Anomalous Transport Induced by Plasmoid Formations in Collisionless Magnetic Reconnection

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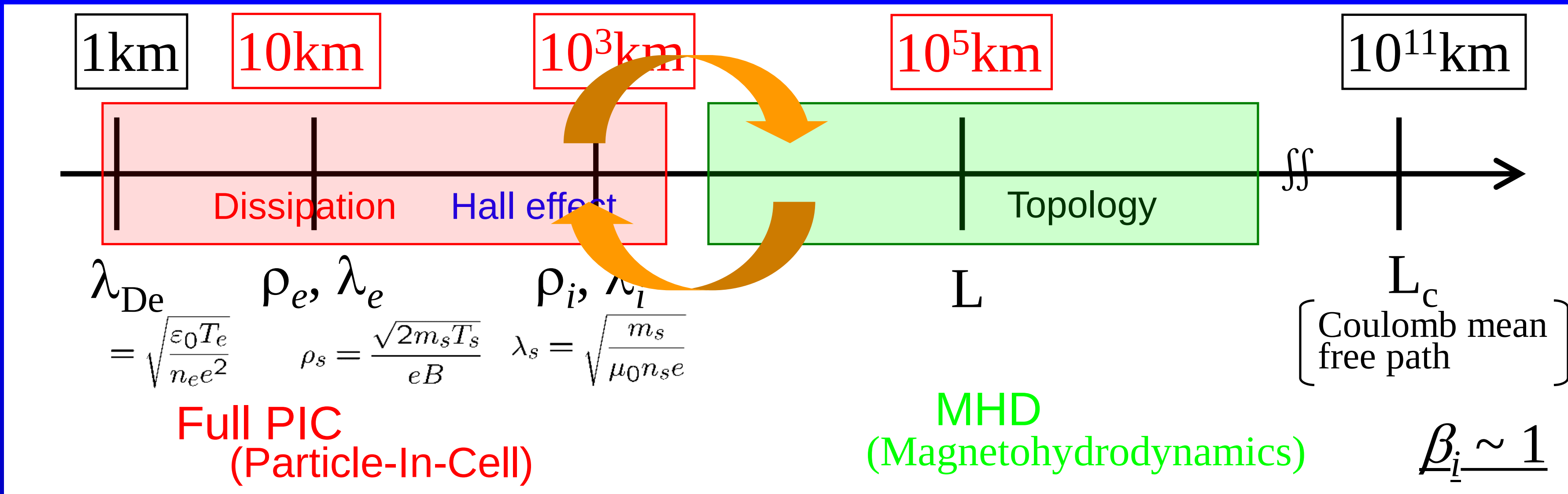
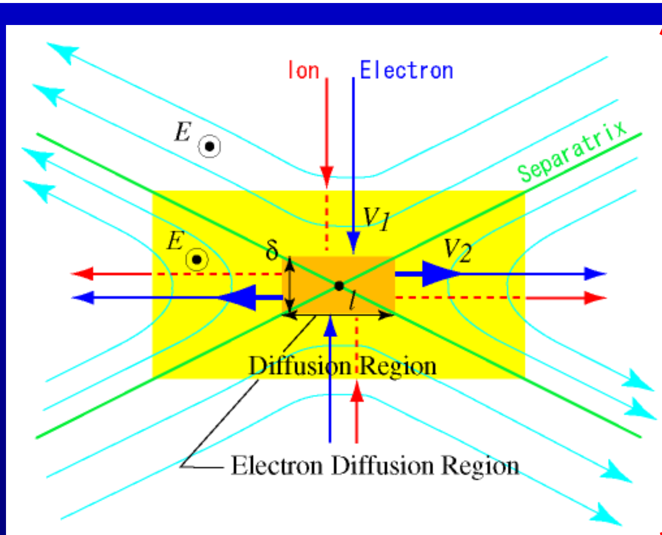
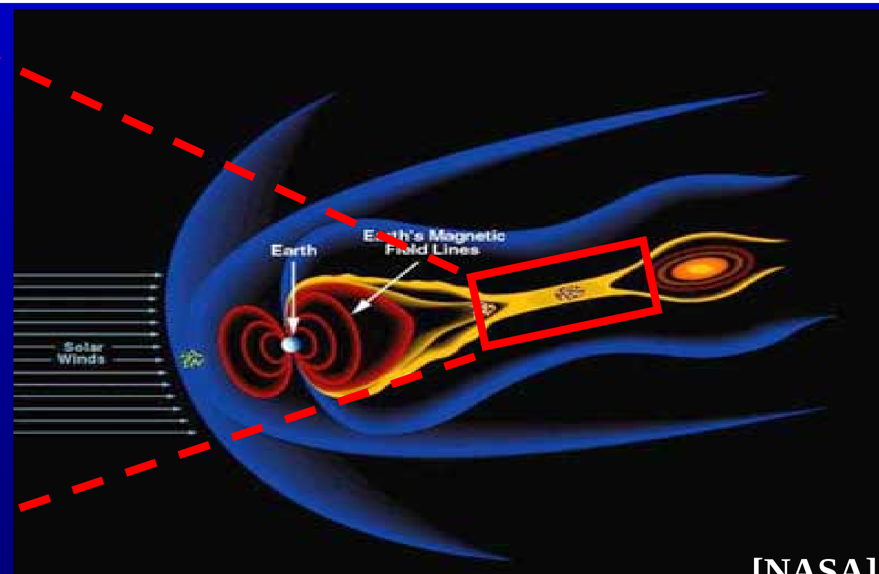
Overview

- Introduction
- 3D PIC simulation
  - Wave activities around the X-line
  - Impact of plasmoid formations
- Linear wave analysis
- Summary

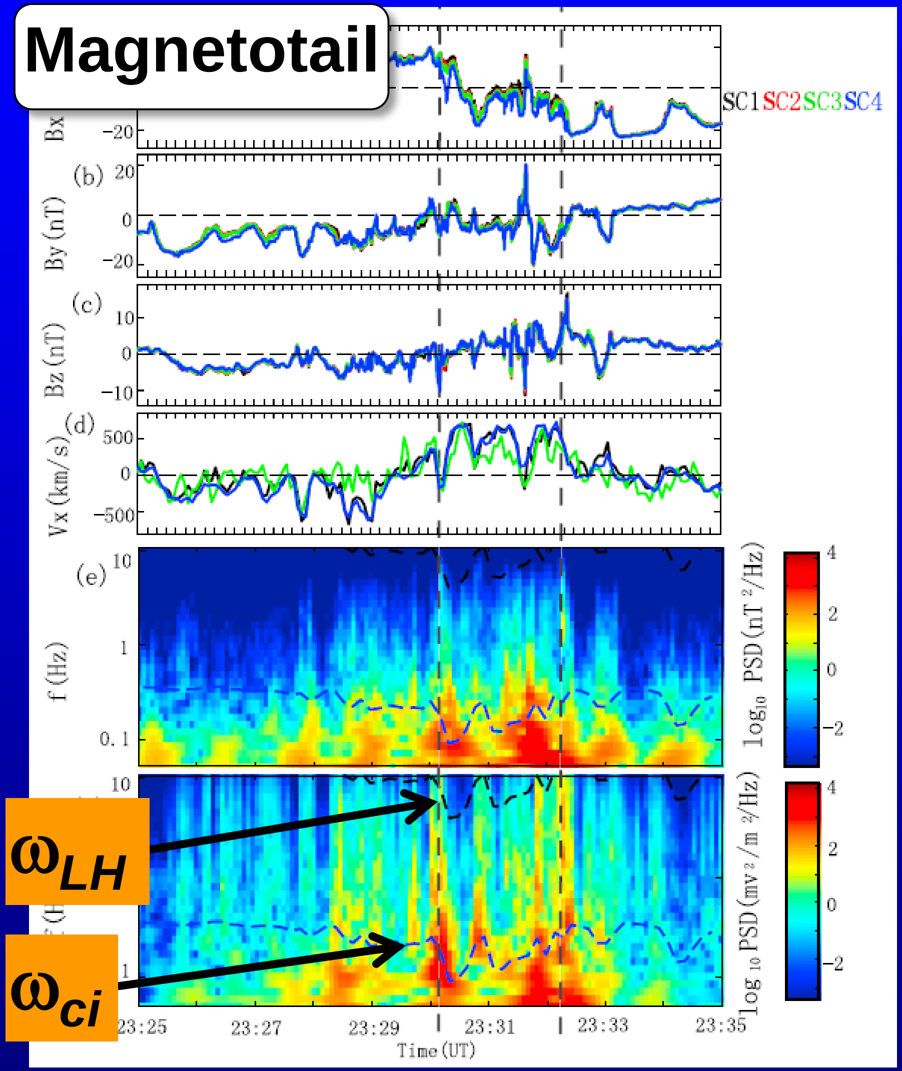
Multi-Scale Nature of Reconnection



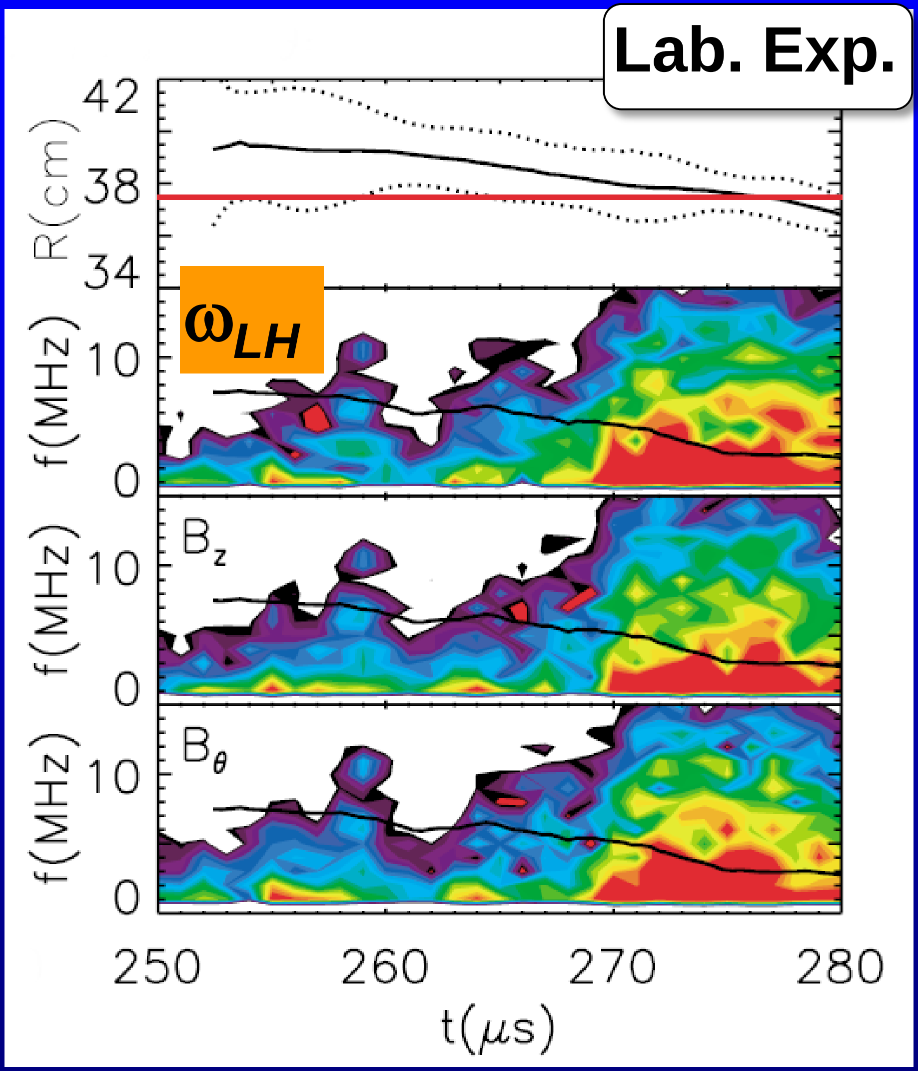




Observations of Wave Activities



[Zhou et al, JGR, 2009]

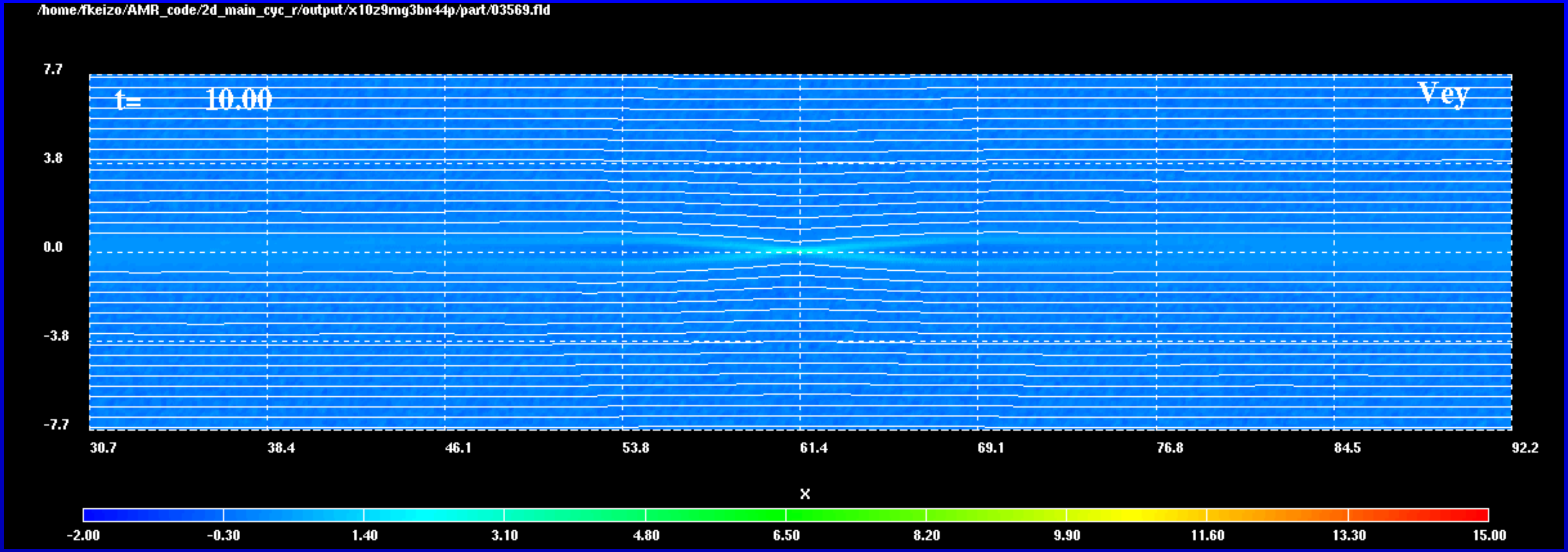


[Ji et al, PRL, 2004]

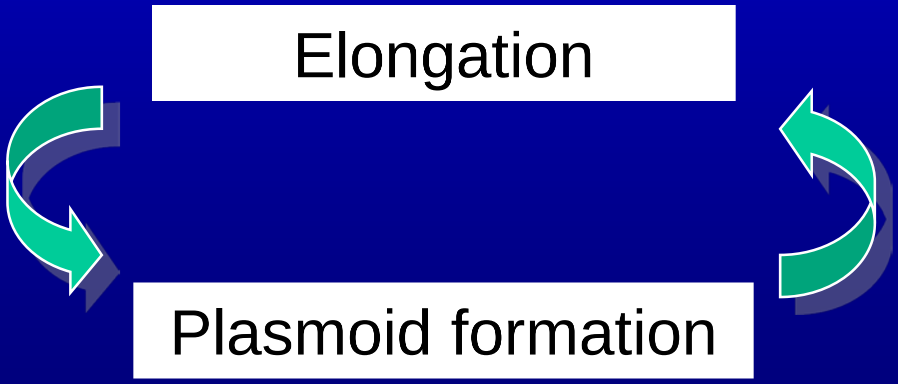
Dynamical Current Sheet

[Fujimoto, PoP, 2006; Daughton et al., PoP, 2006]

2D PIC simulation



Thin current layer:

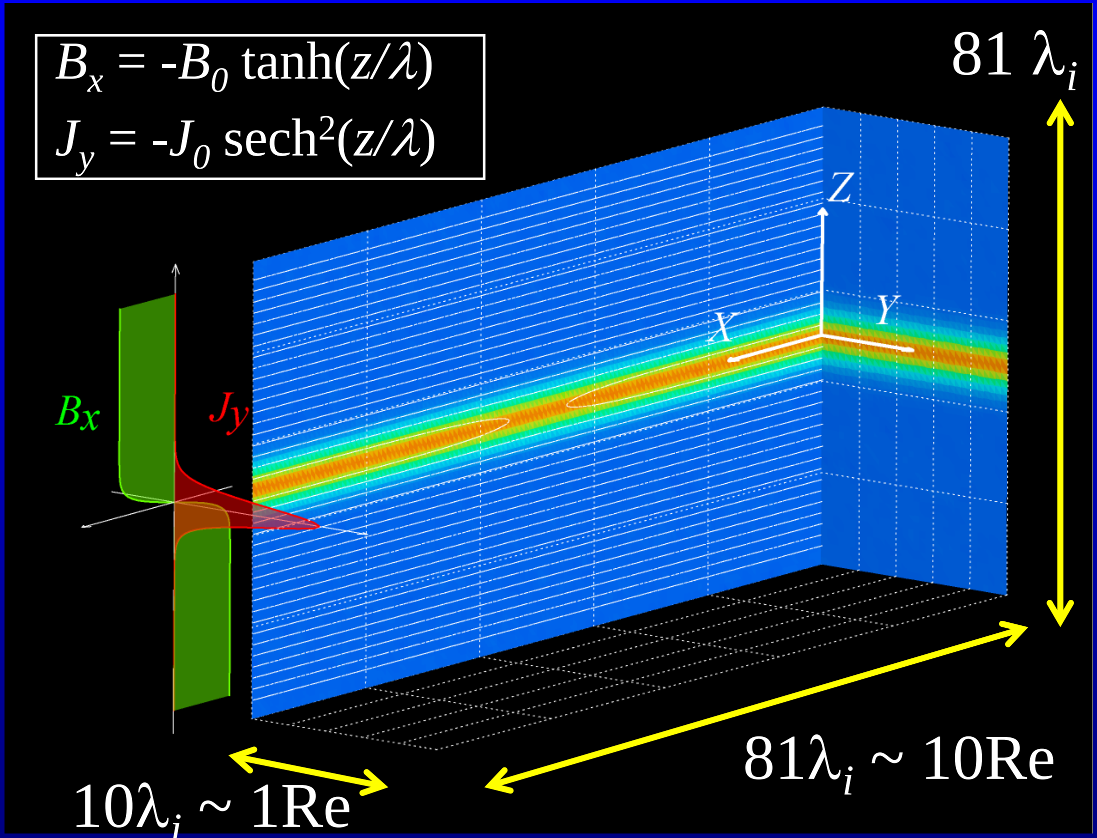


Purpose of This Study

- Generation mechanism of the waves at the X-line.
- Impact of the plasmoids in 3D system.

Simulation Setup

AMR-PIC-3D code [Fujimoto, JCP, 2011]
on Fujitsu FX1 (1024 cores)



$m_i/m_e = 100$

Max resolution:
$4096 \times 512 \times 4096 \sim 10^{10}$

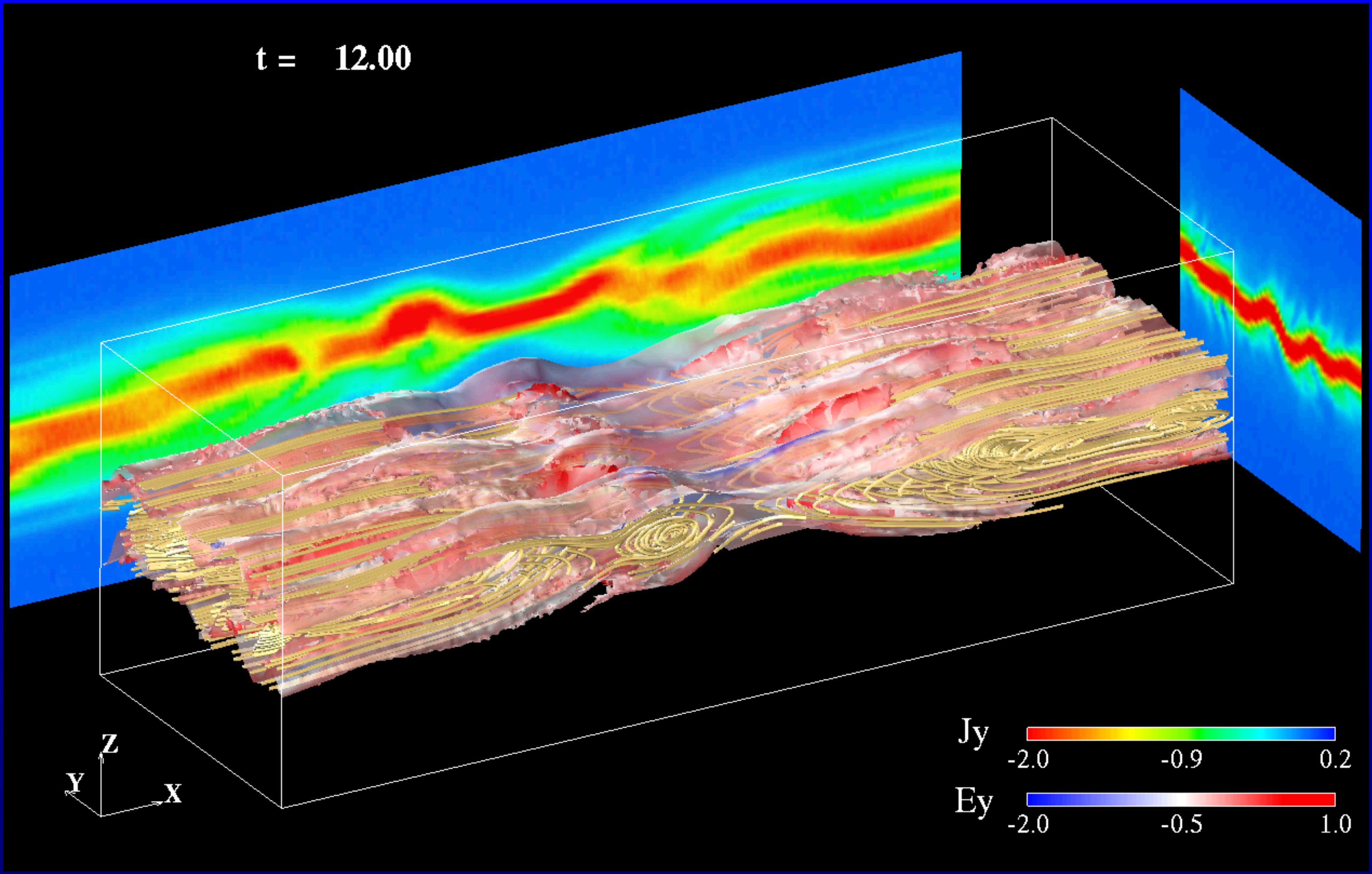
Max number of particles
Ion + Electron ~ 10^{11}

Max memory used ~ 6TB

Time Evolution of the Current Sheet

Surface: |J|, Line: Field line

Color on the surface: Ey, Cut plane：Jy



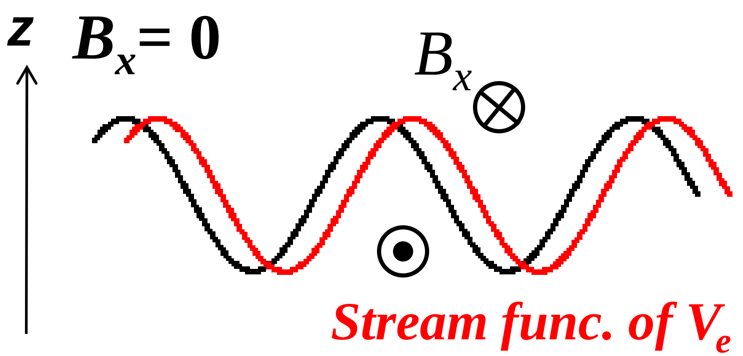
Dissipation Mechanism [Fujimoto & Sydora, PRL, 2012]

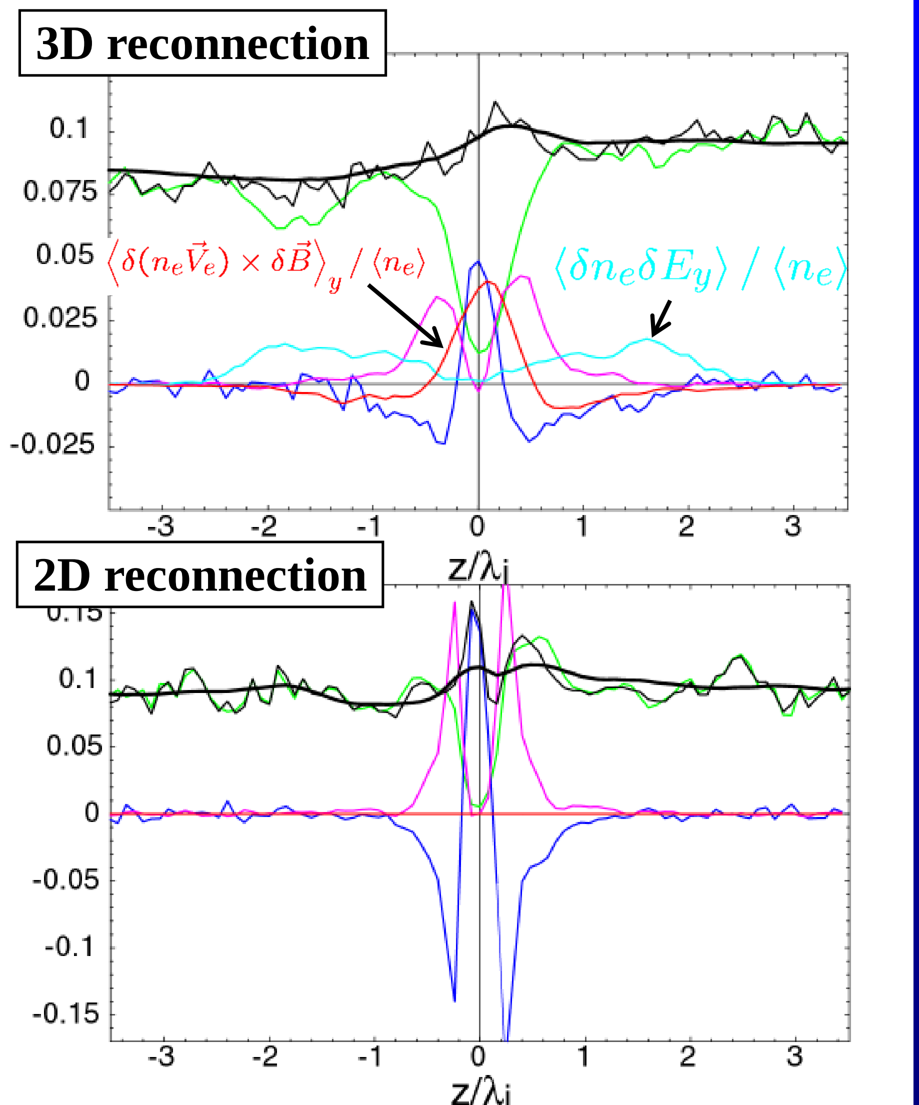
$$A = \langle A \rangle + \delta A \qquad \left(\langle \cdot \rangle = \frac{1}{L_y} \int_0^{L_y} \cdot \, dy \right)$$

$$\begin{aligned}
\langle -E_y \rangle = & \frac{1}{\langle n_e \rangle} \left(\langle n_e \vec{V}_e \rangle \times \langle \vec{B} \rangle \right)_y \\
& + \frac{1}{e \langle n_e \rangle} \langle \nabla \cdot \vec{P}_e \rangle_y \\
& + \frac{m_e}{e \langle n_e \rangle} \left\langle \frac{\partial V_{ey}}{\partial t} + \vec{V}_e \cdot \nabla V_{ey} \right\rangle \\
& + \frac{1}{\langle n_e \rangle} \langle \delta n_e \delta E_y \rangle \\
& + \frac{1}{\langle n_e \rangle} \left\langle \delta (n_e \vec{V}_e) \times \delta \vec{B} \right\rangle_y
\end{aligned}$$

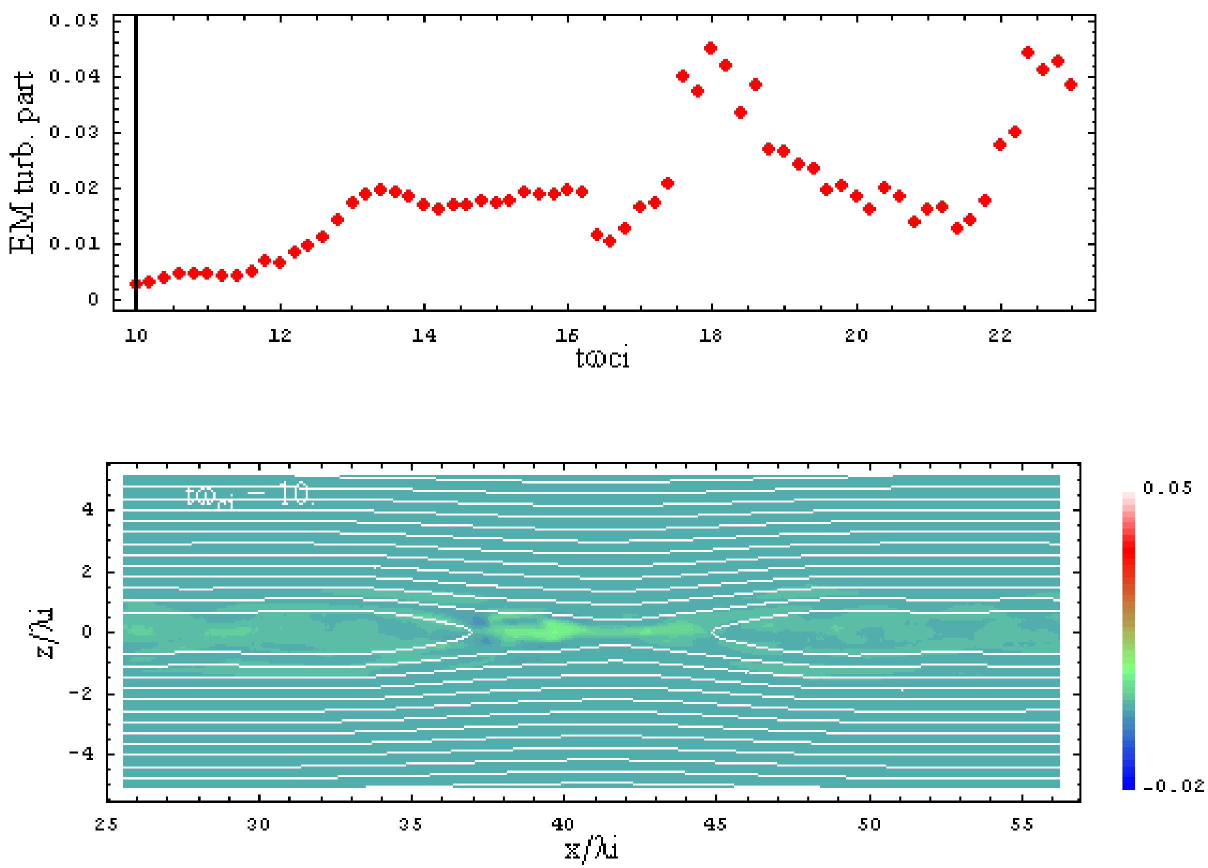
Anomalous effects

$$\left\langle \delta (n_e \vec{V}_e) \times \delta \vec{B} \right\rangle$$

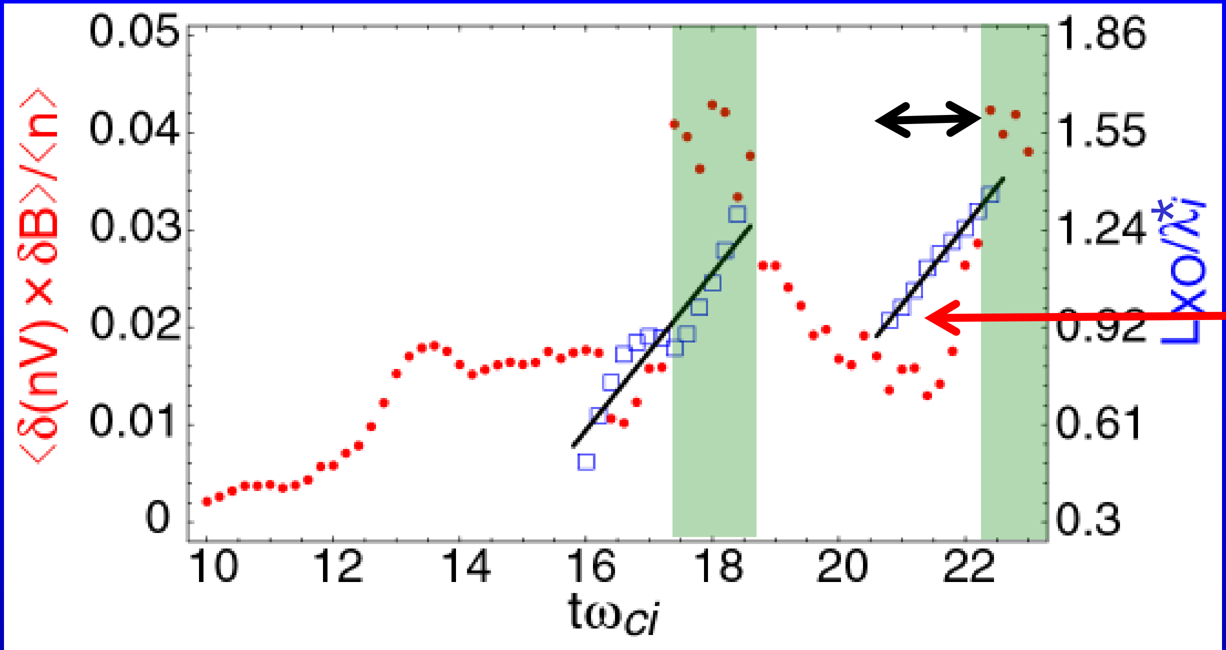




Anomalous Transport at the X-line

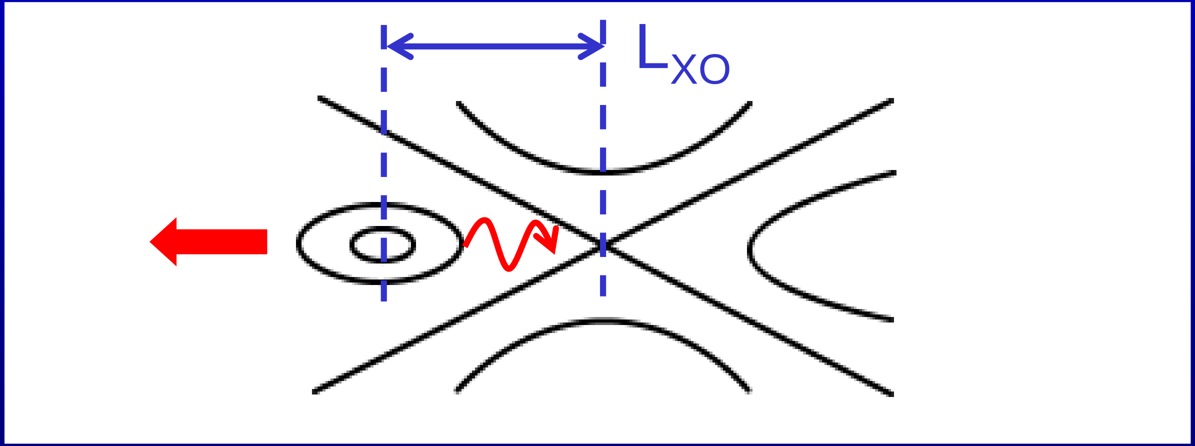


Plasmoid-Induced Turbulence



$\Delta t = 1.6\ \omega_{ci}^{-1}$

$L_{XO} = 0.95\ \lambda_i^*$



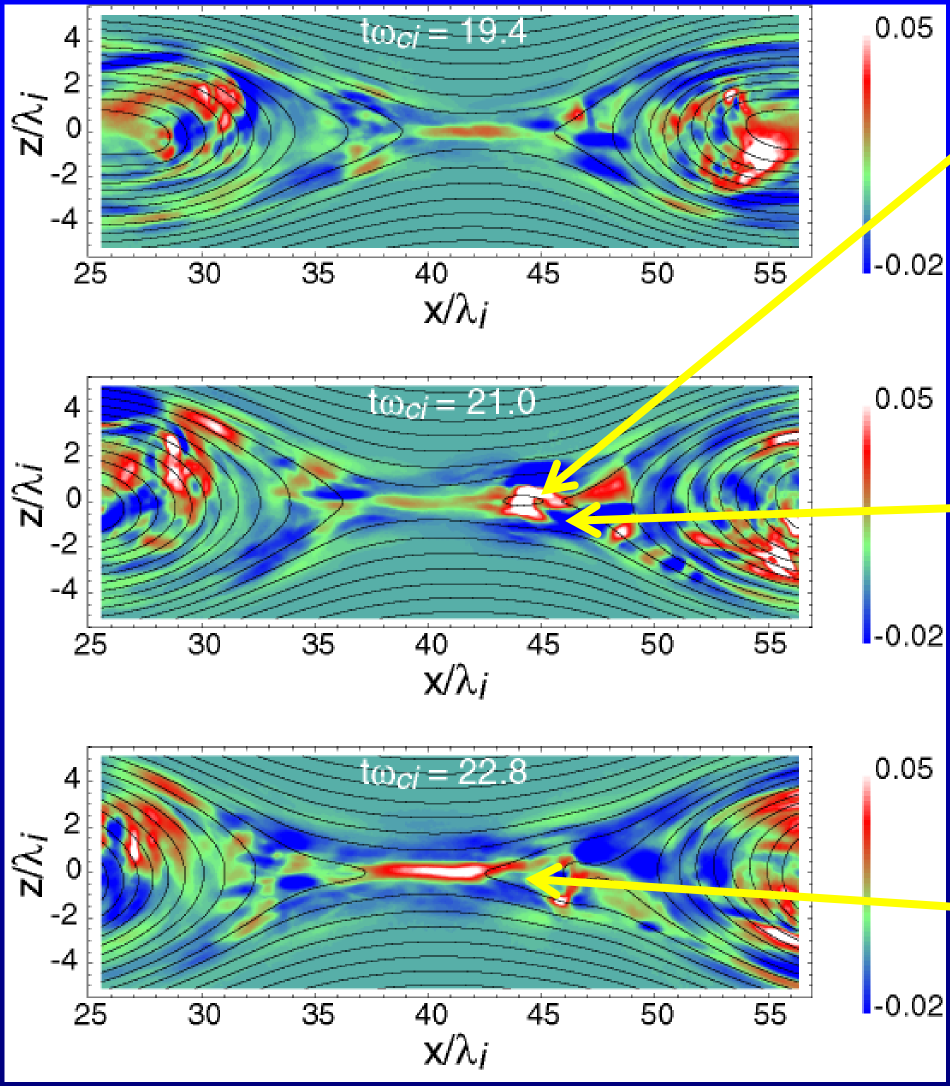
Information propagates at

$V_p \sim V_A^*$

$(B^* = 0.5B_0)$

[Fujimoto & Sydora, PRL, 2012]

Plasmoid-Induced Turbulence



Plasmoid formation

Wave amplification

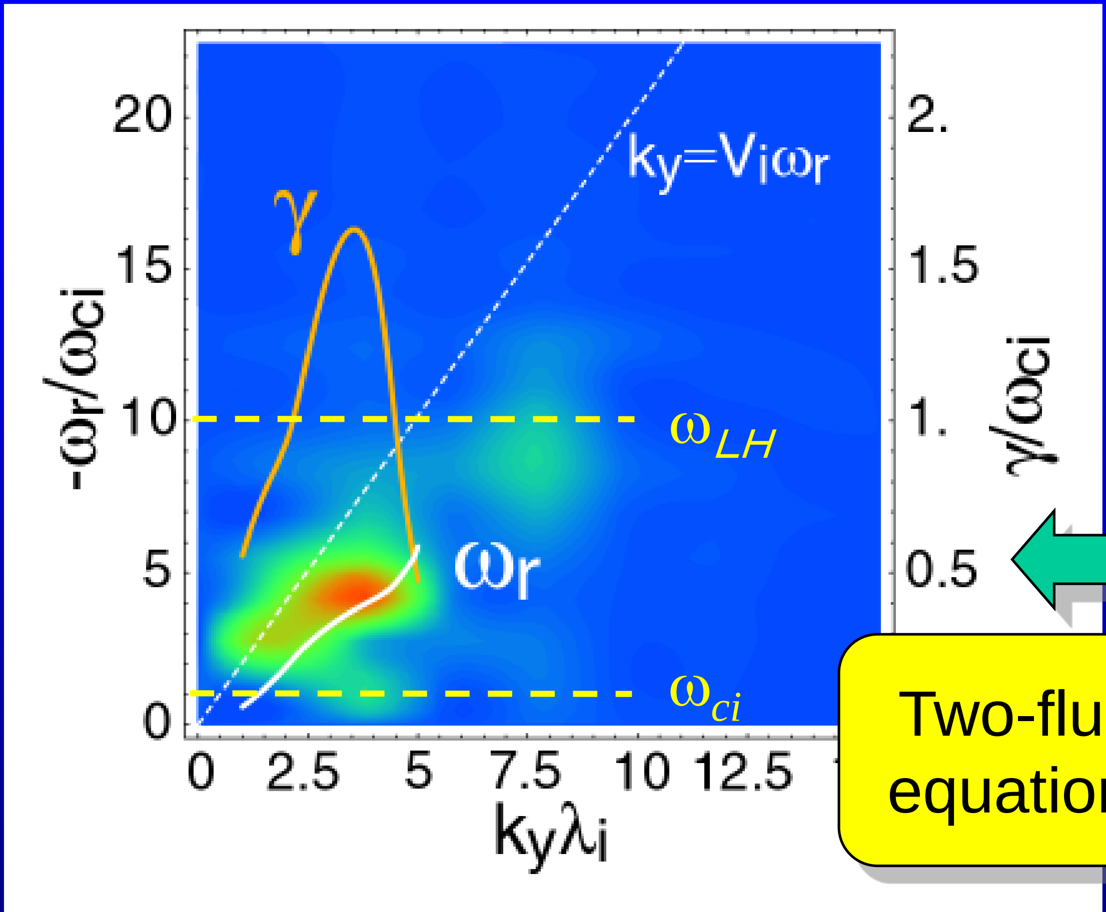
Local turbulence enhancement

Propagation along the field line

Intensified turbulence at the x-line

Wave Properties

$\omega = \omega_r + i\gamma$



[Fujimoto & Sydora, PRL, 2012]

Simulation results

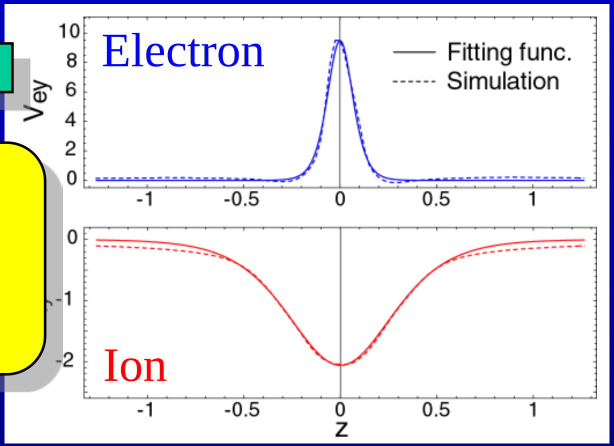
$$\omega_{ci} < |\omega_r| < \omega_{LH}$$

$$V_{ph} \approx V_A$$

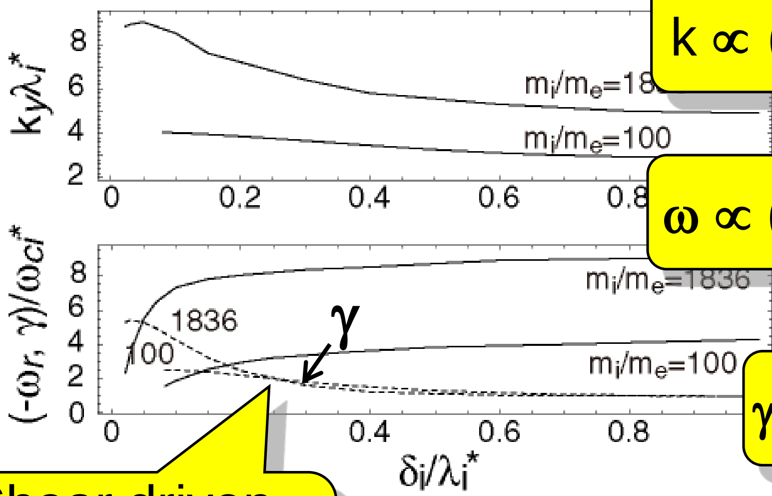
Linear analyses

Profiles taken from simulation

Two-fluid equations



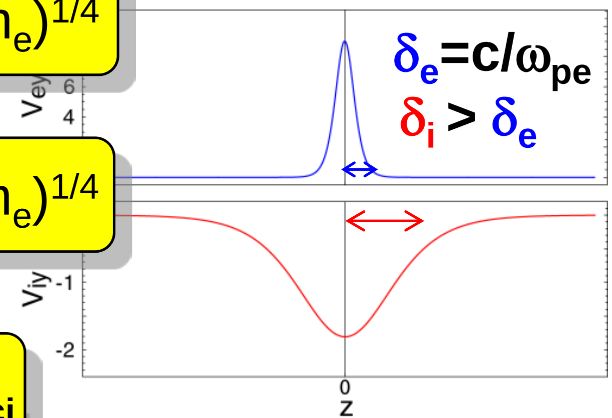
Wave Properties: Linear Analyses



$k \propto (m_i/m_e)^{1/4}$

$\omega \propto (m_i/m_e)^{1/4}$

$\gamma \sim \omega_{ci}$

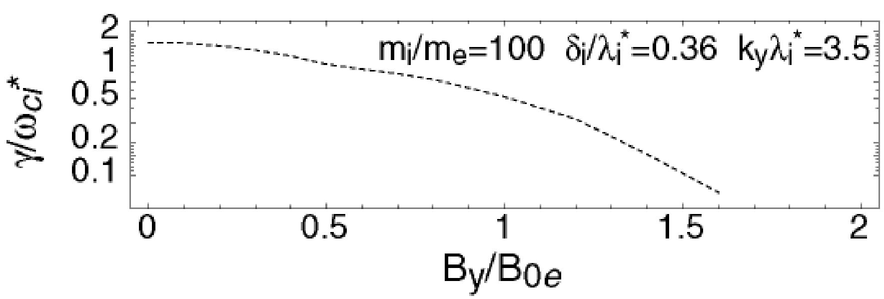


Peak velocities are fixed.

Shear driven mode rather than the drift mode

$\gamma \propto \partial V_d / \partial z$

The wave survives even for m_i/m_e=1836.



Dependence on the guide field (*By*)

Summary

Large-scale 3D PIC simulation has been performed to investigate the dissipation mechanism of collisionless magnetic reconnection under anti-parallel and symmetric configuration.

Plasmoid formations are important to enhance the EM turbulence relevant to the magnetic dissipation.

The linear analyses revealed the properties of the EM mode:

- $\omega_{ci} < \omega_r < \omega_{LH,}$
- Shear-driven instability,
- Large growth rate even for m_i/m_e=1836.