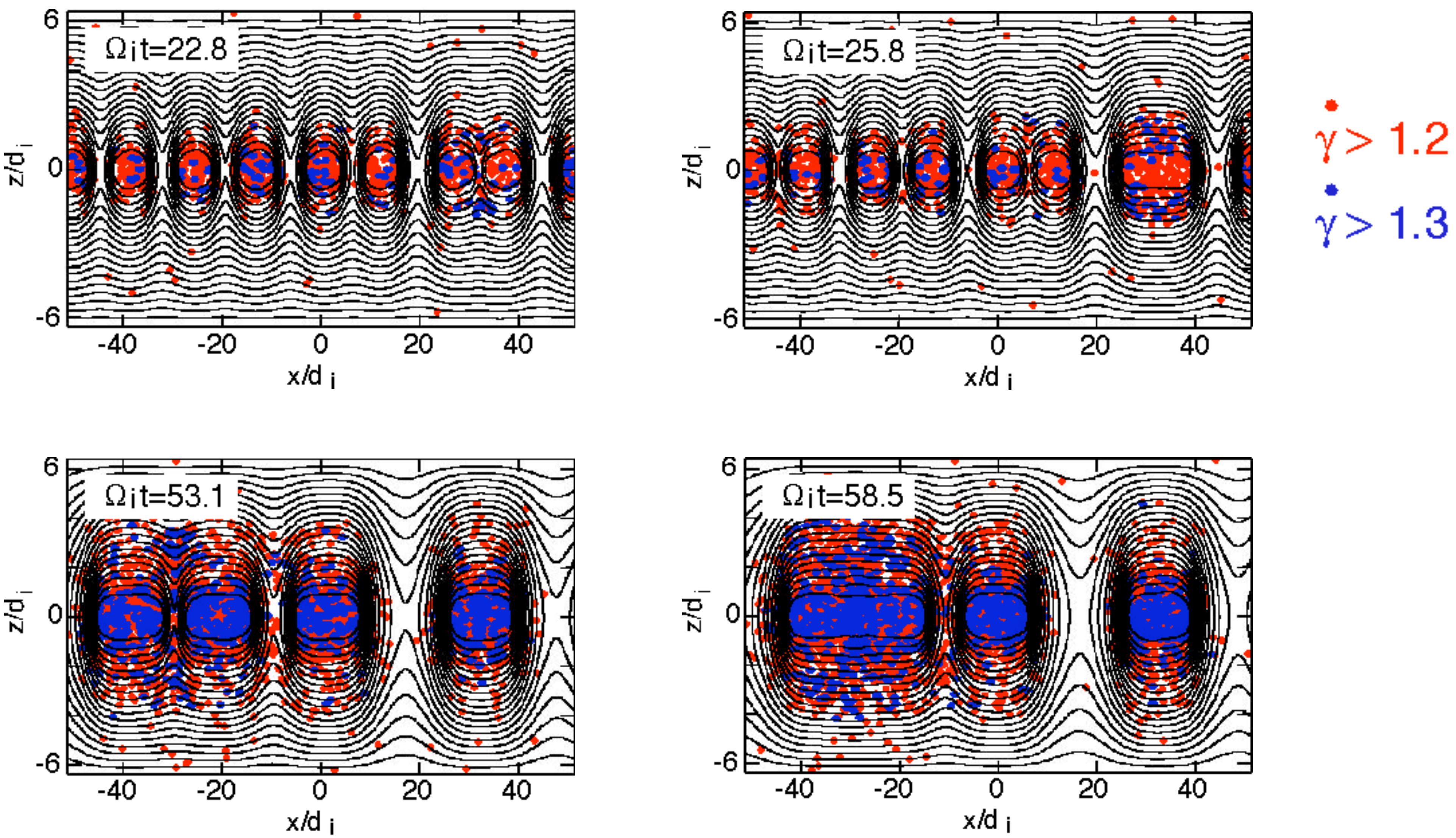
Electrons are energized when their bounce frequencies are close to wave frequencies.

Electron energization in coalescing magnetic islands

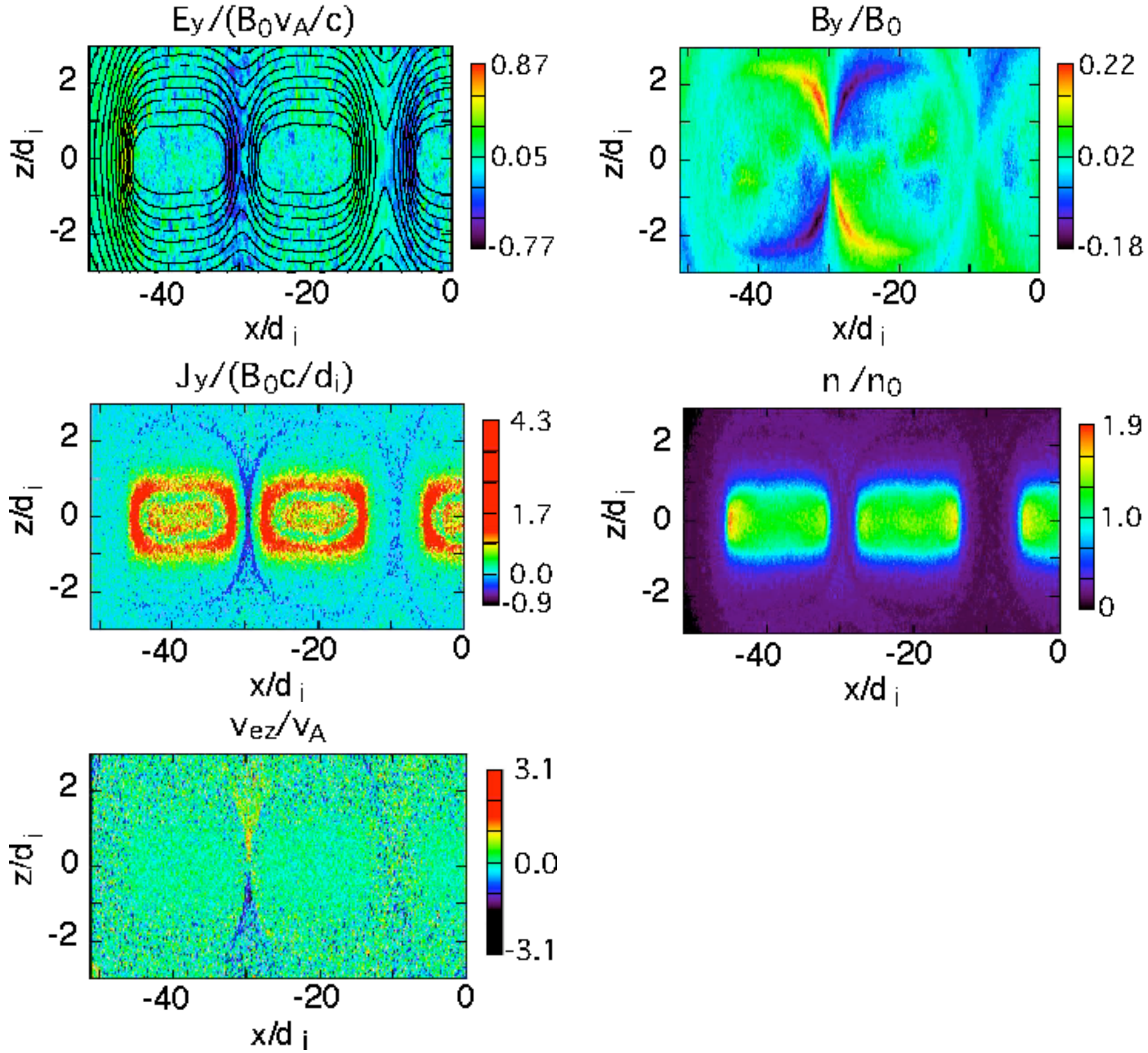
Harris sheet (width 0.5 d_i) with 8 X-lines

m_i/m_e=100, v_A/c=1/20, T_i/T_e=5

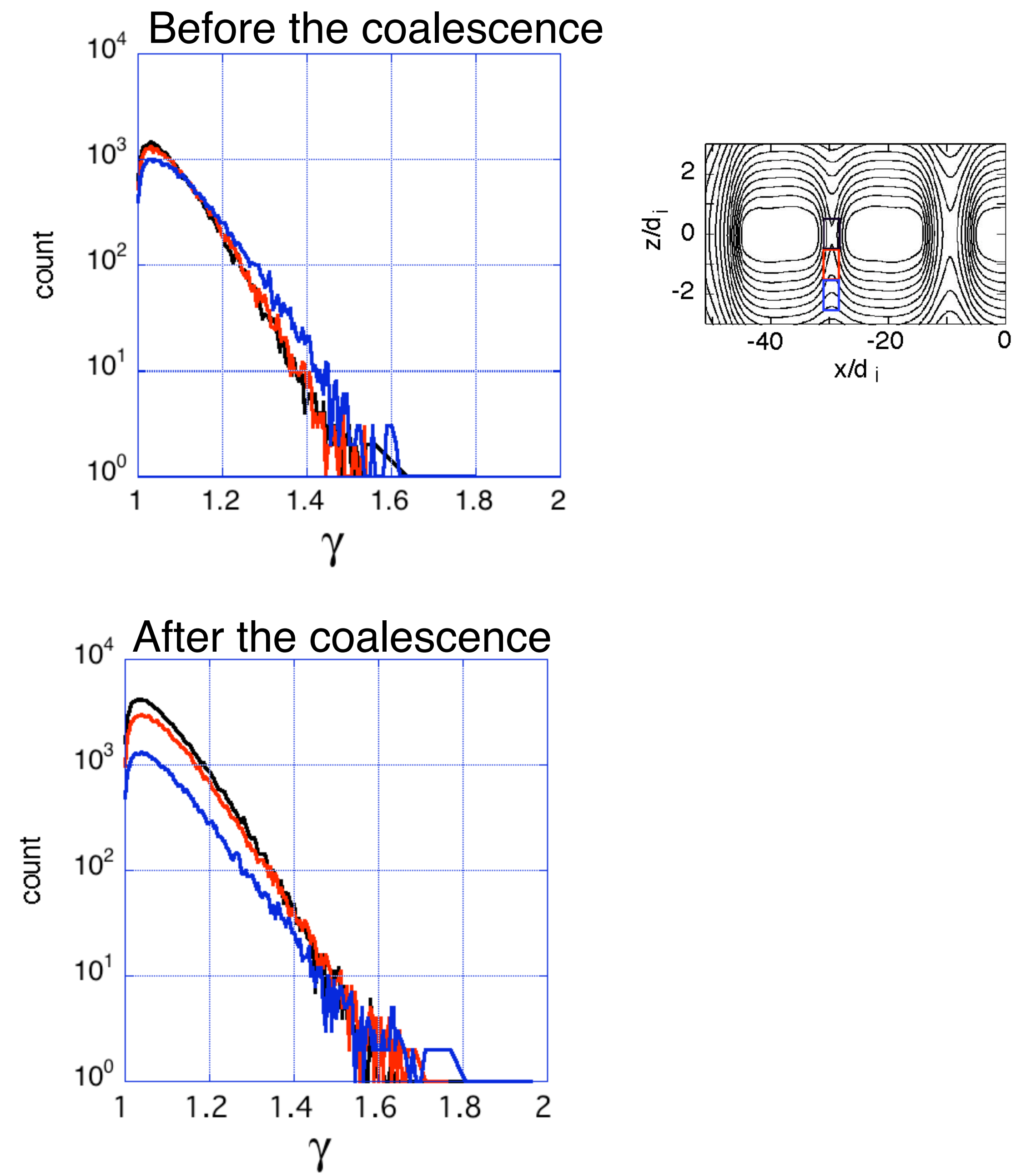
small guide field B_y=0.01B_0



$\Omega_i t=53.1$

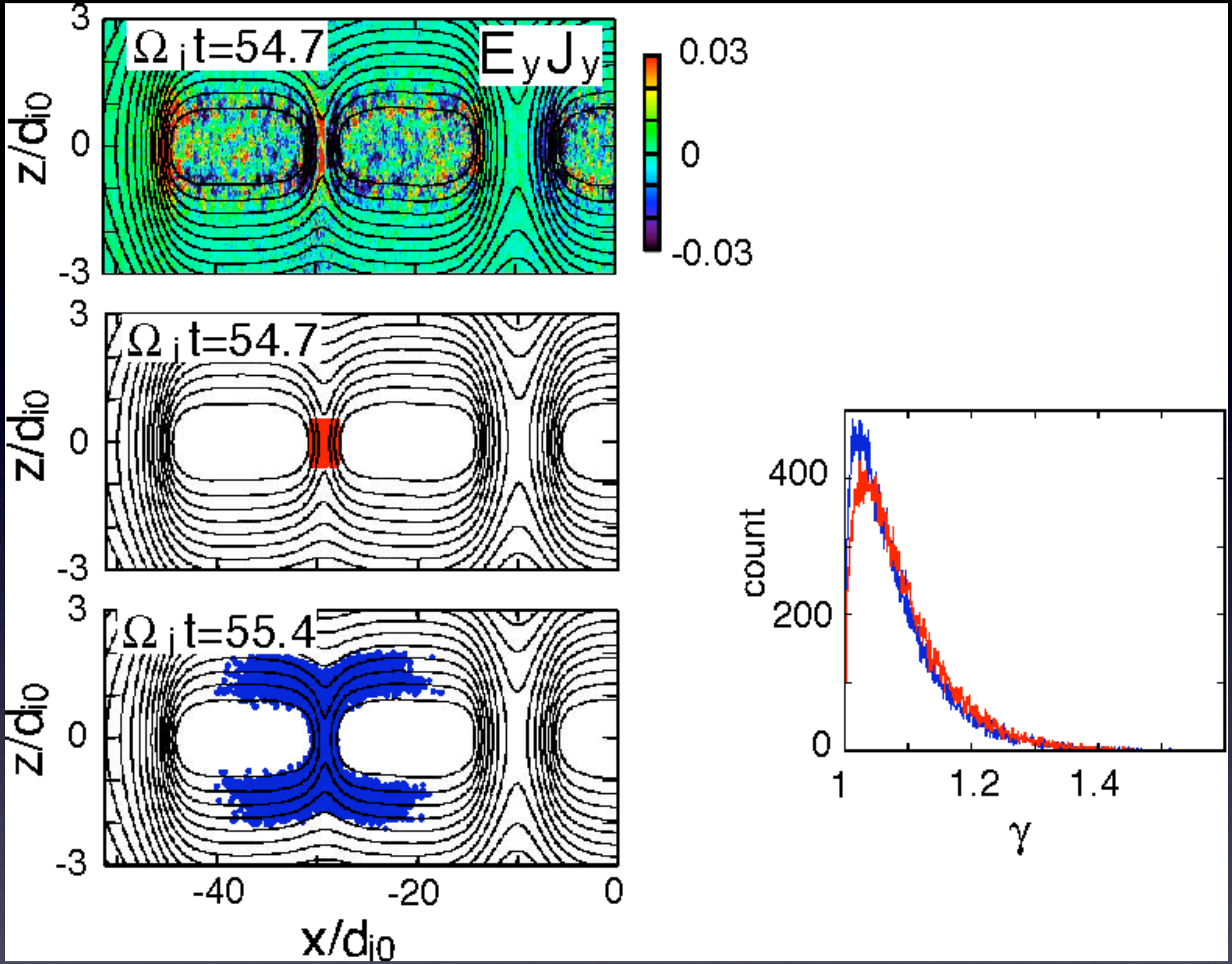


Ey/(B0vA/c)
0.87
0.05
-0.77
By/B0
0.22
0.02
-0.18
Jy/(B0c/di)
4.3
1.7
0.0
-0.9
n/n0
1.9
1.0
0
vez/vA
3.1
0.0
-3.1
z/d i
x/d i
2
0
-2
-40
-20
0



Before the coalescence
After the coalescence
count
γ
10^0
10^1
10^2
10^3
10^4
1
1.2
1.4
1.6
1.8
2
z/d i
x/d i
-40
-20
0

Heating and cooling in coalescing islands



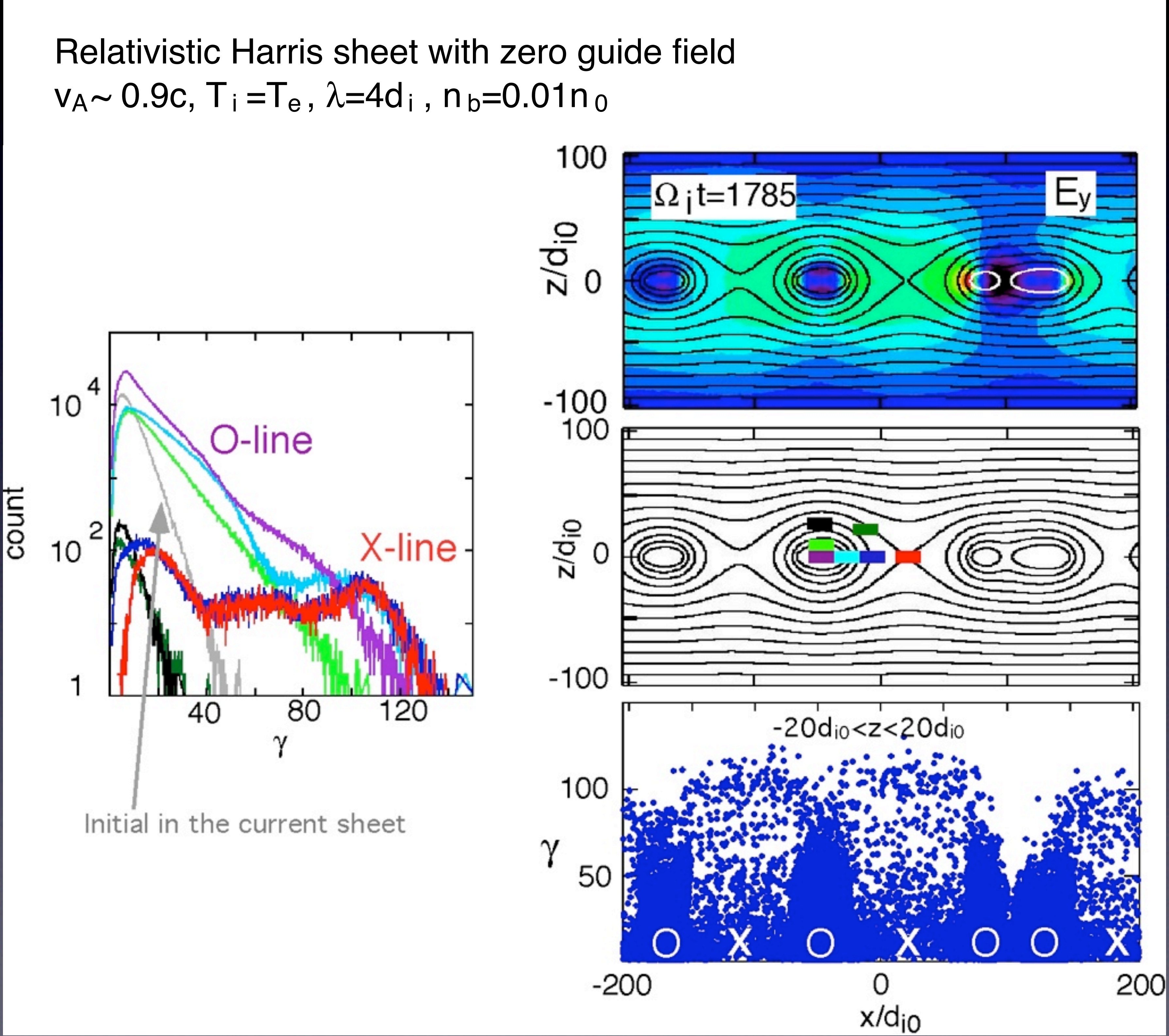
Heating occurs in the thin current sheet and the outer ends of the two coalescing islands.

Cooling occurs in the regions beside the thin current sheet.

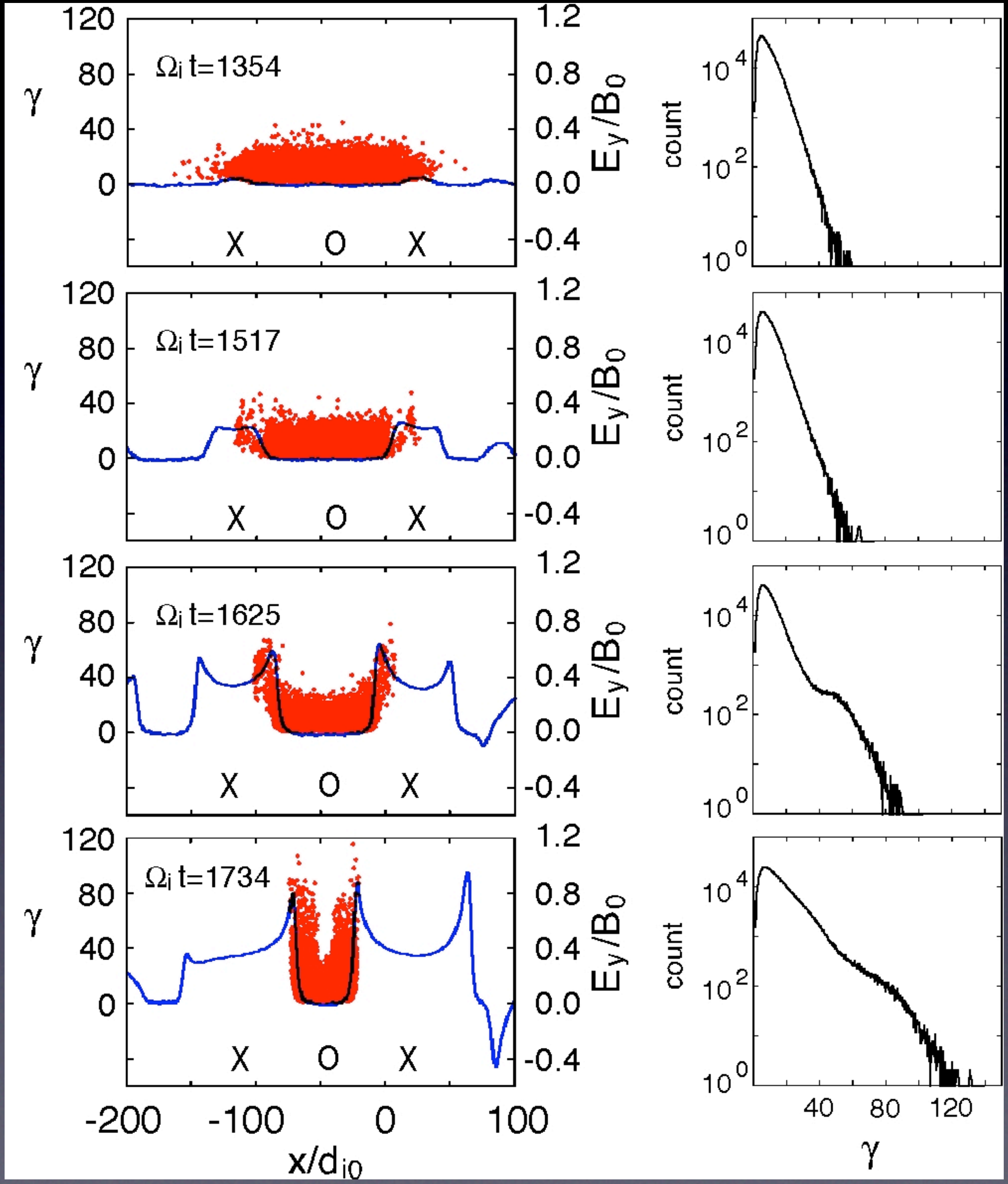
Particle acceleration and heating in electron-positron plasmas

Pulsar winds, extragalactic jets, etc.

Fast reconnection is realized, even though there is no Hall effect.



Particle energization in contracting magnetic islands

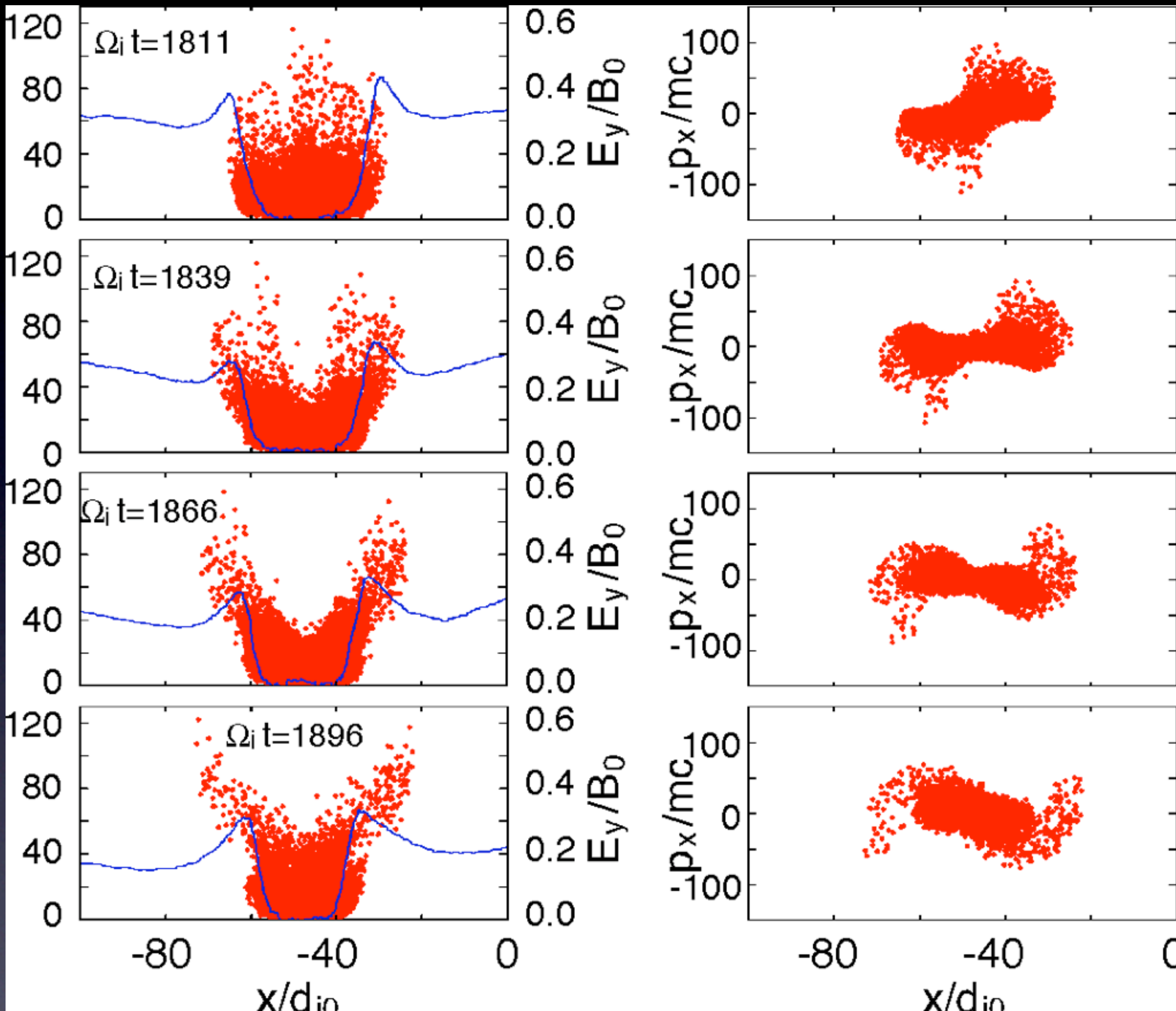


Inductive electric field

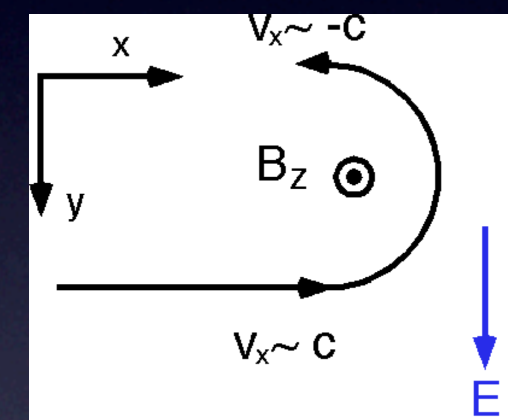
$E_y \sim V_x B_z / c$

Particles are energized by the inductive electric field formed in the two ends of the magnetic island.

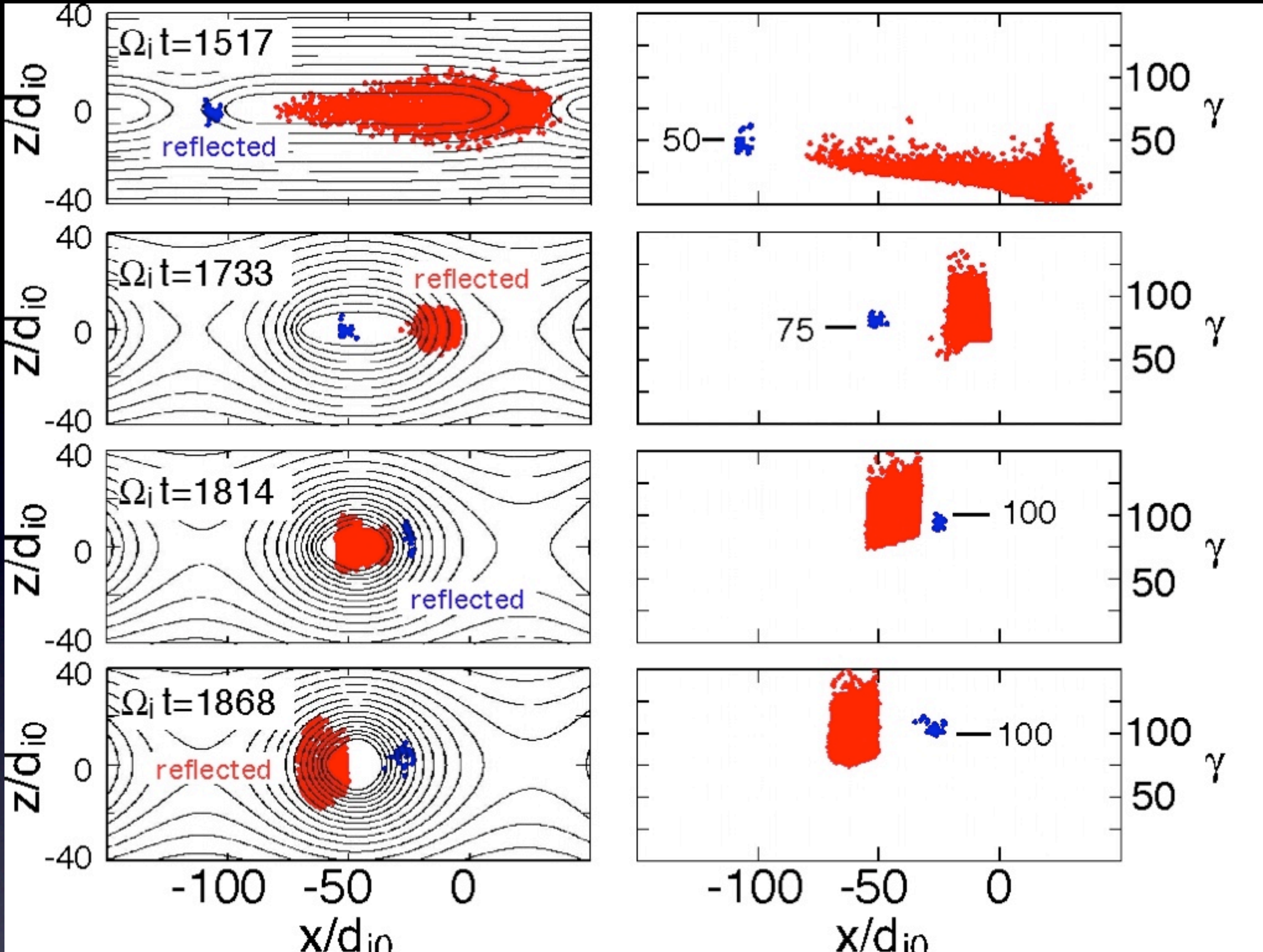
Particle reflection in the ends of the island



Particles are reflected in the ends of the magnetic island, and gain energy.



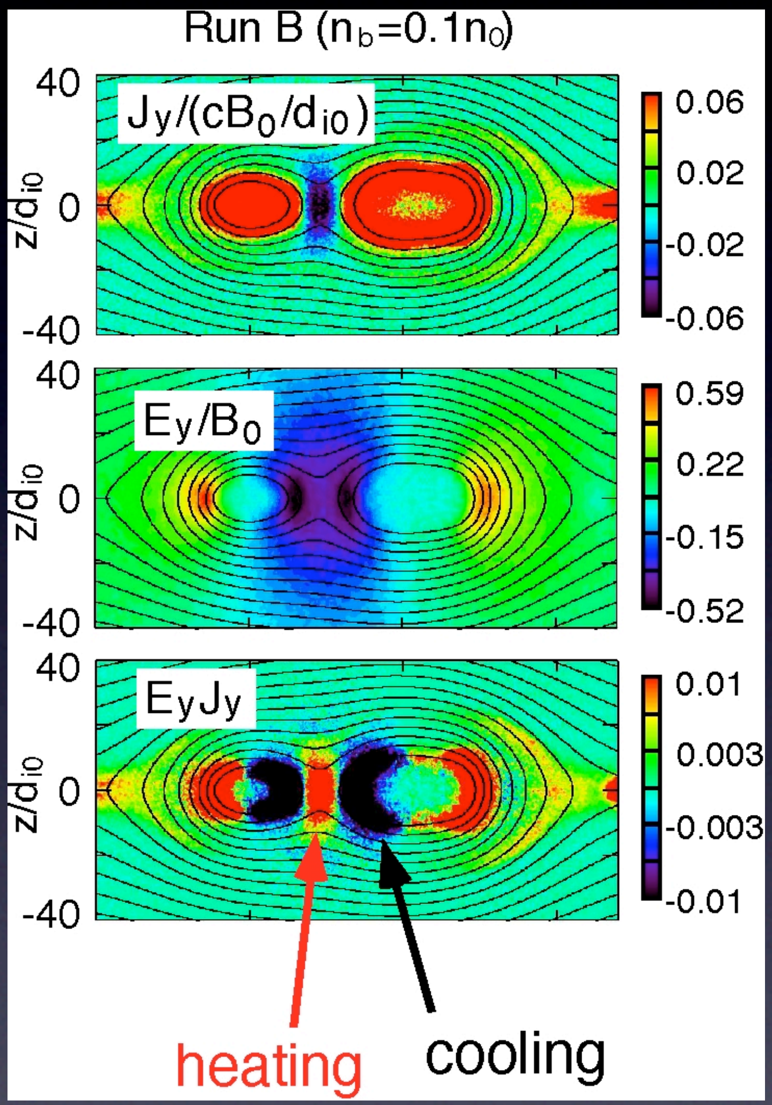
$$\gamma \sim \frac{1+|E_y / B_z|}{1-|E_y / B_z|}\gamma_0 \sim \frac{1+|V_{out} / c|}{1-|V_{out} / c|}\gamma_0$$

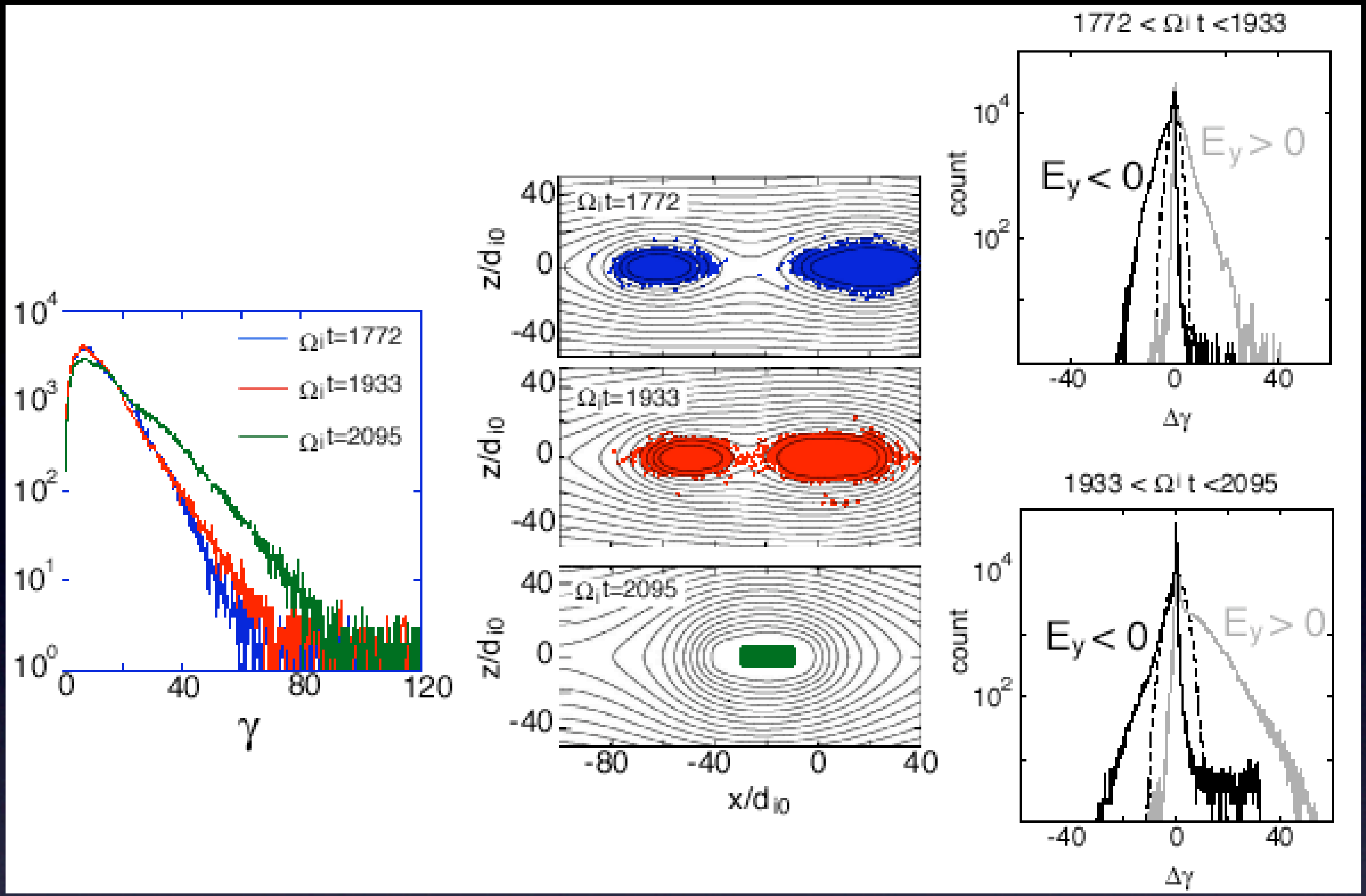


$$\gamma \sim \frac{1+|E_y/B_z|}{1-|E_y/B_z|}\gamma_0 \sim \frac{1+|V_{out}/c|}{1-|V_{out}/c|}\gamma_0$$

There are both similarities and differences between this acceleration mechanism and a Fermi process by Drake et al., 2006.

Particle energization in coalescing islands





Some particles are accelerated
by the reconnection in coalescing islands, but
many are decelerated there.

Particles are accelerated in the two ends of the coalescing islands.

Summary

Electron acceleration in both electron-proton plasmas and electron-positron plasmas has been studied by 2D PIC simulations.

In magnetic islands in electron-proton plasmas, electrons are accelerated by the out-of-plane electric field and the in-plane electric fields. Particles are energized by wave-particle interaction.

In magnetic islands in electron-positron plasmas, particles are accelerated by the out-of-plane electric field in the two ends of the island. Particles are energized by multiple reflection there.

In coalescing islands, reconnection between the two islands can accelerate some particles. Some particles are decelerated by the negative electric field there.