

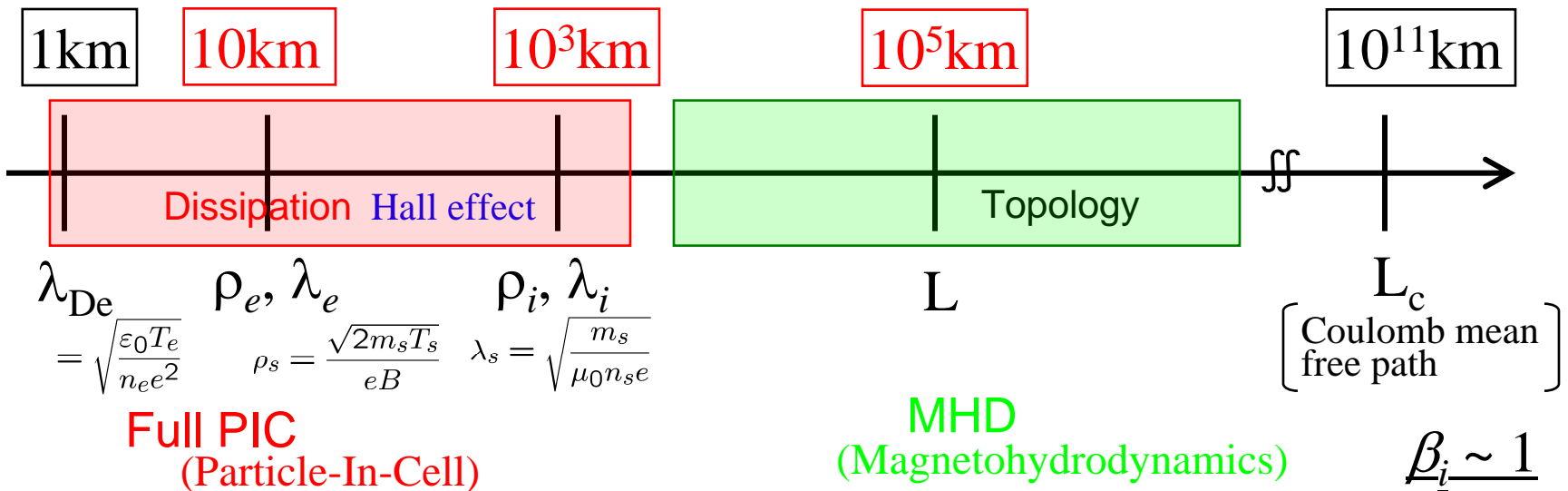
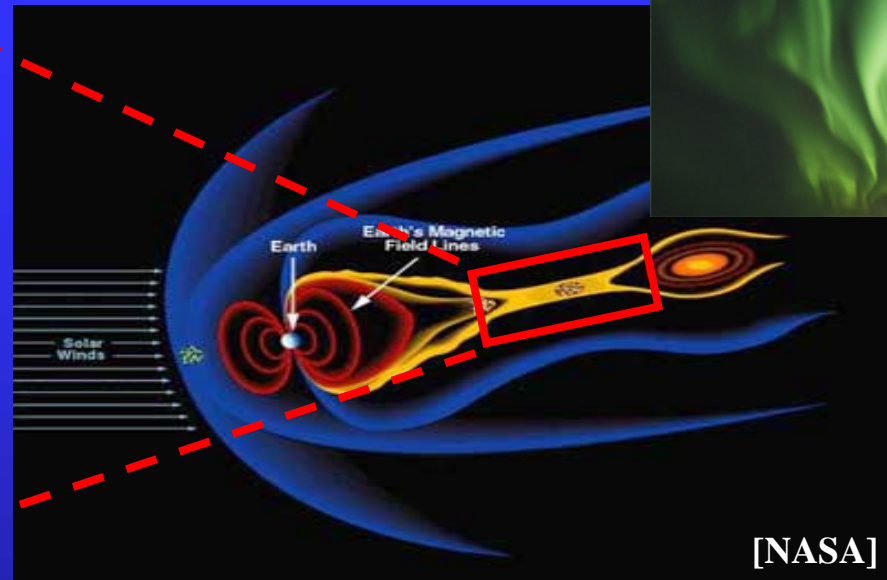
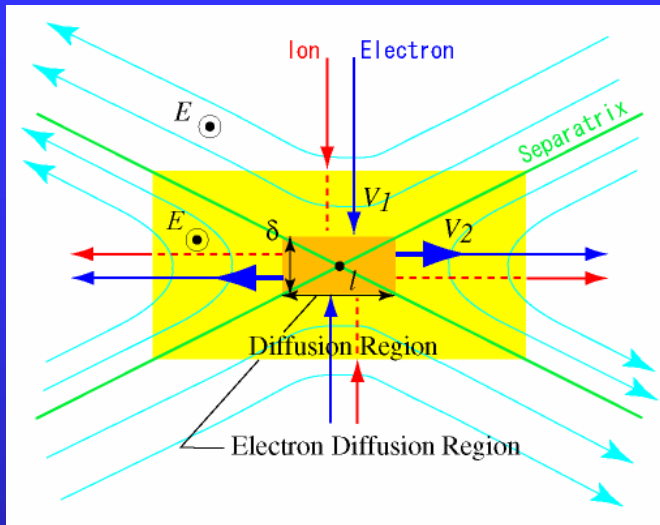
高速磁気リコネクションにともなう電流層 シア不安定性

藤本桂三¹、Richard Sydora²

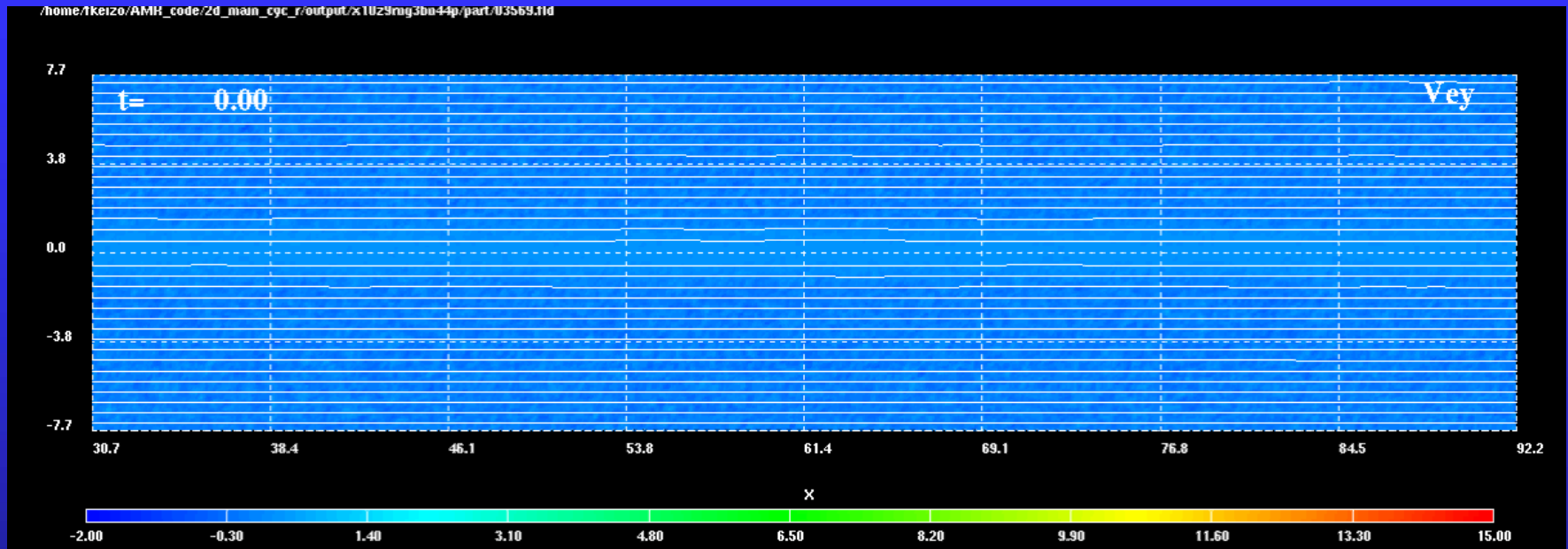
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磁気リコネクションと磁気圏ダイナミクス



変動する磁気拡散領域



シミュレーション: Fujimoto (2006), Daughton et al. (2006), Klimas et al. (2008), Oka et al. (2010)

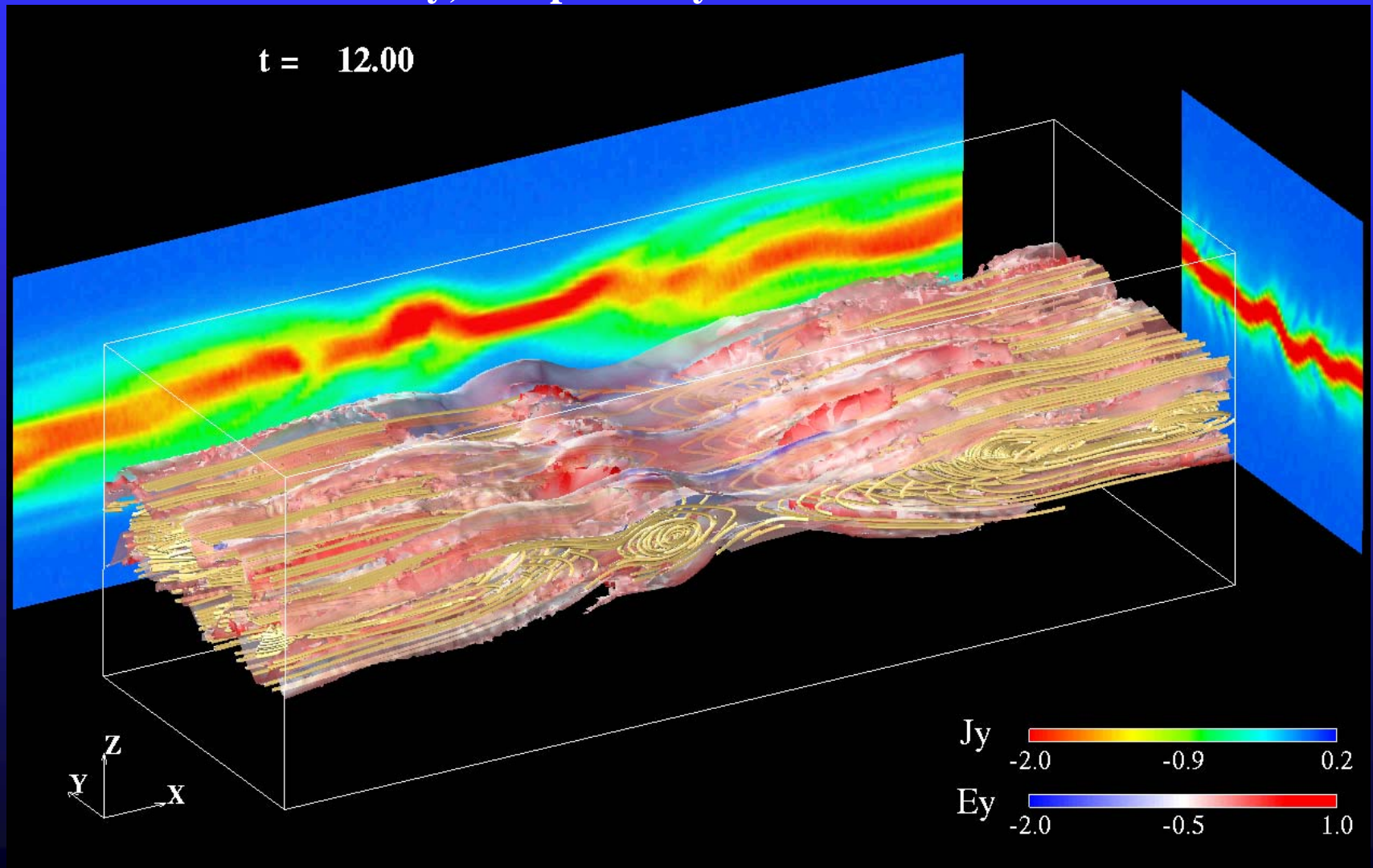
観測: Eastwood et al. (2007), Wang et al. (2010), Chen et al. (2012)

Large-Scale 3D PIC Simulation

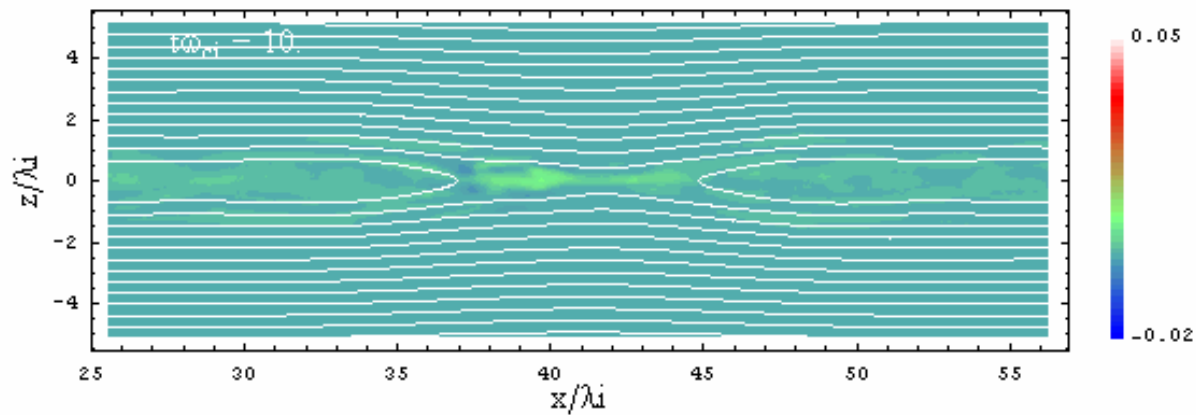
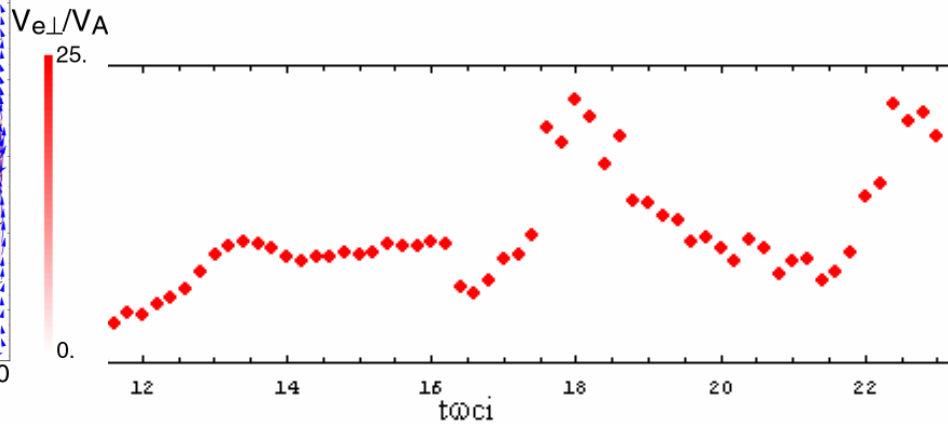
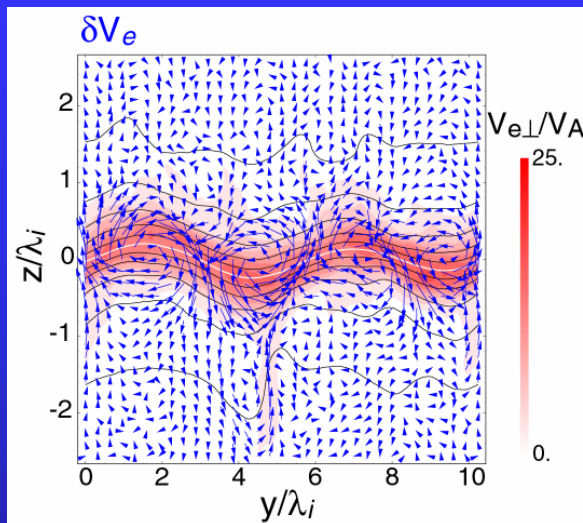
Surface: $|J|$, Line: Field line

[Fujimoto & Sydora, PRL, submitted]

Color on the surface: E_y , Cut plane: J_y



プラズモイドにともなう電磁擾乱の増幅



電流層に励起する電磁波動

- Drift mode {
- Drift kink ($k\delta \sim 1, \omega \sim \omega_{ci}$) [Pritchett & Coroniti, 1996]
 - Current sheet kink instability ($k(\lambda_i \lambda_e)^{1/2} \sim 1$) [Suzuki et al., 2002]
 - Electromagnetic LHDI ($k(\rho_i \rho_e)^{1/2} \sim 1$) [Daughton, 2003]

Based on the Harris current sheet:

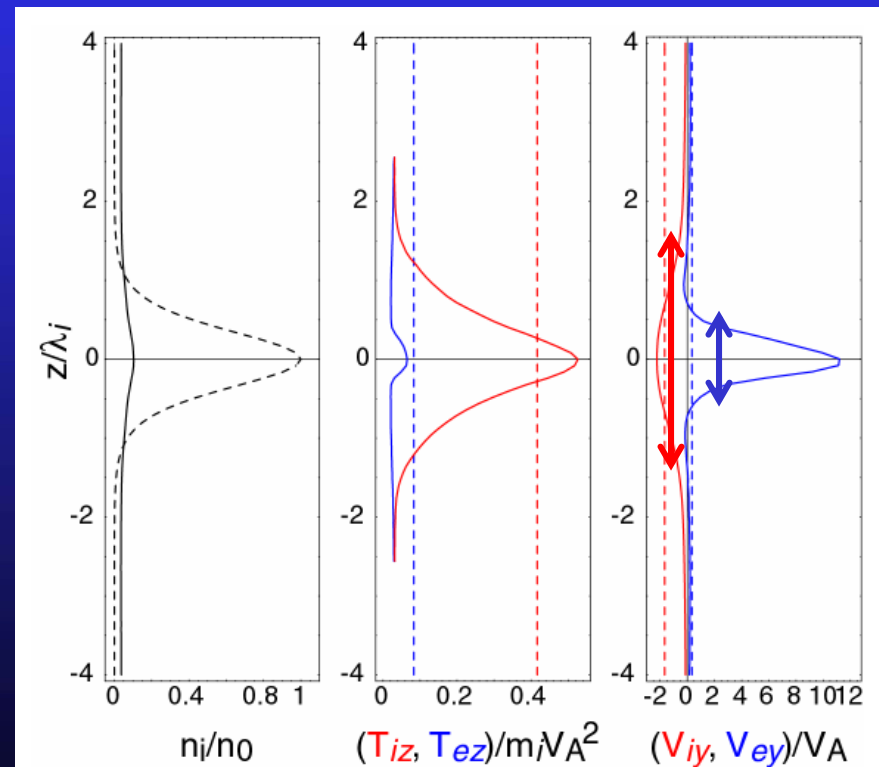
$$B_x(z) = -B_0 \tanh(z/\delta)$$

$$n_s(z) = n_0 / \cosh^2(z/\delta)$$

which satisfy

$$q_s n_s \vec{V}_s \times \vec{B} - \nabla(n_s T_s) = 0$$

$$\nabla \times \vec{B} = \mu_0 e (n_i \vec{V}_i - n_e \vec{V}_e)$$



平衡解

$$n_s(z) = n_0$$

$$B_x(z) = -B_{0i} \tanh(z/\delta_i) - B_{0e} \tanh(z/\delta_e)$$

$$V_s(z) = -V_{s0} / \cosh^2(z/\delta_s)$$

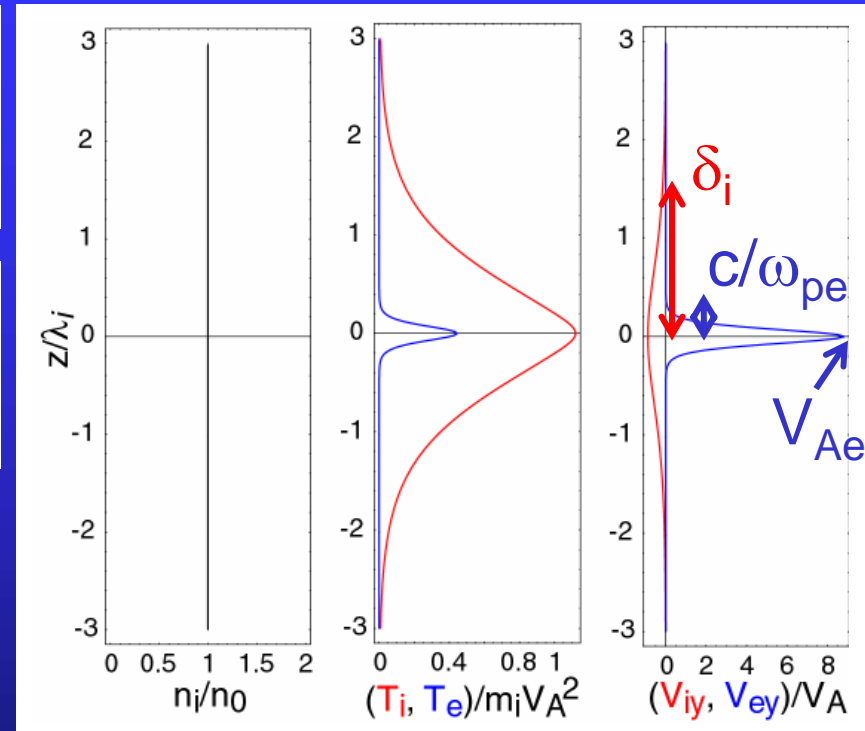
$$V_{s0} = (1/\mu_0 n_s q_s) (B_{s0} / \delta_s)$$

$$T_s(z) = - \int^z q_s V_s(\xi) B_x(\xi) d\xi$$

These profiles satisfy

$$q_s n_s \vec{V}_s \times \vec{B} - \nabla(n_s T_s) = 0$$

$$\nabla \times \vec{B} = \mu_0 e (n_i \vec{V}_i - n_e \vec{V}_e)$$



$$\delta_e = c/\omega_{pe}, \quad V_{e0} = V_{Ae} = B_{0e}/(\mu_0 n_0 m_e)^{1/2},$$

$m_i/m_e, \delta_i$ 依存性

解析手法

$$A(y, z, t) = A_0(z) + \delta A(y, z, t)$$

$$\delta A(y, z, t) = \delta \hat{A}(z, t) e^{ik_y y}$$

$$\frac{\partial \vec{B}}{\partial t} = -\nabla \times \vec{E}$$

$$\frac{\partial \vec{E}}{\partial t} = c^2 \nabla \times \vec{B} - c^2 (n_i \vec{V}_i - n_e \vec{V}_e)$$

$$\frac{\partial \vec{V}_s}{\partial t} + (\vec{V}_s \cdot \nabla) \vec{V}_s = \frac{q_s}{m_s} (\vec{E} + \vec{V}_s \times \vec{B}) - \frac{1}{m_s n_s} \nabla (n_s T_s)$$

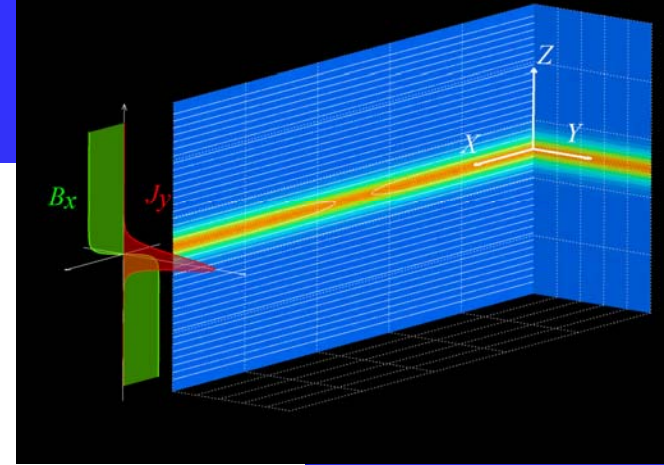
$$\frac{\partial n_s}{\partial t} + \nabla \cdot (n_s \vec{V}_s)$$

$$\frac{d}{dt} (T_s n_s^{-\gamma+1}) = 0$$

Solved for $(\delta \hat{B}_x, \delta \hat{E}_y, \delta \hat{E}_z, \delta \hat{V}_{sy}, \delta \hat{V}_{sz}, \delta \hat{n}_s, \delta \hat{T}_s)$

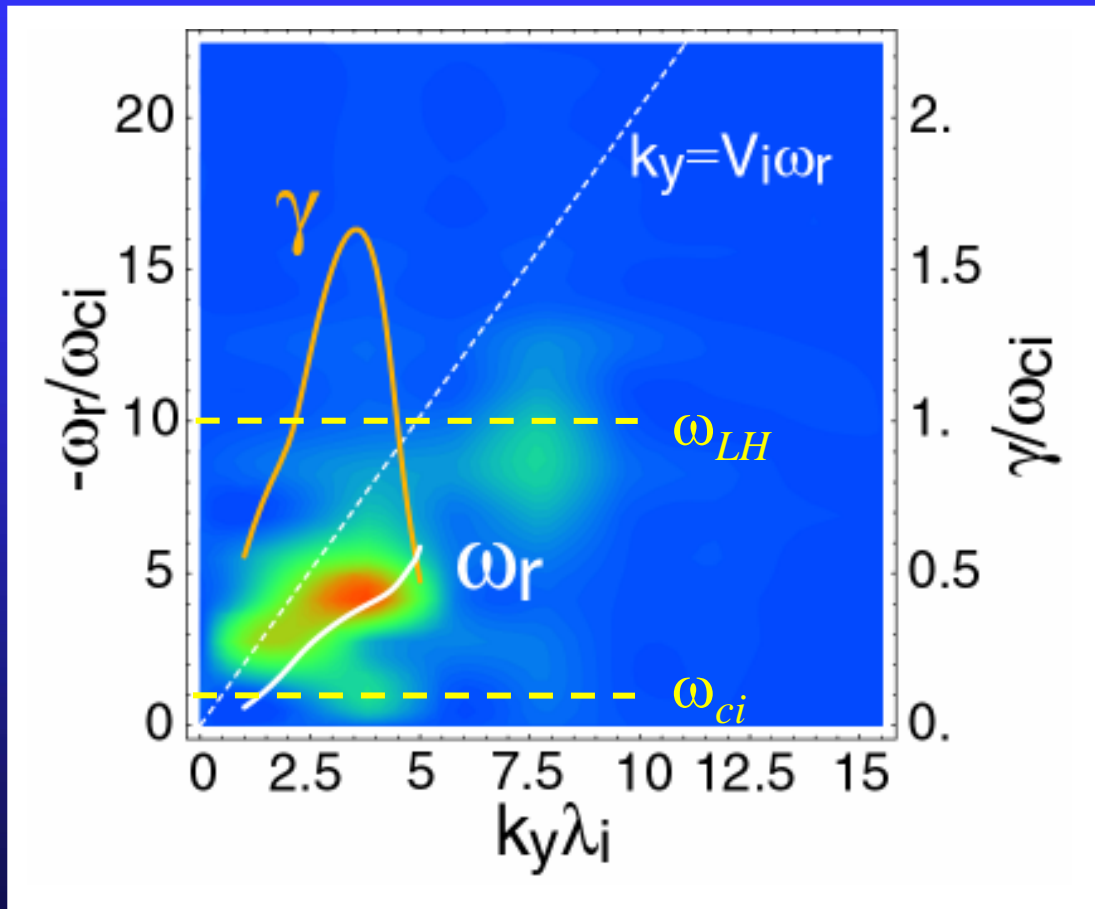
with an initial value approach.

[Pritchett et al., JGR, 1996]



シミュレーション結果との比較(分散関係)

$$\omega = \omega_r + i\gamma$$

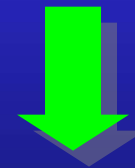


シミュレーションでの値

$$m_i/m_e = 100$$

$$\delta_i/\lambda_i = 0.36$$

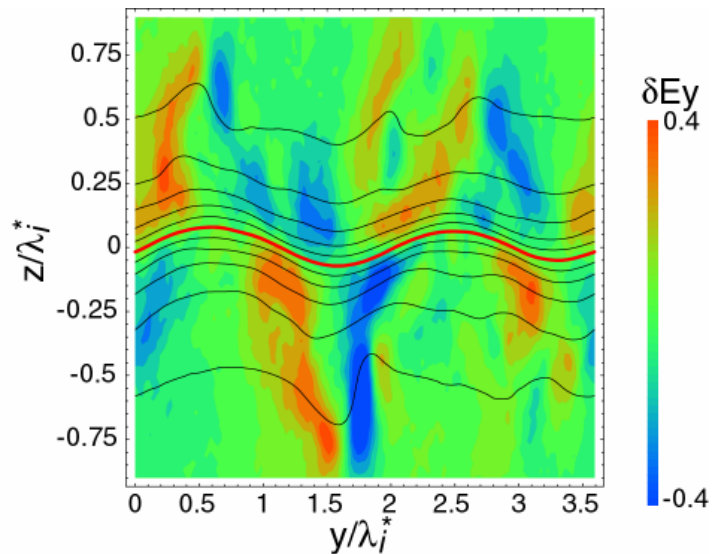
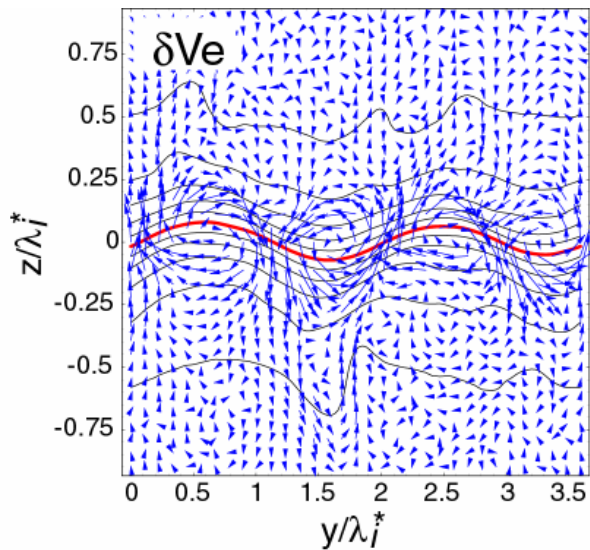
$$V_{i0}/V_A = 2.0$$



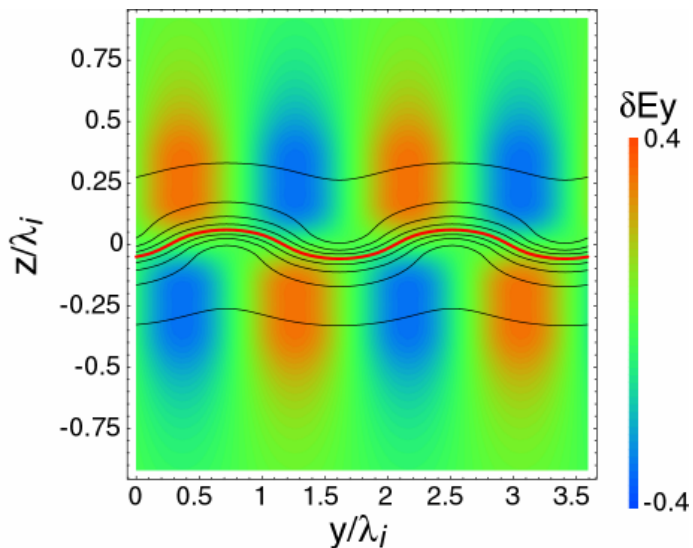
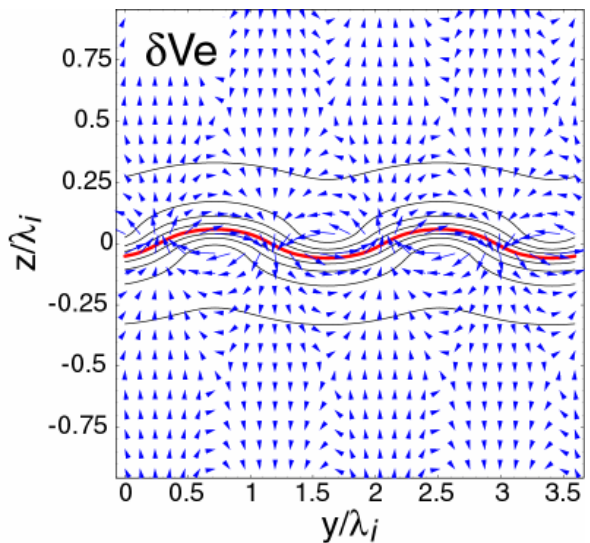
線形分散と良い一致

シミュレーション結果との比較(固有関数)

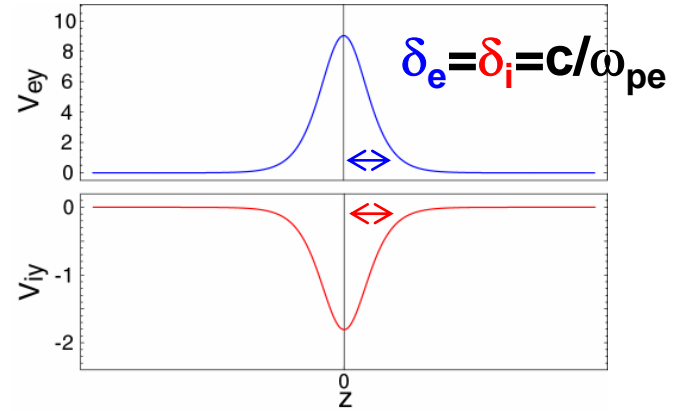
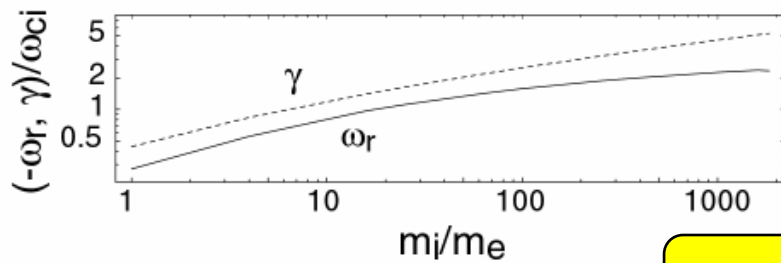
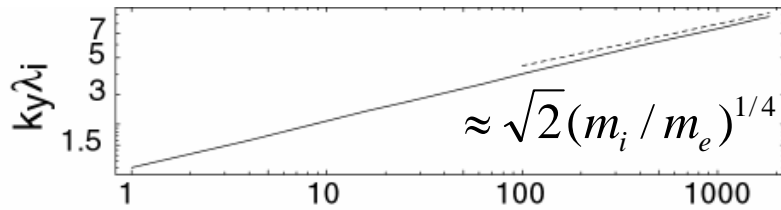
シミュレーション



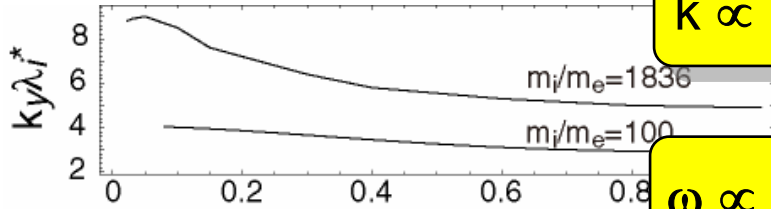
線形理論



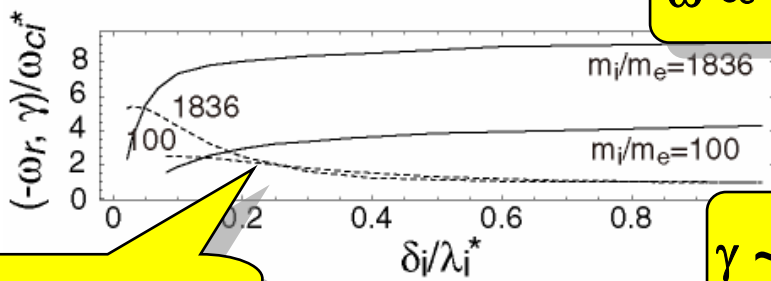
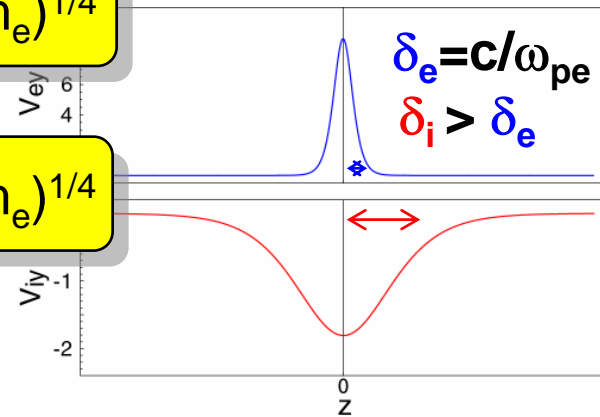
m_i/m_e 、 δ_i 依存性



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



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



$\gamma \sim \omega_{ci}$

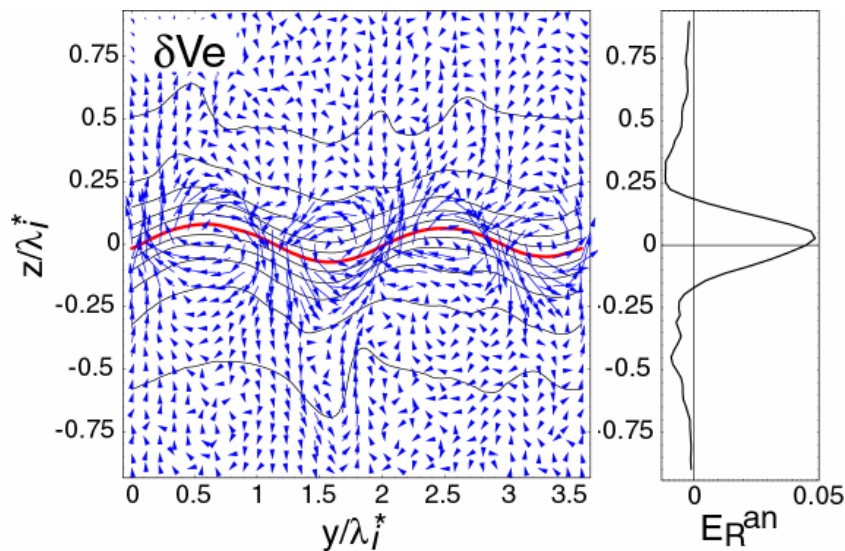
Shear is important factor.

運動量の異常輸送

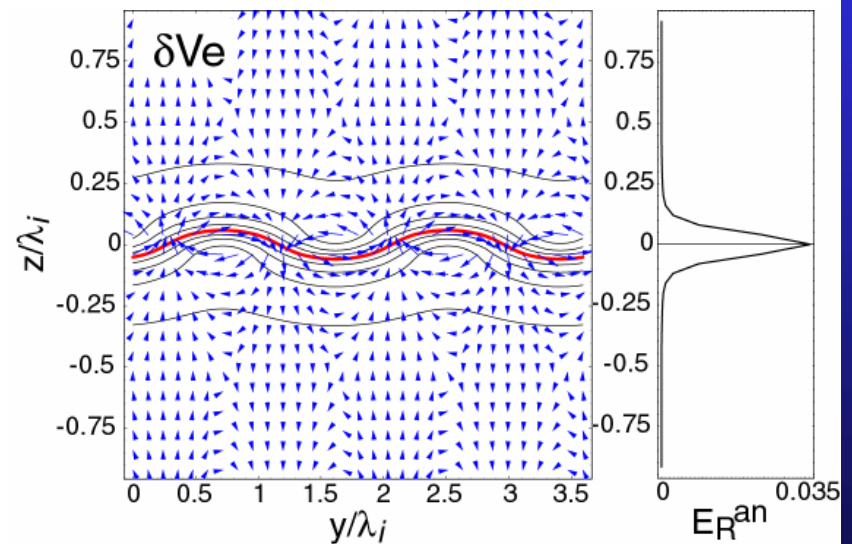
電磁波動による電子運動量の異常輸送

$$E_R^{an} = \frac{1}{\langle n_e \rangle} \langle \delta(n_e \vec{V}_e) \times \delta \vec{B} \rangle_y \quad \left(\langle \cdot \rangle = \frac{1}{L_y} \int_0^{L_y} \cdot dy \right)$$

シミュレーション



線形理論



まとめ

高速磁気リコネクション時に形成される電流層に励起する電磁波動に関する線形解析を実施した。

- 現実的な新しい平衡解
- シミュレーション結果と良く一致
- 成長率は速度シアに強く依存 \Rightarrow シア不安定性
- 成長率はほとんど質量比に依存しない
- $k \propto (m_i/m_e)^{1/4}$, $\omega \propto (m_i/m_e)^{1/4} \Rightarrow$ 物理機構は今後の課題
- 運動量の異常輸送