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Electron Heating Mechanism in the Plasma Sheet-Lobe Boundary Region Associated with Magnetic Reconnection

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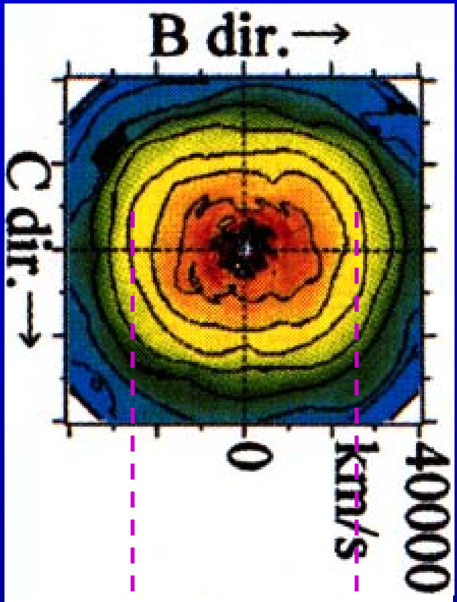
Introduction

- ✧ Reaveling plasma acceleration and heating mechanism is very important in understanding energy transport processes associated with magnetic reconnection.

- ✧ Recent in-situ observations in the Earth magnetotail have showed that a flat-topped electron distribution is formed in the plasma sheet-lobe boundary region associated with magnetic reconnection. [*Saito et al*., 1995; *Shinohara et al*., 1998; *Hoshino et al*., 2001]



[*Shinohara et al*., 1998]

~ A few keV

Introduction

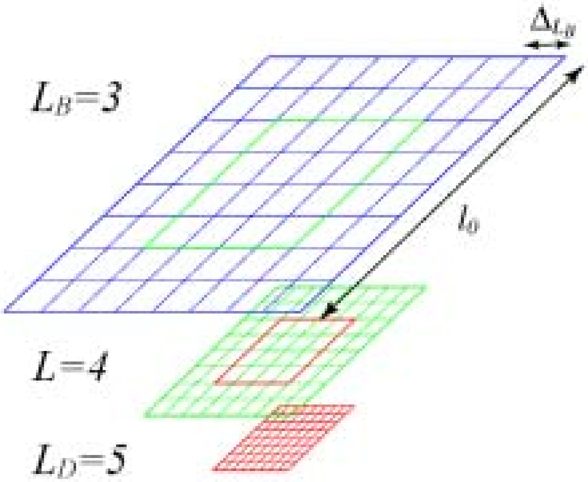
✧ Suggesting mechanisms for the electron heating are,

- Slow-mode shock [*Schwartz et al.*, 1987; *Saito et al.*, 1995]
- Lower hybrid drift instability (LHDI) [*Huba et al.*, 1978; *Shinohara et al.*, 1998]
- Buneman or Bump-on-tail instabilities [*Hoshino et al.*, 2001; *Drake et al.*, 2003]

However, the nature of the instabilities is not yet specified because of low space-time resolution of satellite observations and limited computer resources.

Electromagnetic Particle Simulation with AMR Technique

AMR technique



Particle splitting algorithm

$\Delta r = \Delta_L / N^{1/2}$

N: Number of particles in the cell.

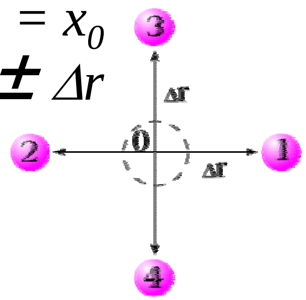
$x_{1,2} = x_0 \pm \Delta r$; $x_{3,4} = x_0$

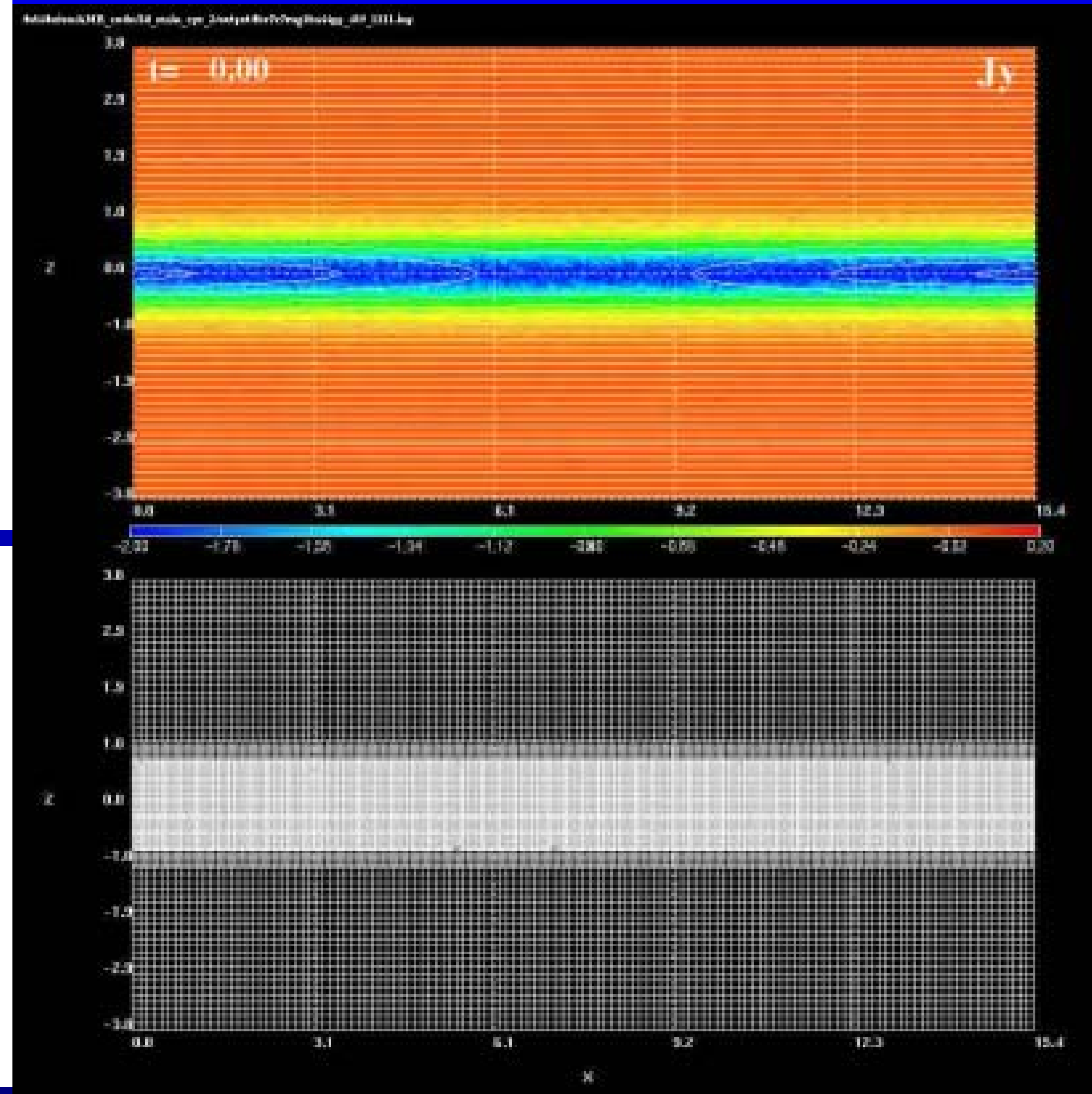
$y_{1,2} = y_0$; $y_{3,4} = y_0 \pm \Delta r$

$\mathbf{V}_{1,2,3,4} = \mathbf{V}_0$;

$q_{1,2,3,4} = q_0/4$;

$m_{1,2,3,4} = m_0/4$





Large-Scale Simulations of Magnetic Reconnection

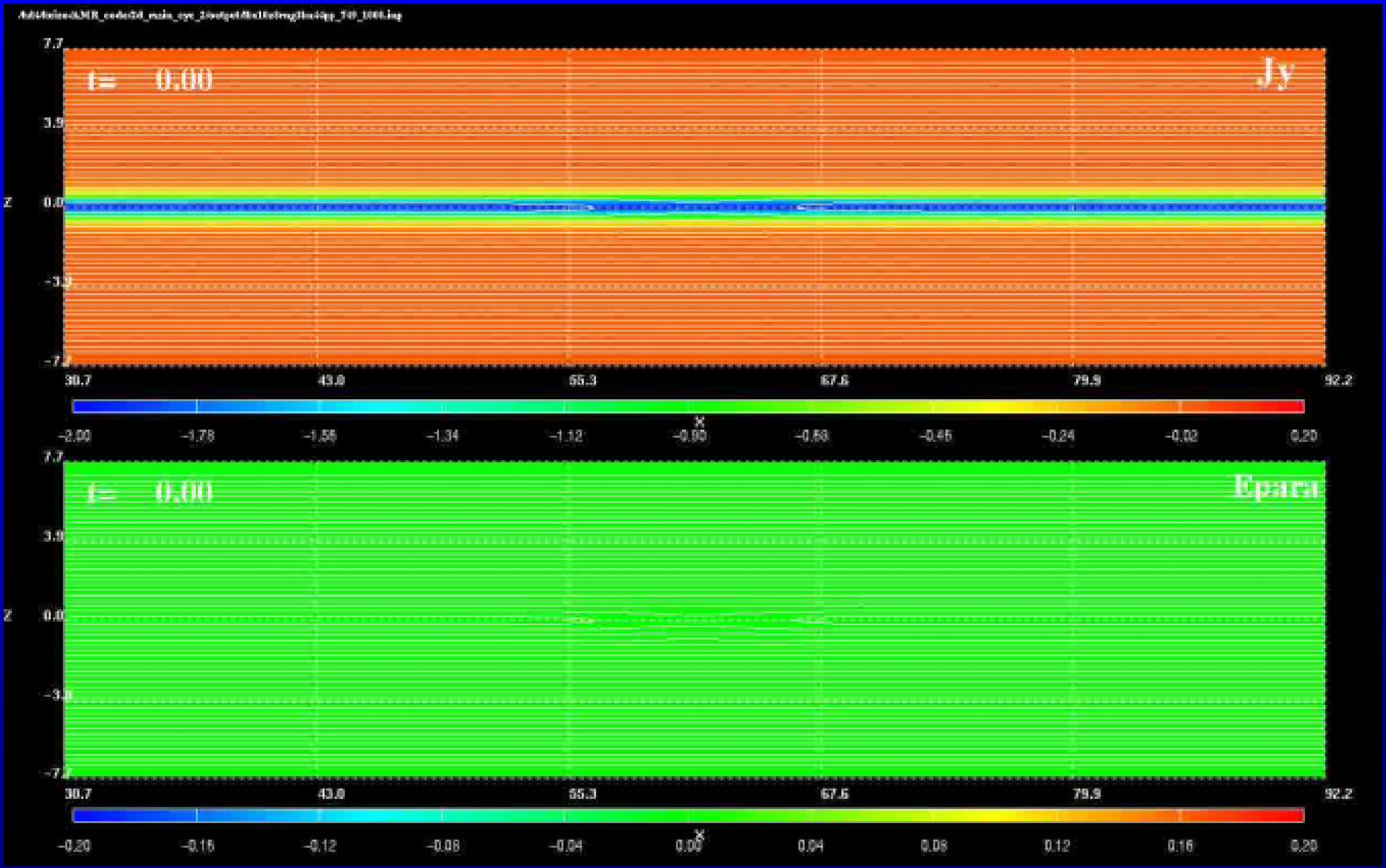
System size : $L_x \times L_z = 122.9\lambda_i \times 30.7\lambda_i$ (Maximum resolution : 8192×2048)
Boundary conditions : Periodic boundaries in x, conducting walls in z.
$\Delta_{LB} = 0.12\lambda_i$, $\Delta t = 0.0008\ \omega_{ci}^{-1}$
Number of layers: 4
Refinement criteria : Electron Debye length ($\Delta > 2\lambda_{De}$),
Electron bulk velocity ($V_{ey} > 2.0\ V_A$),
Electron current density ($(j_{ex}^2+j_{ez}^2)^{1/2} > 0.5\ e n_{ps} V_A$)

[*Initial conditions*]

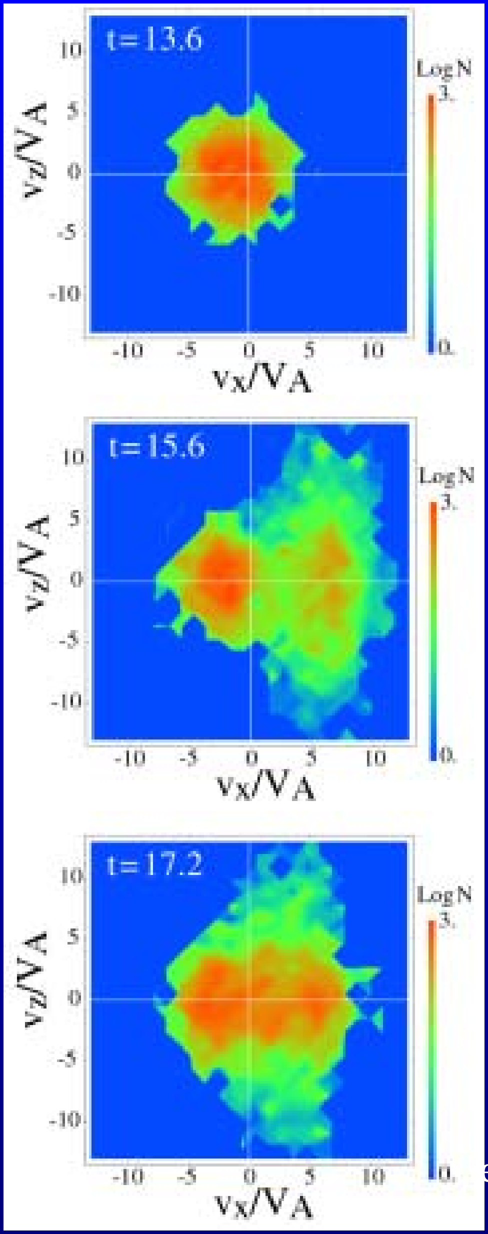
Harris-type current sheet [*Harris*, 1962]
$m_i/m_e = 100$, $T_{i,ps}/T_{e,ps} = 8$, $c/V_A = 16.7$
$\lambda = 0.5\ \lambda_i$, $n_b = 0.04\ n_{ps}$,
Number of cells $\sim 6.4\times 10^5$, Number of particles $\sim 2.1\times 10^7$

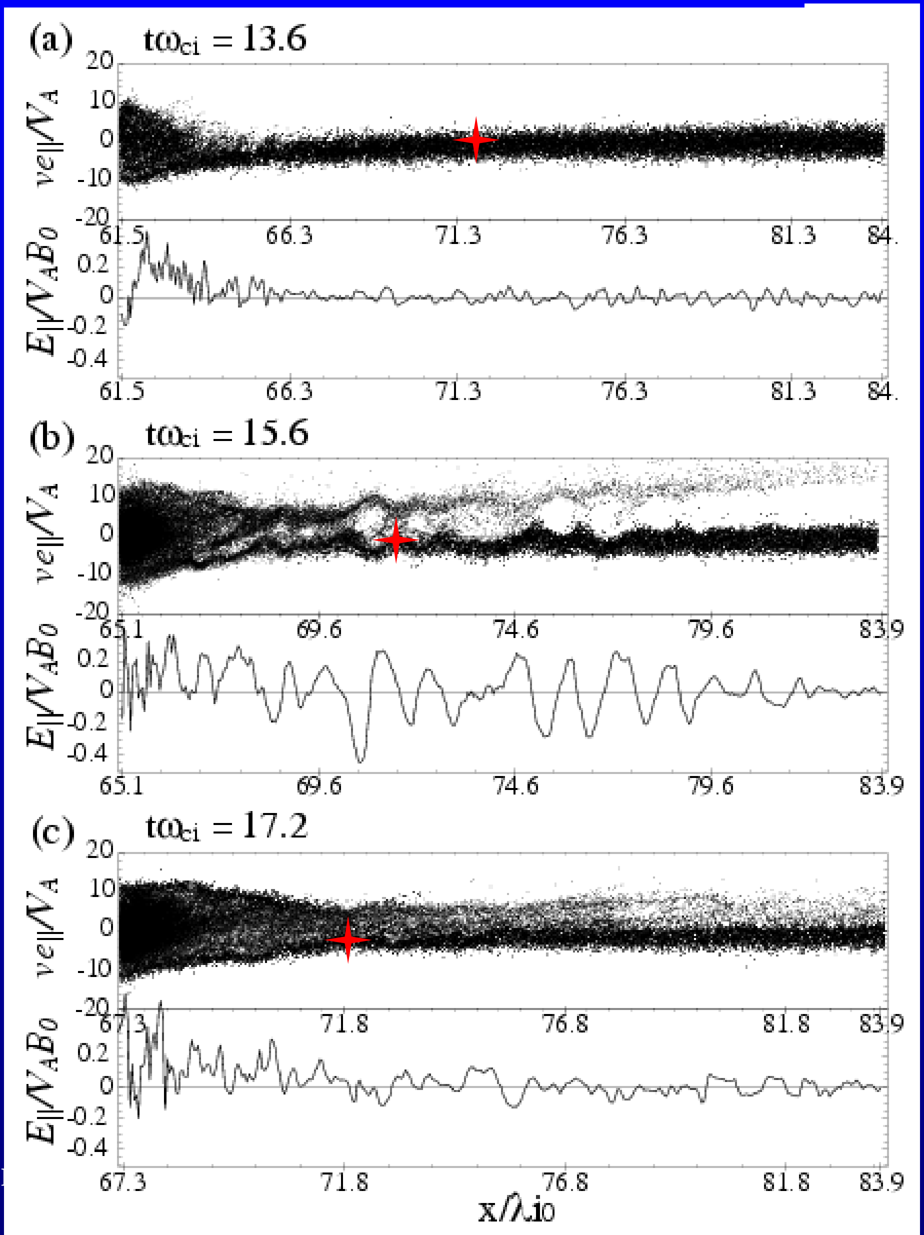
$$B_x(x,z) = -B_0 \tanh(z/\lambda) + 2a_0/\lambda\, \mathrm{sech}^2((x-L_x/2)/L)\, \mathrm{sech}^2(z/\lambda)\tanh(z/\lambda)$$
$$B_z(x,z) = -2a_0/L\, \mathrm{sech}^2((x-L_x/2)/L)\, \mathrm{sech}^2(z/\lambda)\tanh((x-L_x/2)/L)$$
$$a_0 = 0.15 B_0 \lambda_i,\ L = 3.8\lambda_i$$

Wave Activity in Lobe-Sheet Boundary Region



Electron Heating

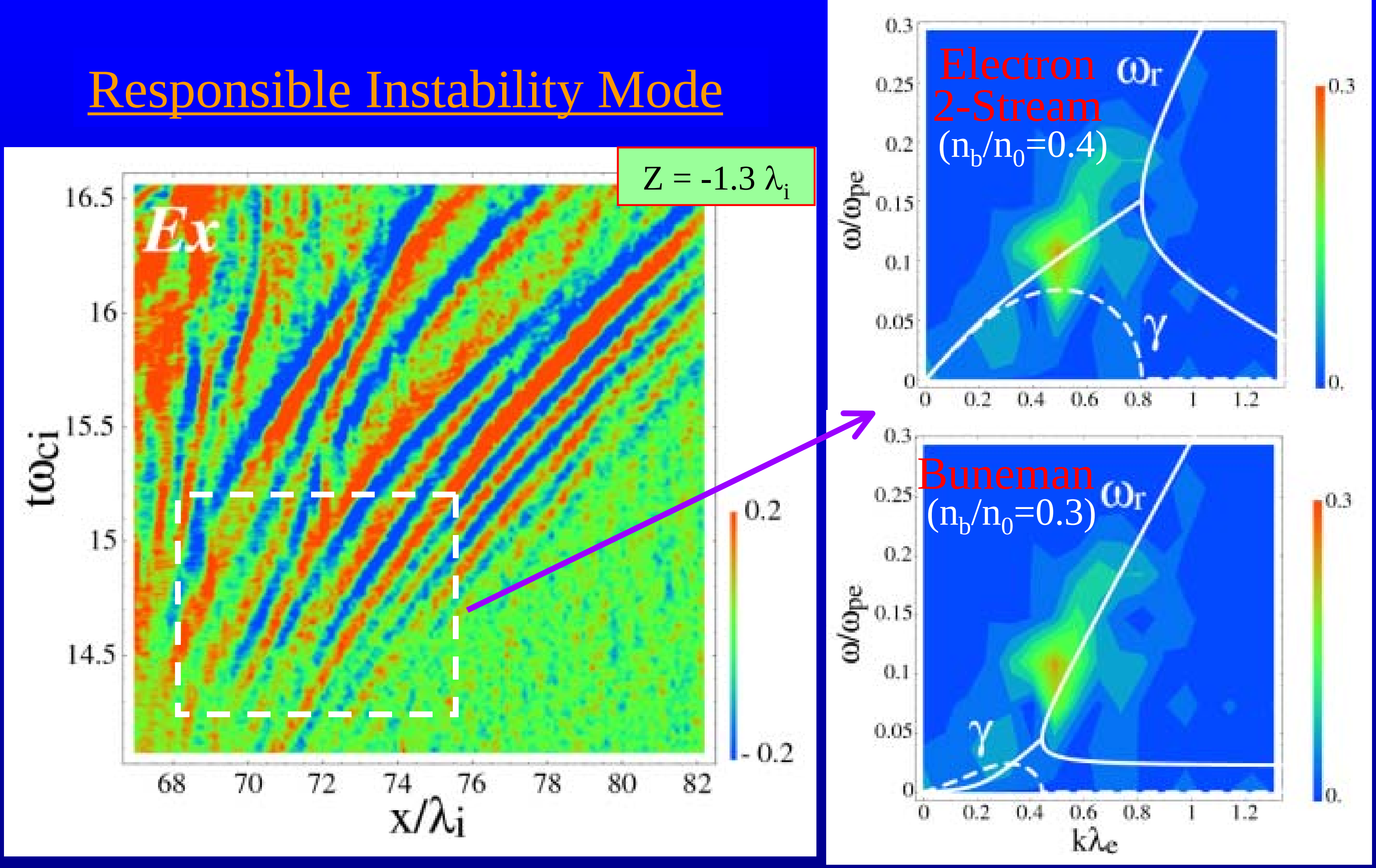




Electrons are scattered by the waves along field line.

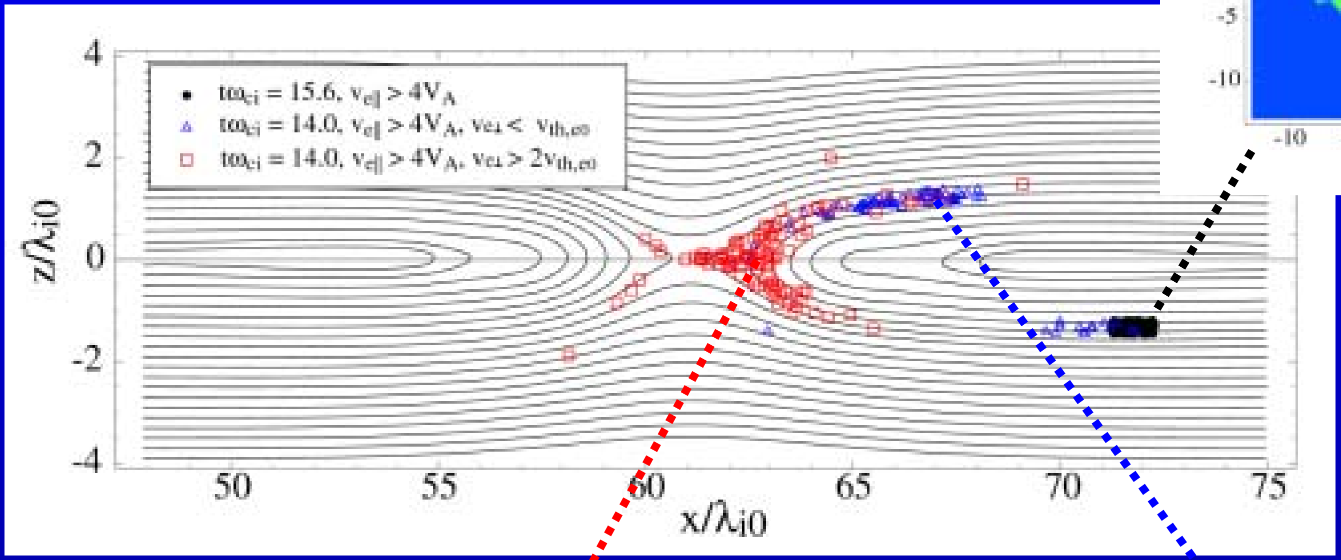
$$\mathcal{E}_{sh} \sim \frac{2eE_0}{k} \sim 1\,\mathrm{keV}$$

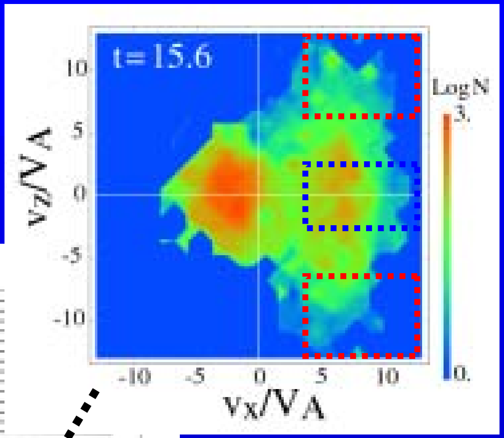
Responsible Instability Mode

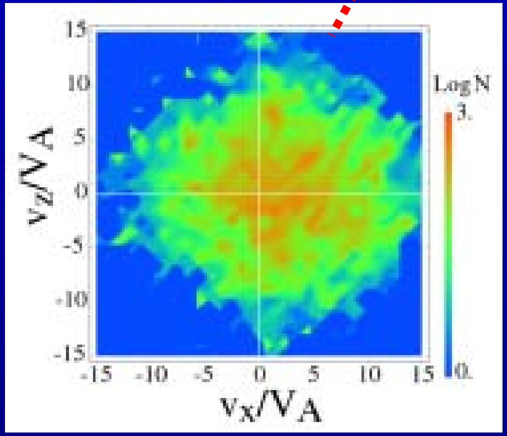


Electron two-stream instability is responsible for the wave activity.

Origin of the Electron Beam

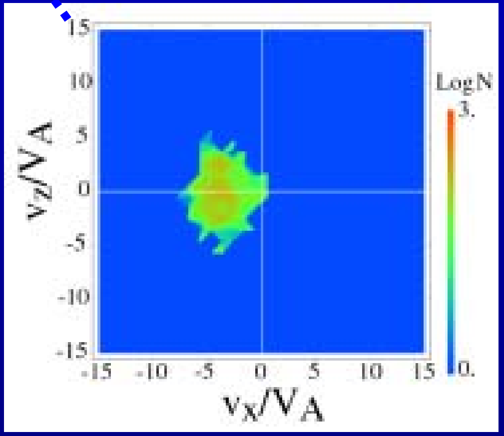






Hot electrons heated quite near the X-line.

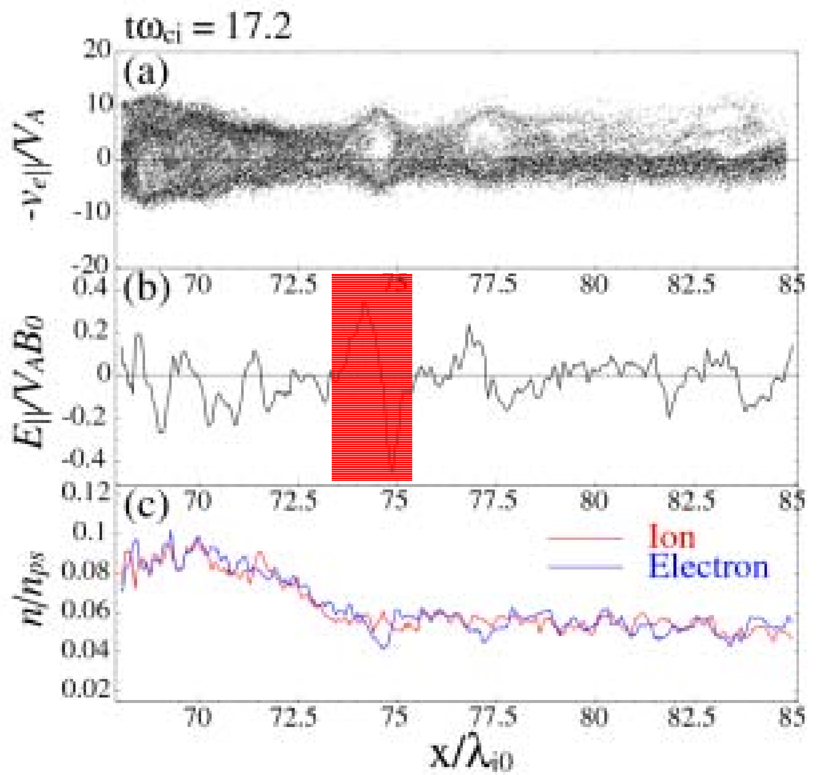
Cold electrons in the opposite side of the plasma sheet.

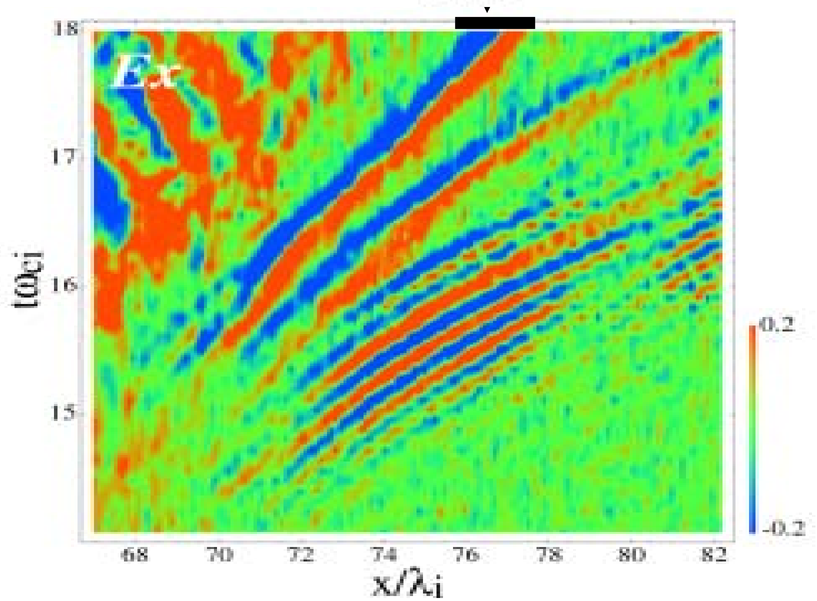


Generation of ESW

- Electrostatic Solitary Waves (ESW) have been often observed in the PSBL of the Earth magnetotail. [e.g., *Matsumoto et al.*, 1994; *Kojima et al.*, 1994]
- It is suggested that the ESW result from nonlinear evolutions of the electron 2-stream instability. [*Matsumoto et al.*, 1994; *Omura et al.*, 1996]。
- However, it is not clear how the intense electron beams are produced.

Our simulation results indicate that magnetic reconnection can be a significant candidate to produce the electron beams which are responsible for the generation of ESW.





Summary and Conclusions

We studied electron heating mechanism in the plasma sheet-lobe boundary region associated with magnetic reconnection. We used a newly developed electromagnetic full particle code with AMR technique.

We found that the electron 2-stream instability is excited between the background (lobe) cold electrons and the intense beam electrons with high perpendicular temperature. Electrons are scattered and heated along the field line and the flat-topped electron distribution is formed.

We have also revealed that the ESW are evolved from the electron 2-stream instability associated with magnetic reconnection.

Thus, the electron 2-stream instability is responsible not only for the formation of the flat-topped electron distribution, but also for the generation of the ESW associated with magnetic reconnection.

Further Study

- Heating due to Slow-mode Shock

We could not find any clear structure of the slow-mode shocks in the present simulations. Much larger-scale simulations lasting for longer time would be necessary for generation of the slow-mode shocks. [e.g., *Arzner and Scholer*, 2001]。

- Heating due to the LHDI

Growth rate of LHDI：$\gamma_{LH} \sim 0.1\ \omega_{LH} = (\omega_{ci}\ \omega_{ce})^{1/2}$

Growth rate of electron 2-stream inst.：$\gamma_{TS} \sim 0.1\ \omega_{pe}$

This leads to $\gamma_{LH} \sim (m_e/m_i)^{1/2}\ \gamma_{TS}$, so that the electron 2-stream instability can be excited much easily and affect more the electron heating. It is necessary to perform 3-D simulations to see this.