無衝突磁気リコネクションにおける異常磁気散逸機構

藤本桂三

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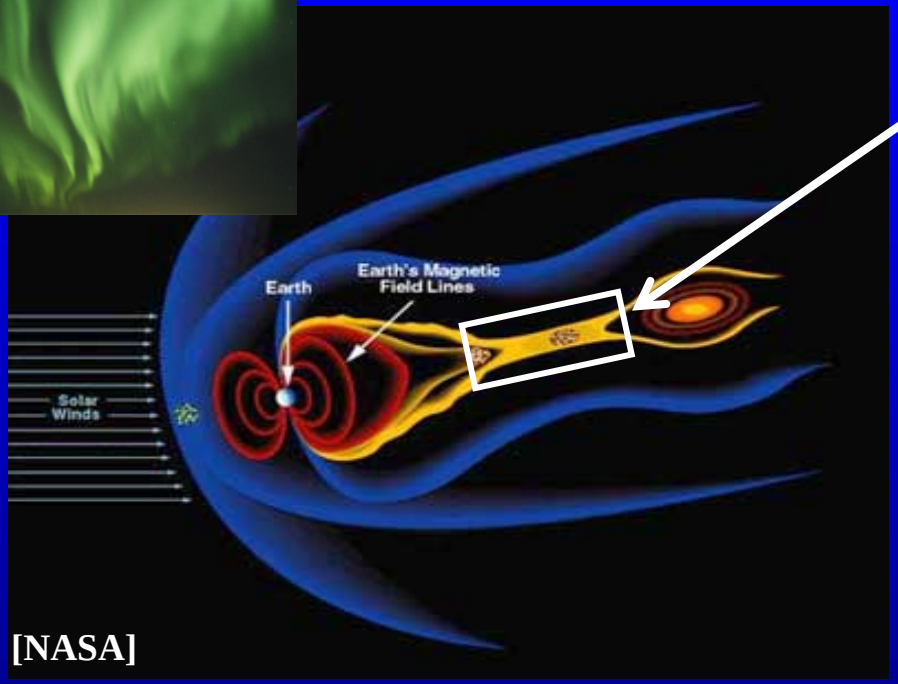
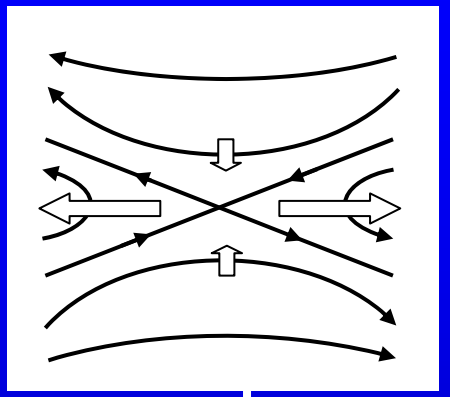
発表内容

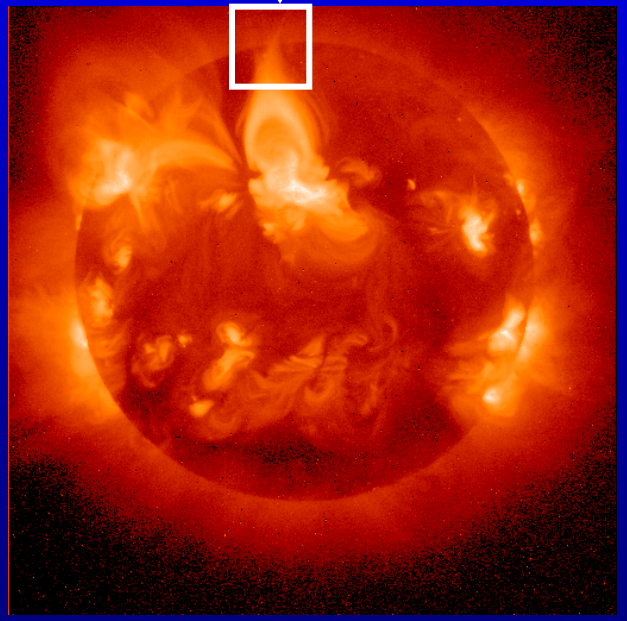
- Introduction
- Large-scale 3D PIC simulations (*Instabilities, turbulence, and anomalous transport at the x-line*)
- Impact of plasmoid formations
- Summary

Magnetic Reconnection in Space

Auroral Substorms

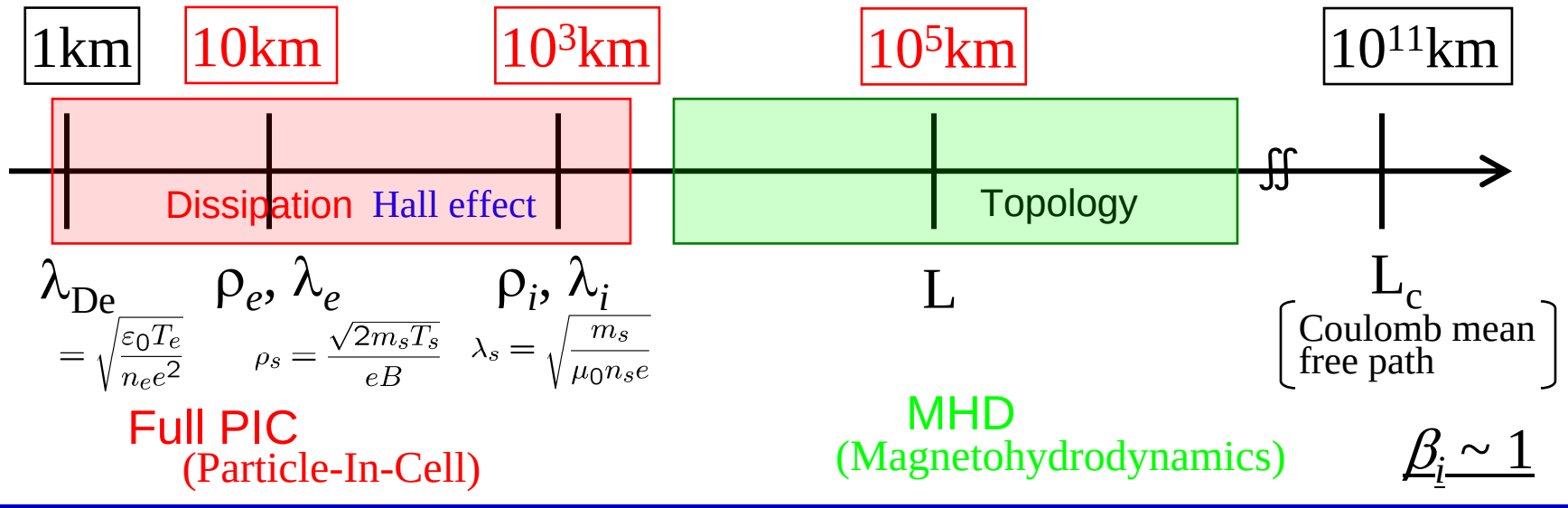


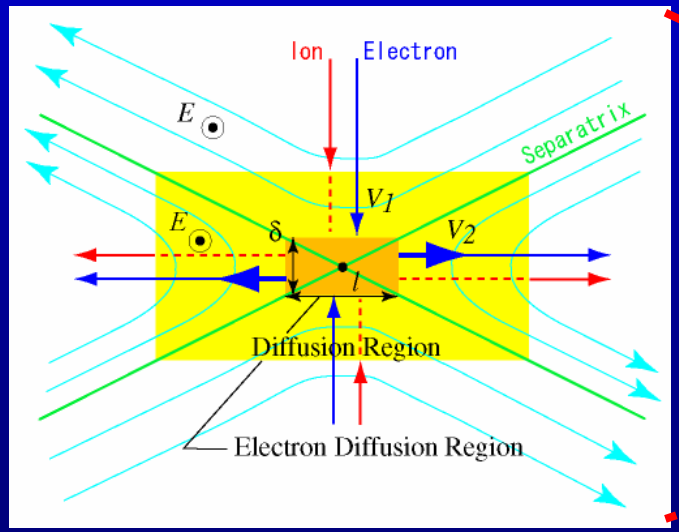


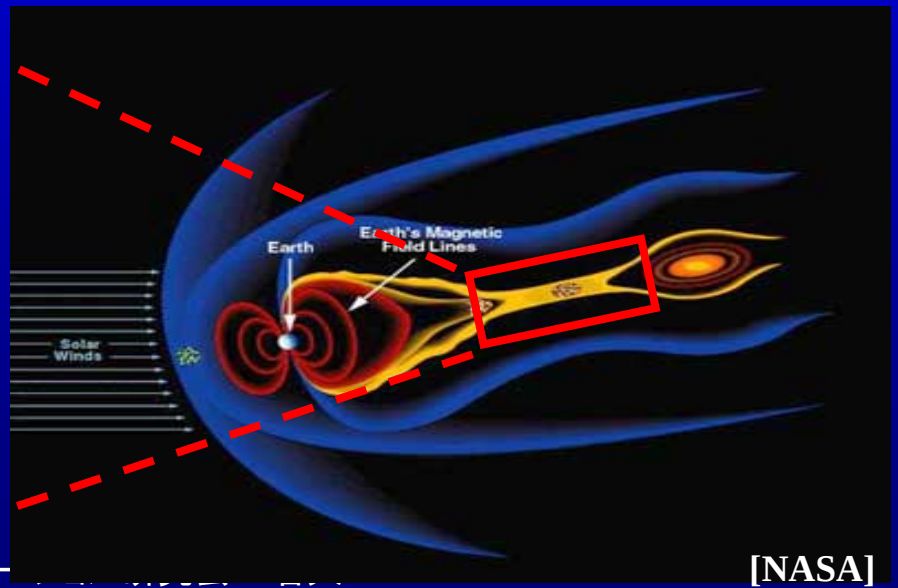


Solar Flares

Multi-Scale Nature of Reconnection







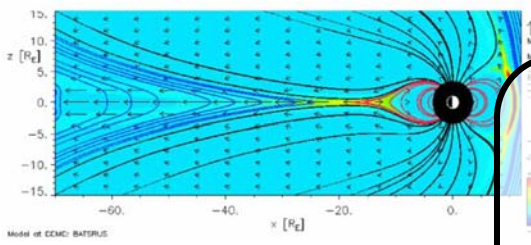
STEシミュレー

[NASA]

Kuznetsova et al., J. Geophys. Res., 2007

$$\frac{\partial B}{\partial t} = \eta \nabla^2 B/\mu_0$$

Numerical resistivity only

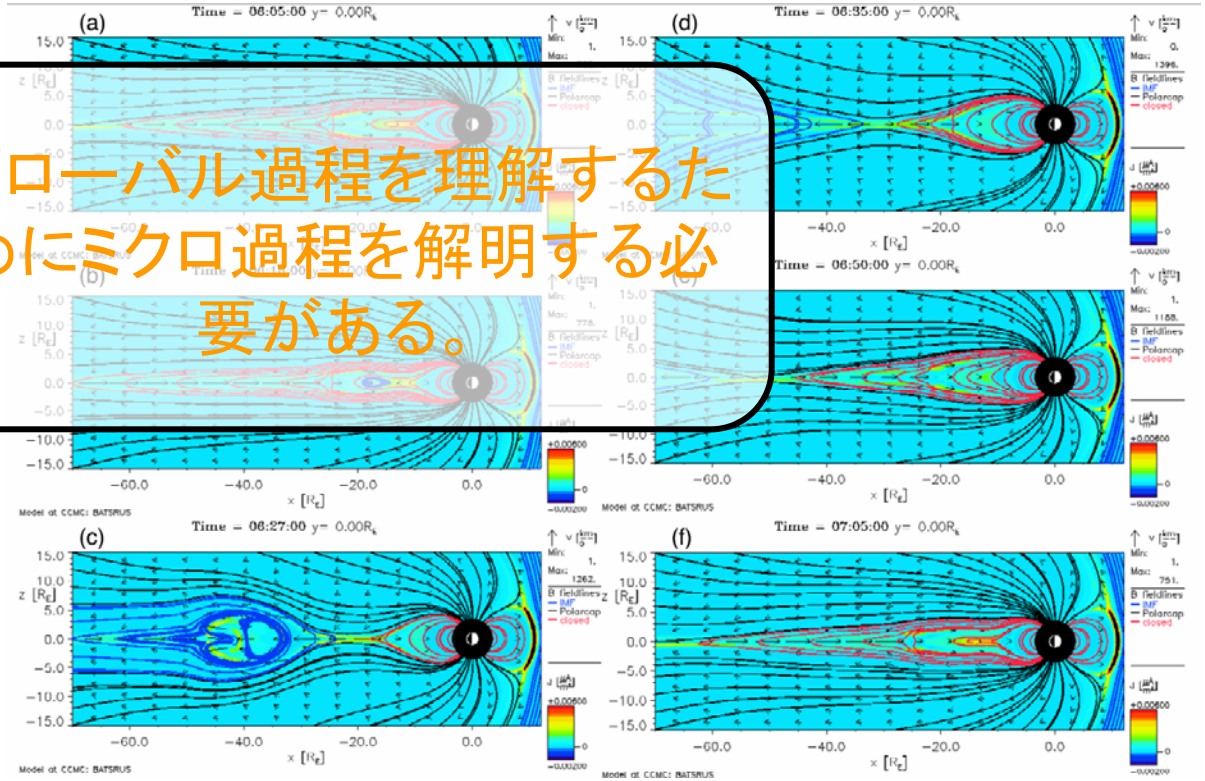


- Slow reconnection
- Quasi-steady configuration

- Fast reconnection
- Quasi-periodic process

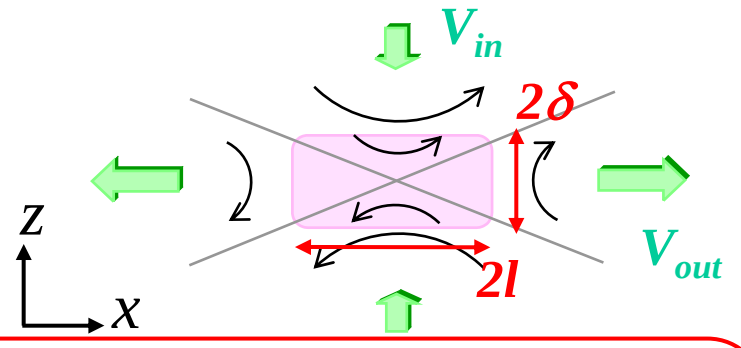
Nongyrotropic correction case

$$E^{ng} = \frac{1}{ne}\left(\frac{\partial P_{ixy}}{\partial x} + \frac{\partial P_{ixz}}{\partial z}\right) = \frac{m_i}{e}\sqrt{\frac{2P}{\rho}}\frac{\partial V_x}{\partial x}$$



グローバル過程を理解するためにミクロ過程を解明する必要がある。

Reconnection Rate and Resistivity η



無衝突プラズマにおいて衝突効果を生む物理は？

マクロ過程へのインパクト？

3D、マルチスケール、非線形、Kinetic ⇒ 大規模運動論計算

リコネクション効率

$$E_R \equiv -\frac{\partial \Phi_m^*}{\partial t} \approx \frac{V_{in}}{V_{out}} \approx \frac{\delta}{l}$$

$$\Phi_m^* = \int_0^{L_z} B_x^* \, dz$$

磁気散逸領域の縦と横の長さに依存

$$\delta \approx \eta / \mu_0 V_{in} \quad \rightarrow c/\omega_{pe}$$

Inertia resistivity limit

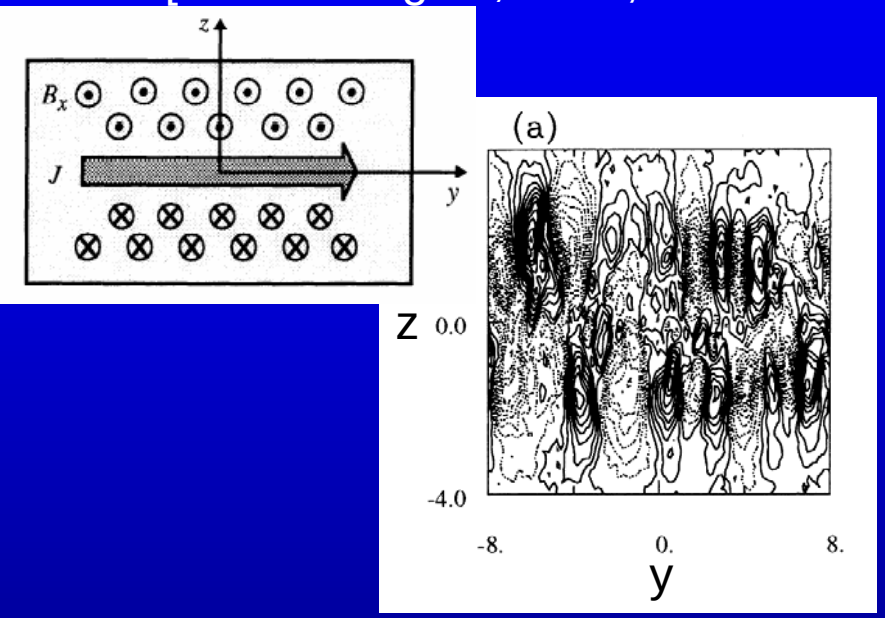
観測事実と不一致

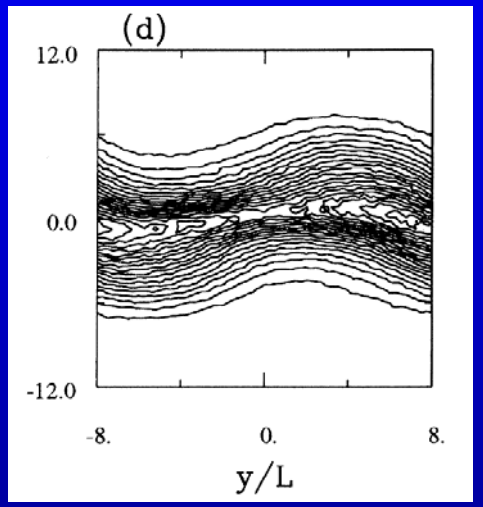
異常磁気散逸の可能性

Pioneering 3D PIC Simulations of MR

磁気リコネクションのトリガー機構としての異常散逸

[Zhu & Winglee, 1996; Pritchett et al., 1996; Horiuchi & Sato, 1999]





Trigger!

Lower hybrid drift Inst. (LHDI)

$k_y r_{Le} \sim 1$

$\gamma \sim \omega_{lh}$

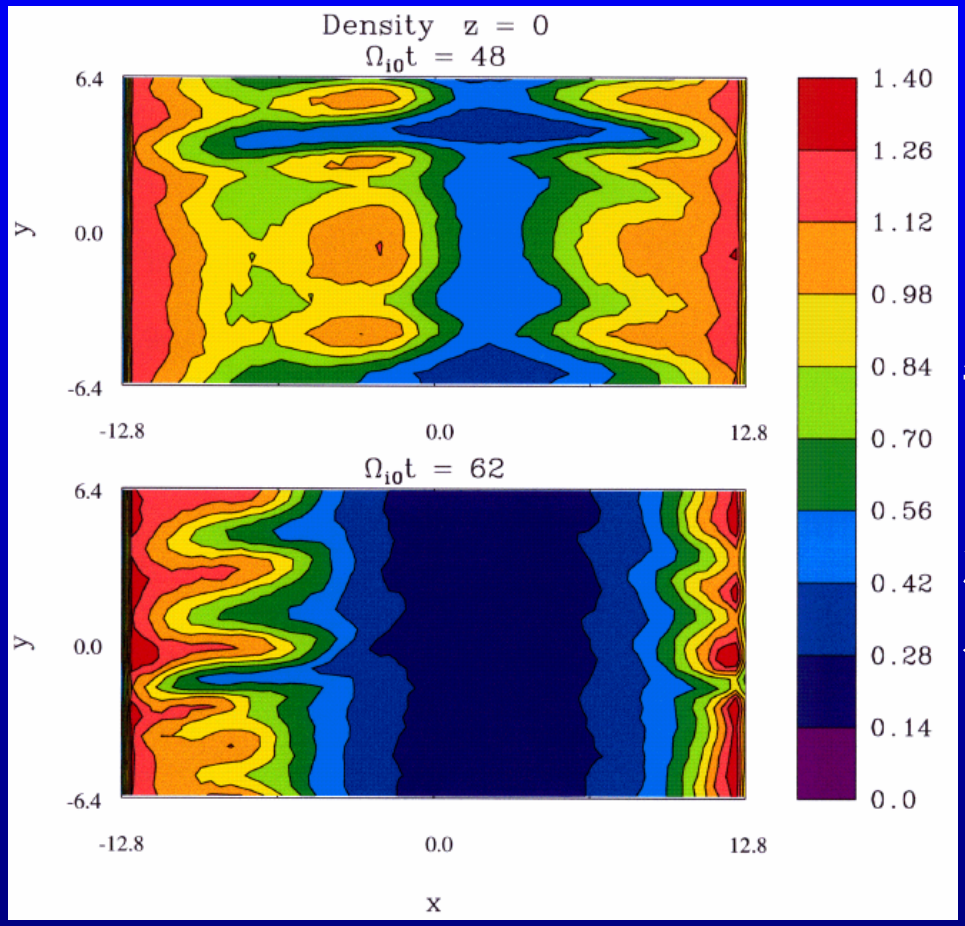
Drift Kink Inst. (DKI)

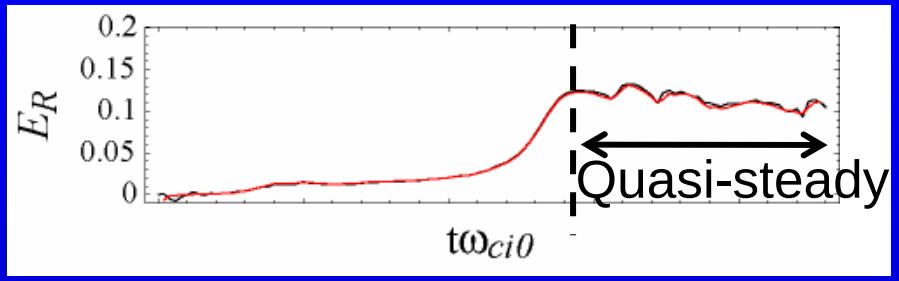
$k_y \delta \sim 1$

$\gamma \sim \omega_{ci} \propto k_y V_d$

Quasi-Steady Process of MR （~ 2000年代前半）

[Horiuchi & Sato, POP, 1999; Pritchett & Coroniti, EPS, 2001; Karimabadi et al., JGR, 2003]





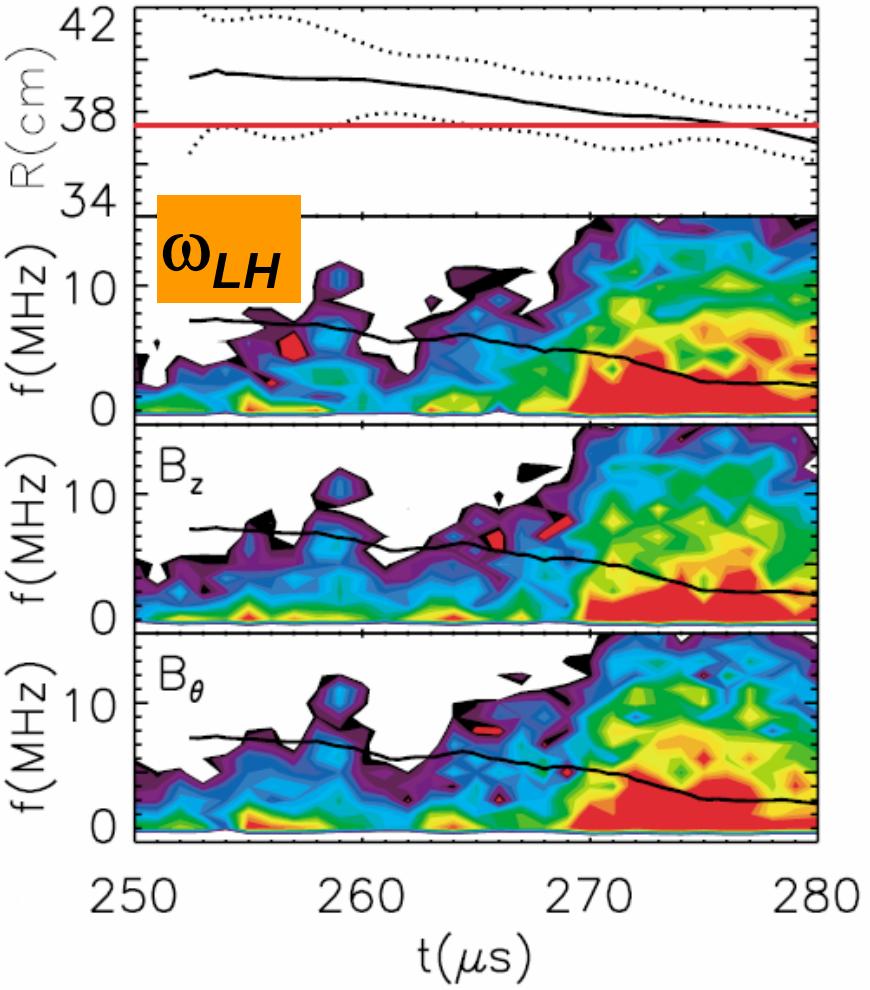
準定常過程ではDKIが励起しない。

（ドリフト速度を持つプラズマは下流へ、ドリフト速度を持たないプラズマが磁気X線へ。）

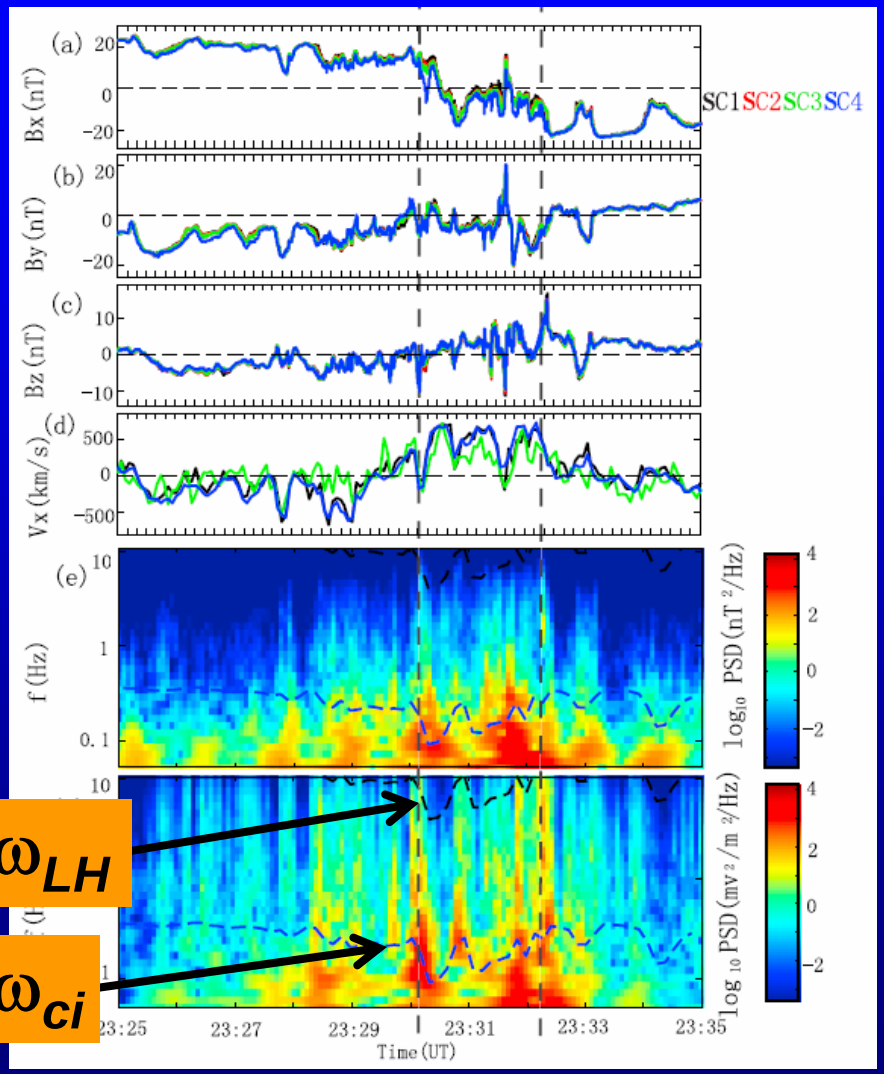
準定常過程は2次元的である。

Implication of Anomalous Dissipation: Wave Activities

[Ji et al, PRL, 2004]



[Zhou et al, JGR, 2009]



3D AM

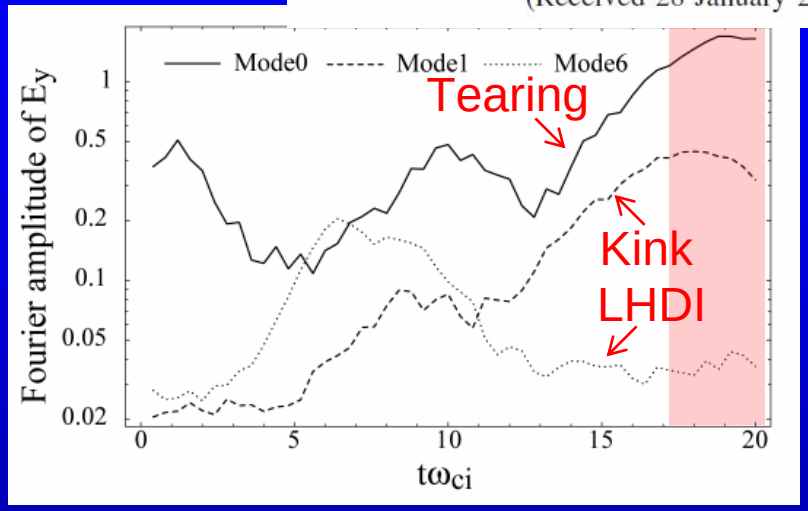
[Fujimoto &
Fujimoto, F

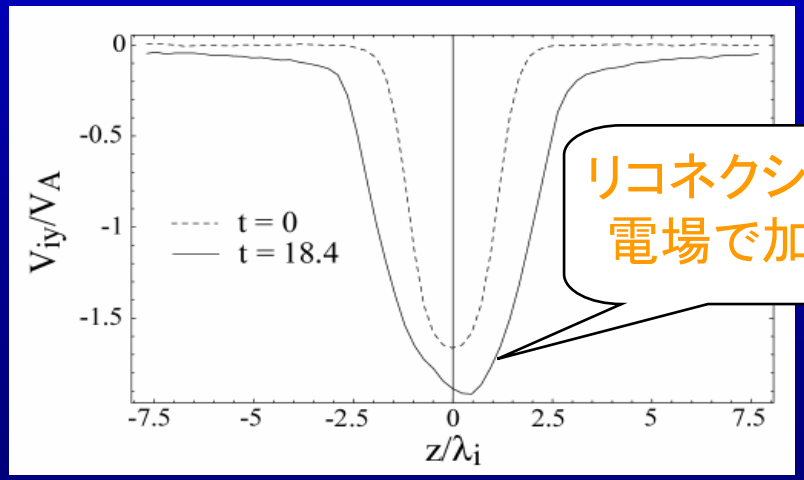
PHYSICS OF PLASMAS 16, 042103 (2009)

Fast magnetic reconnection in a kinked current sheet

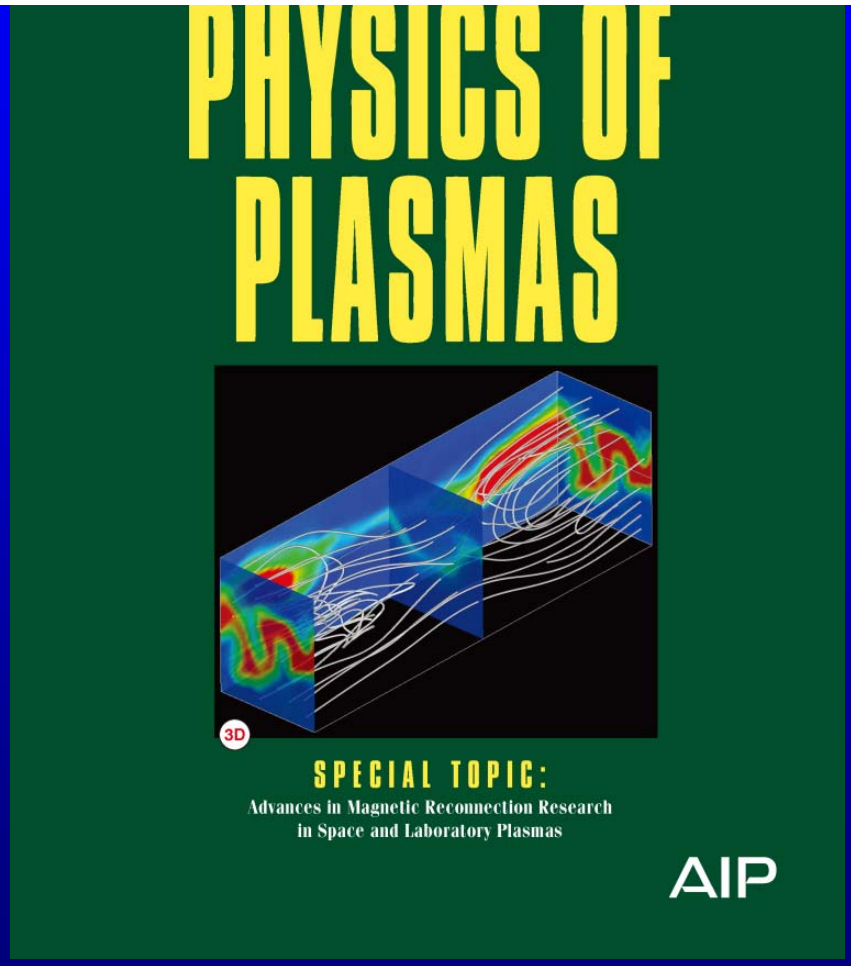
Keizo Fujimoto[a)]
Solar-Terrestrial Environment Laboratory, Nagoya University, Furoh-cho, Chikusa-ku, Nagoya, Aichi 464-8601, Japan

(Received 28 January 2009; accepted 5 March 2009; published online 9 April 2009)

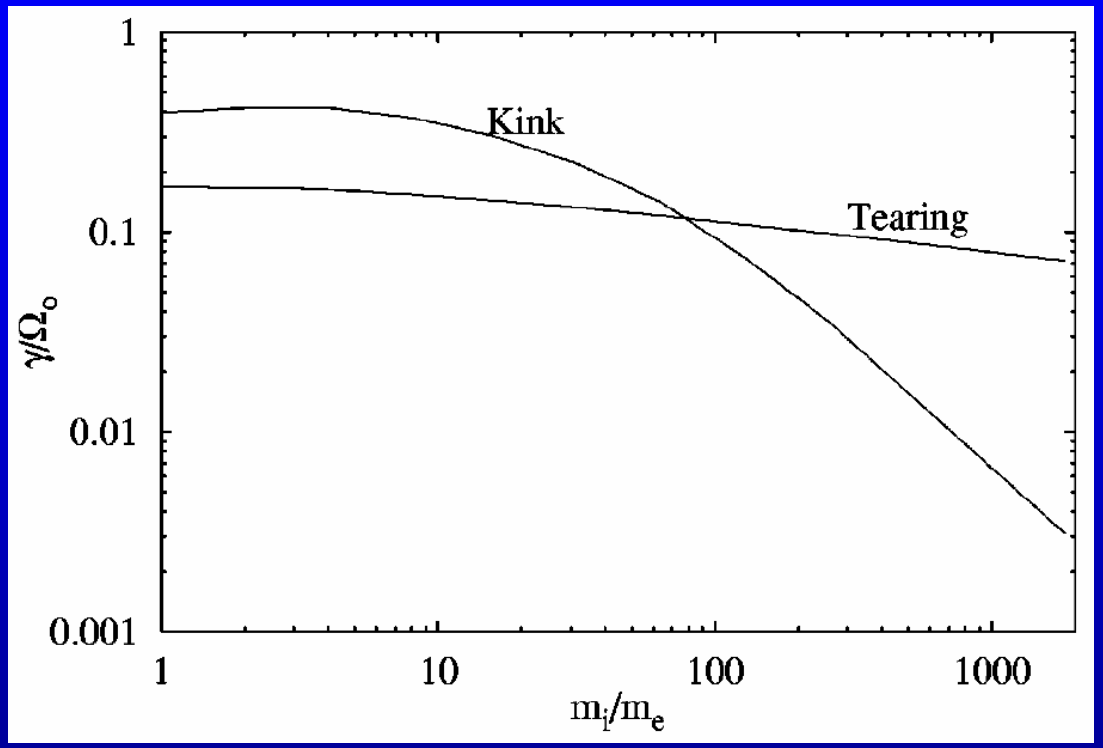




リコネクション
電場で加速



m_i/m_e Dependence of the DKI



[Daughton, POP, 1999]

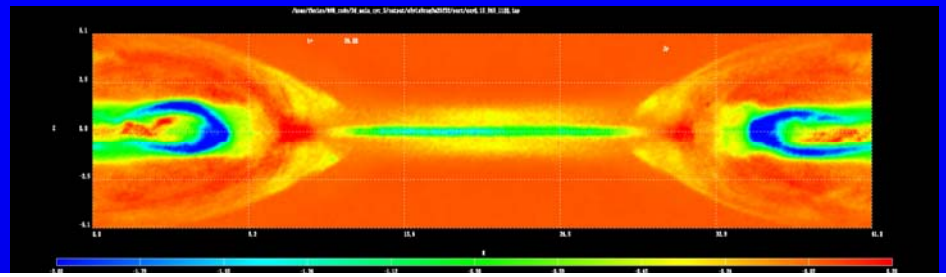
DKIの成長率はm_i/m_eに強く依存。

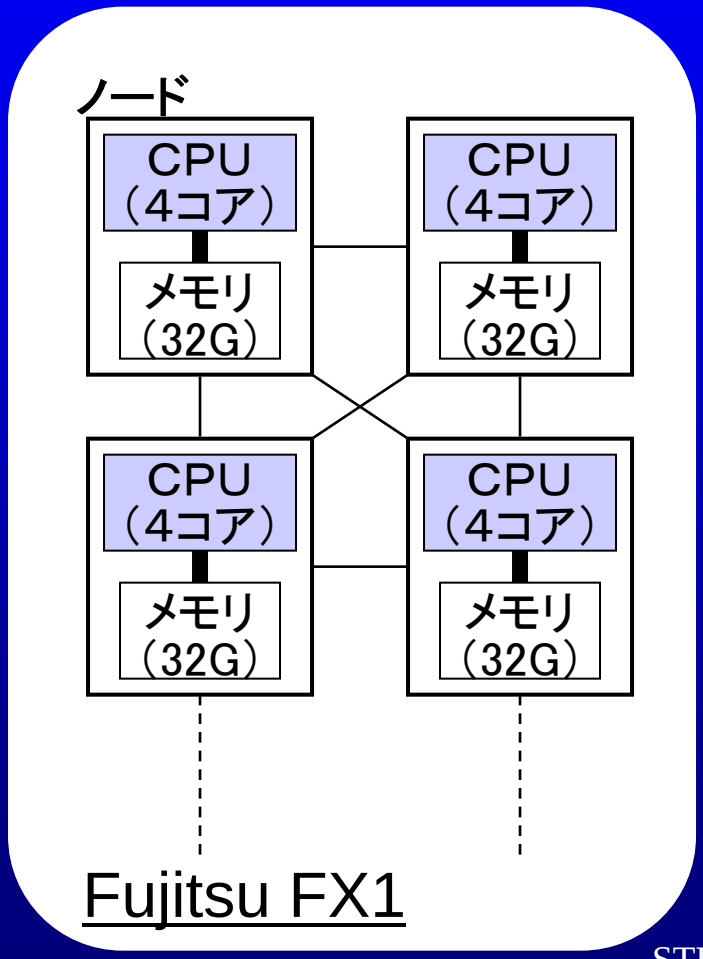
Real mass ではDKIは励起しない？

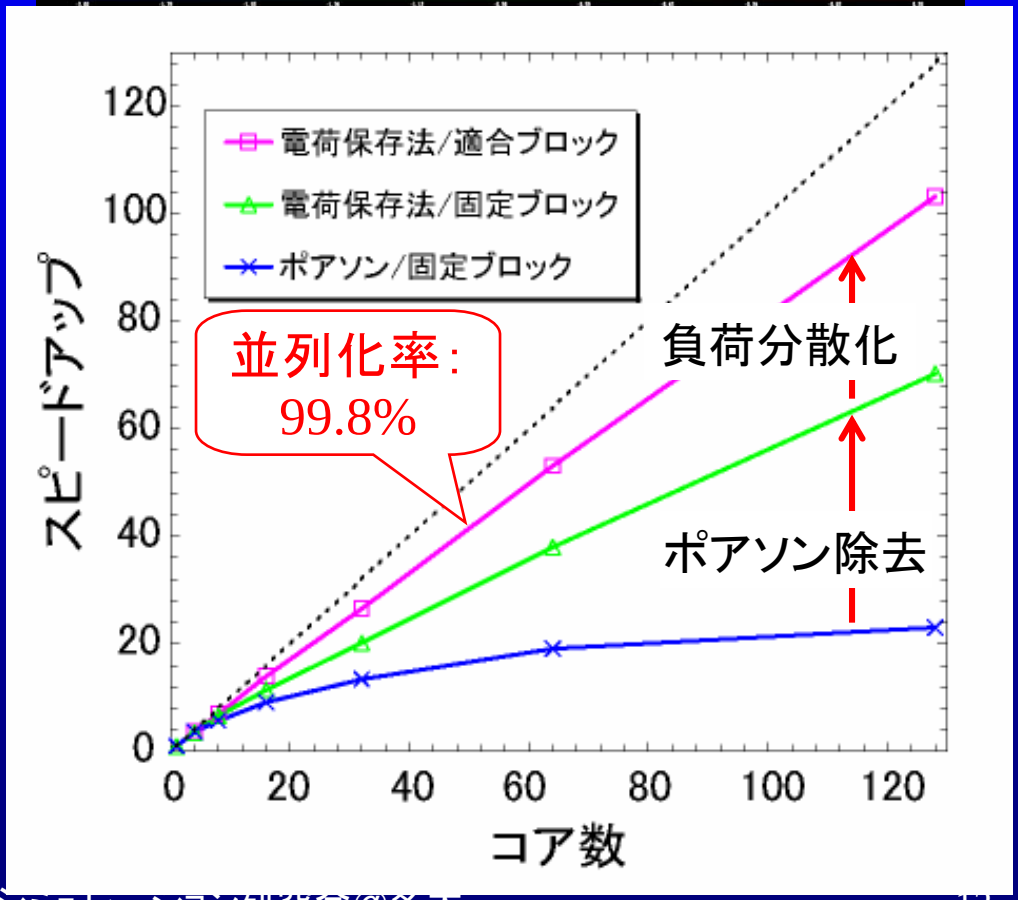
計算コスト ∝ $(m_i/m_e)^{5/2}$

Massively Parallel AMR-PIC Model

[Fujimoto, JCP, 2011]







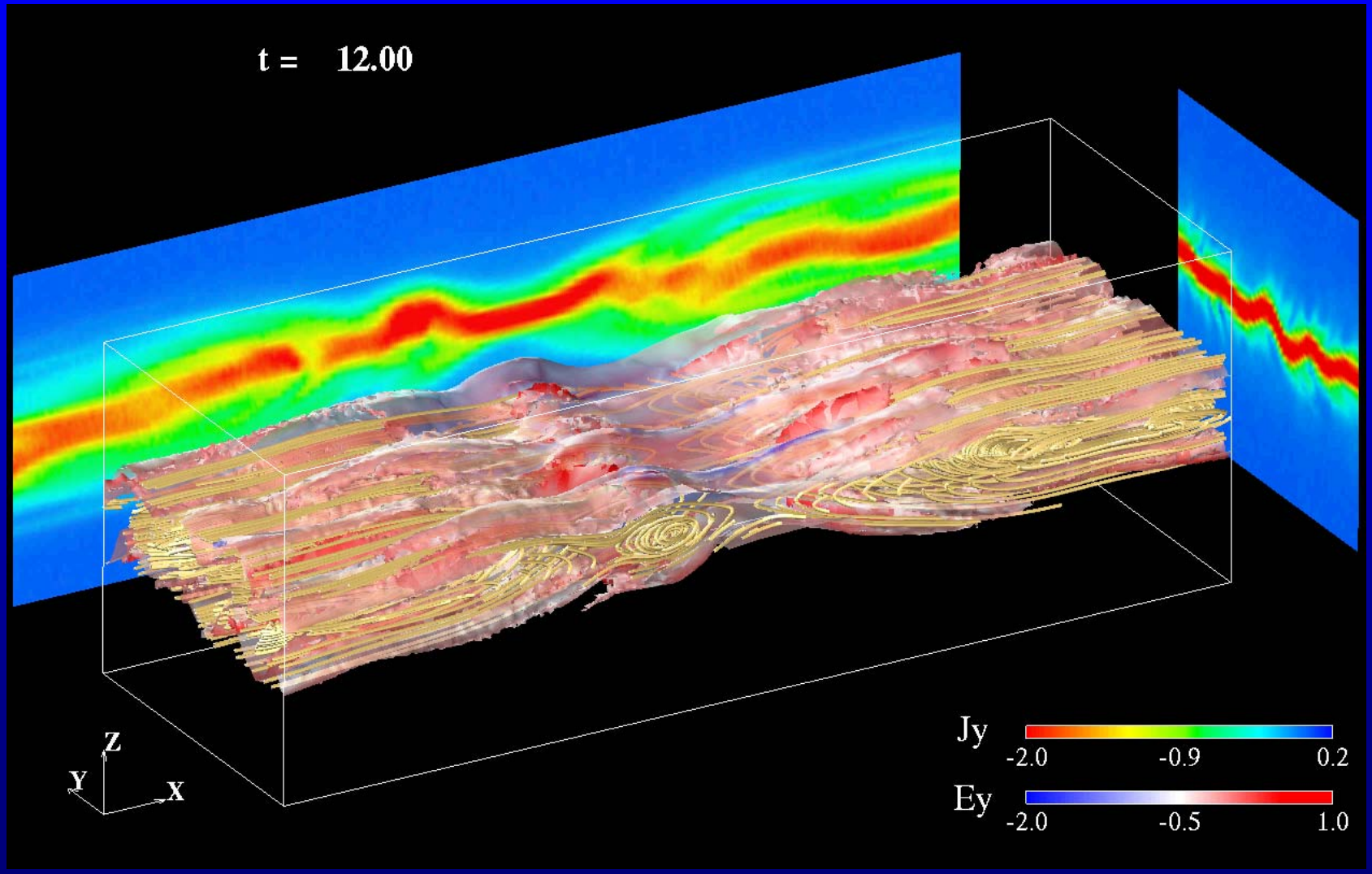
Time Evolution of the Current Sheet

~ 10^{11} particles

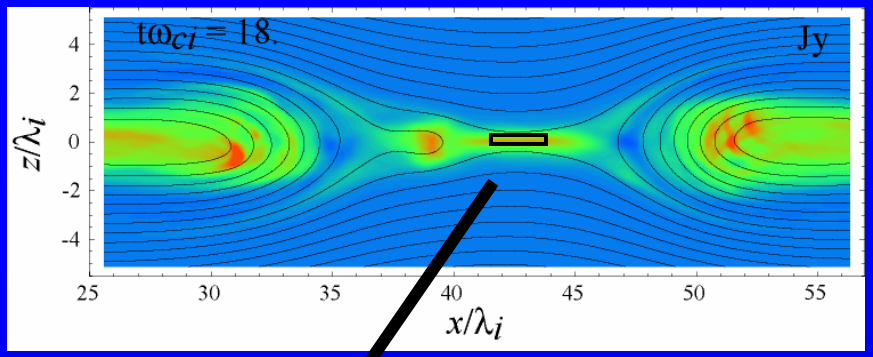
~ 6 TB memory

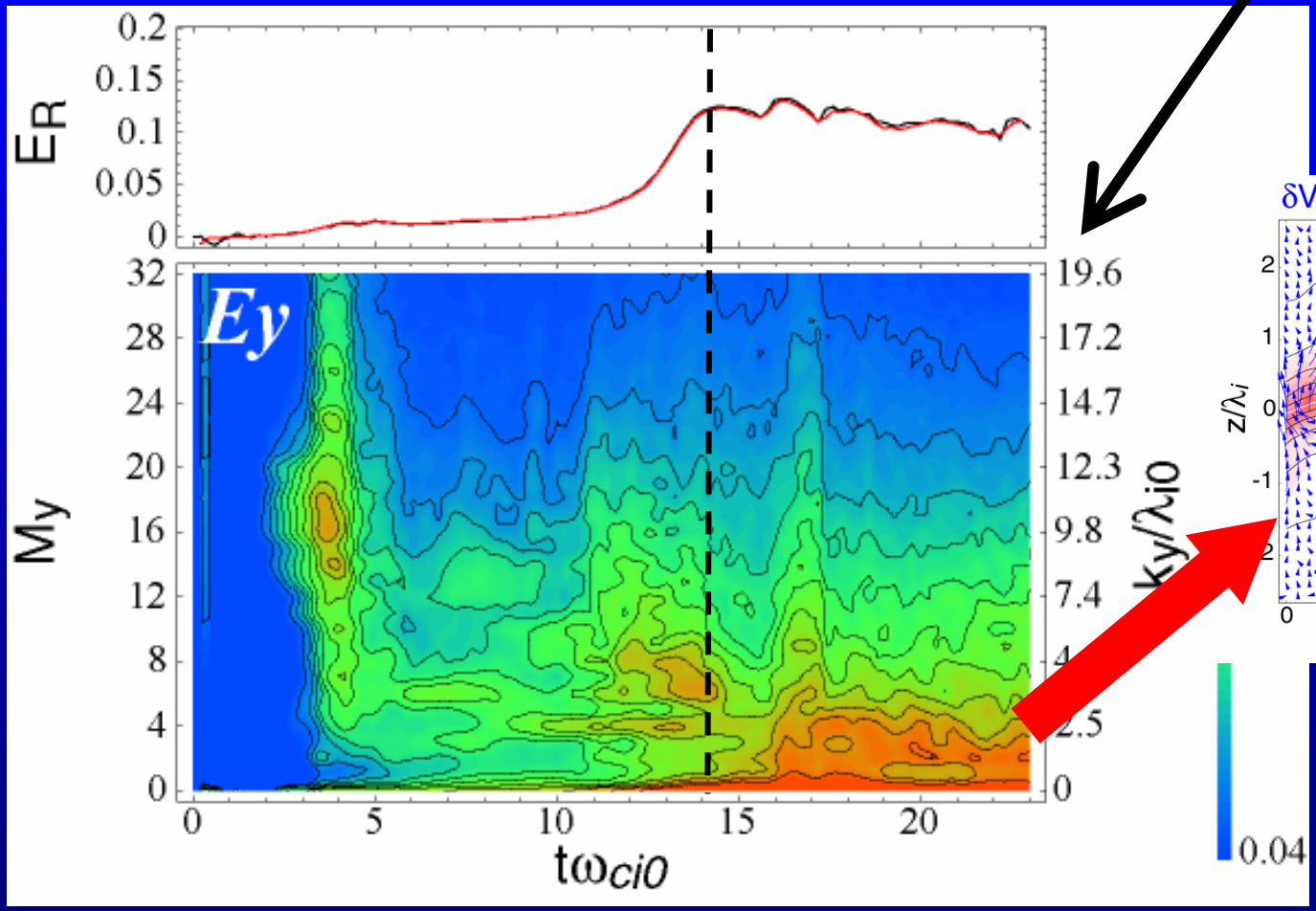
Surface: |J|, Line: Field line

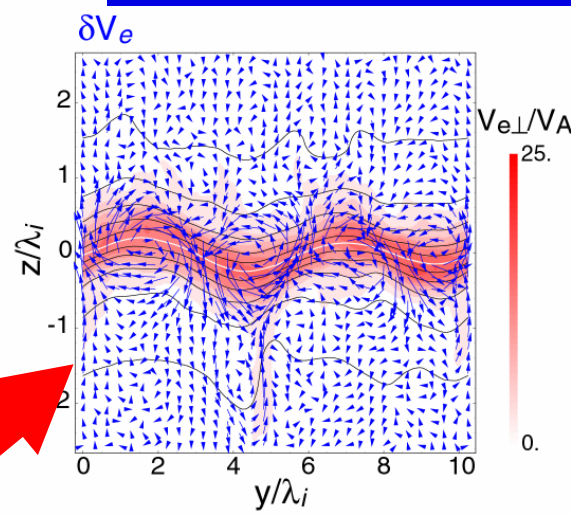
Color on the surface: Ey, Cut plane : Jy



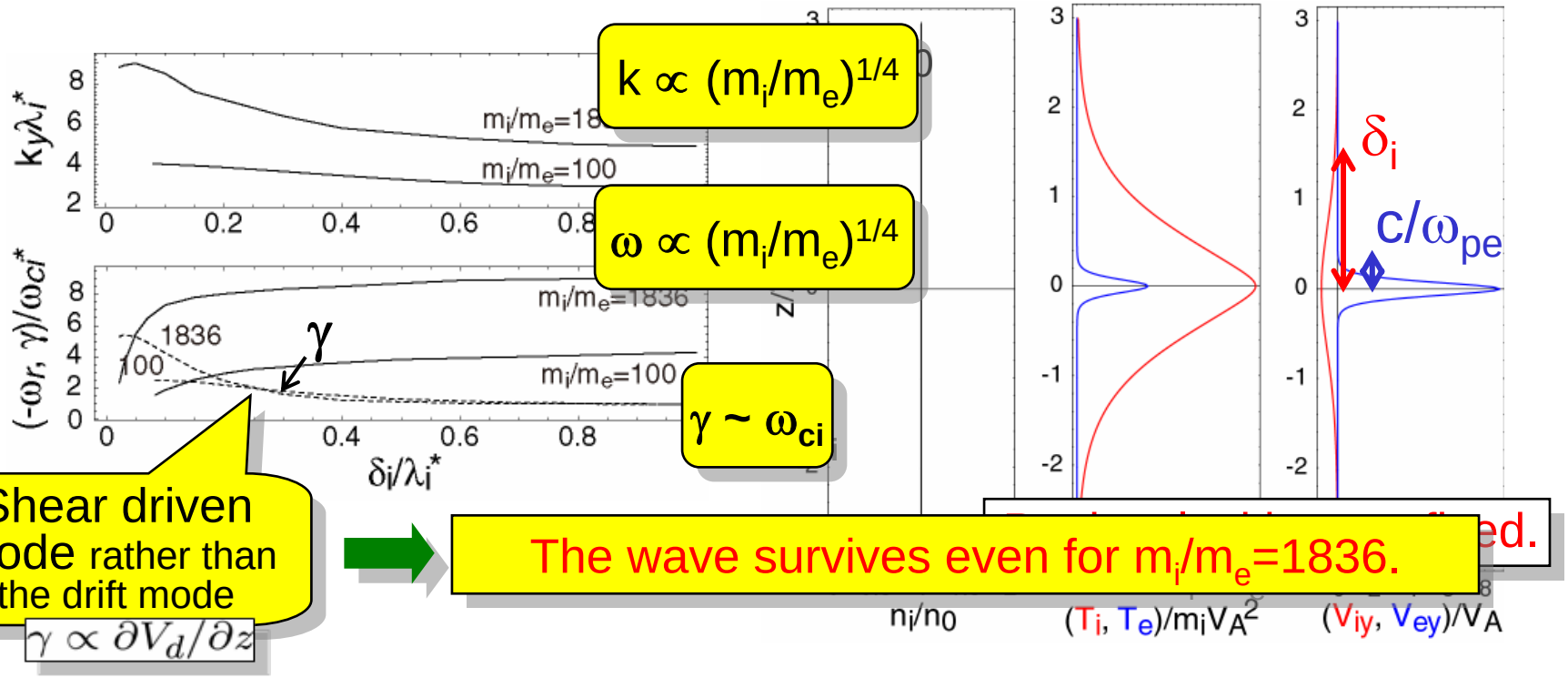
Wave Activity

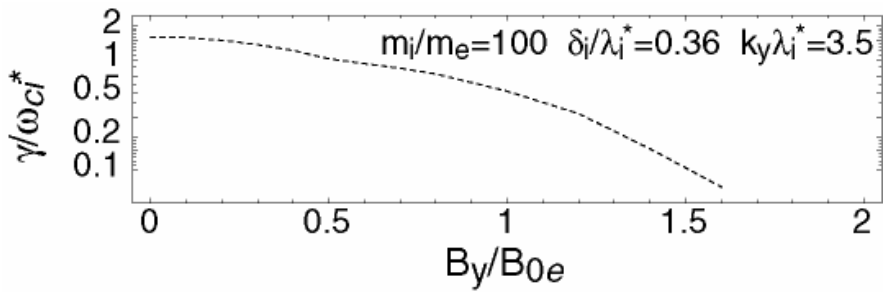






Wave Properties: Linear Analyses

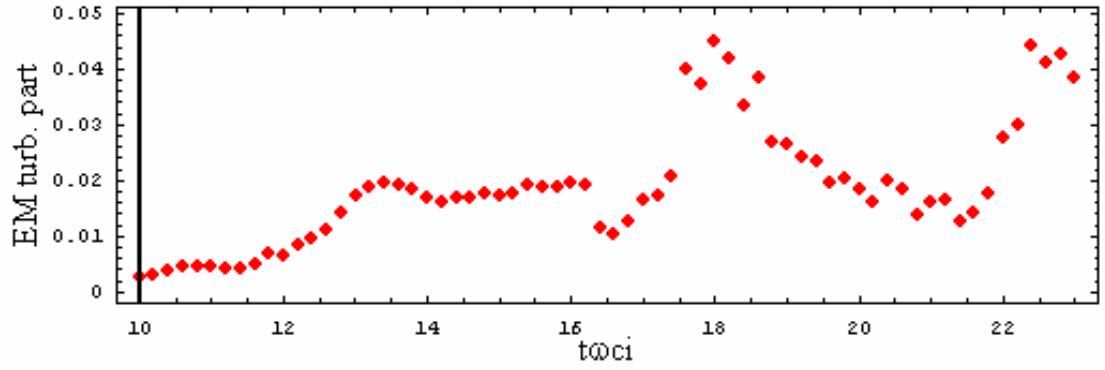


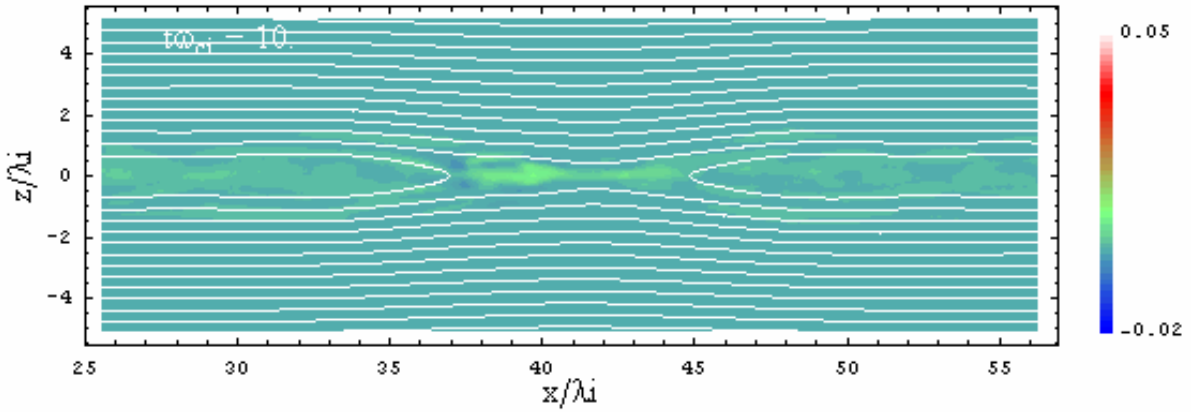


Dependence on the guide field (*By*)

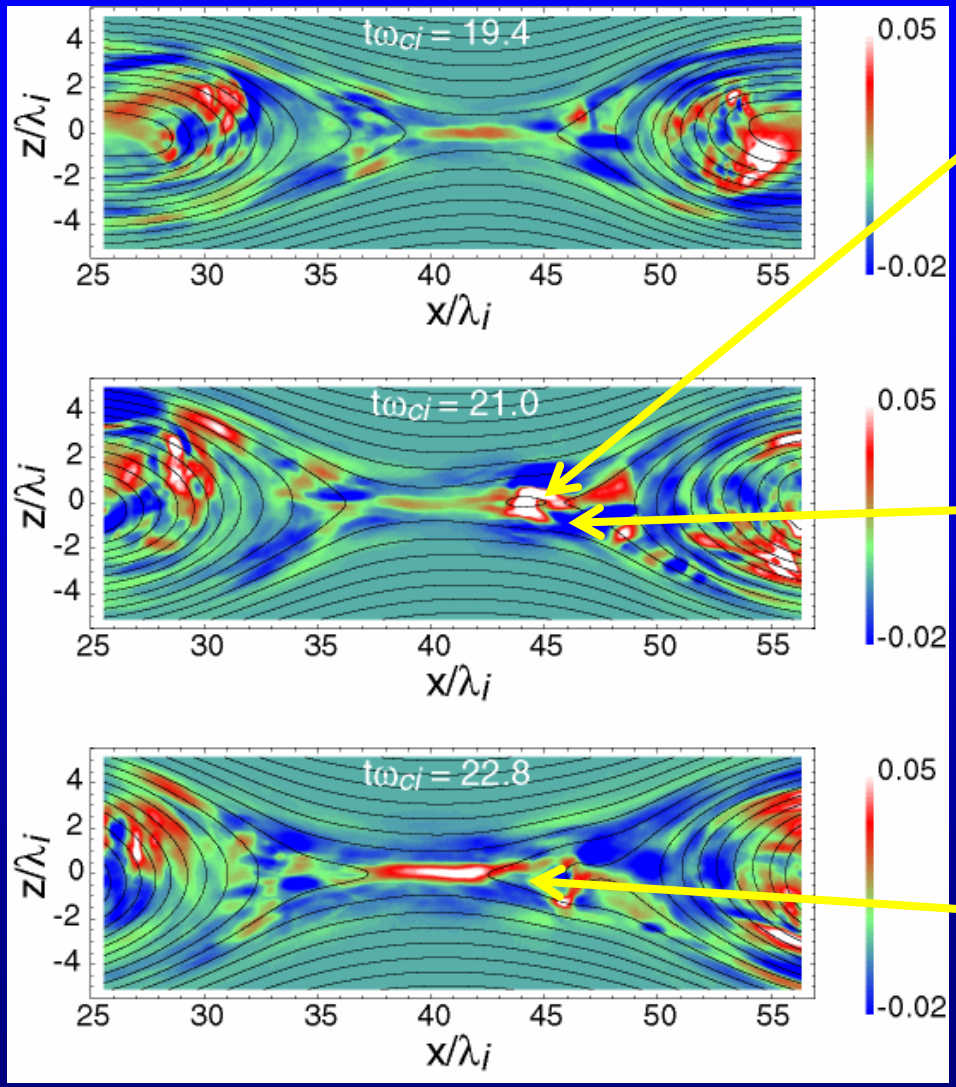
Anomalous Transport at the X-line

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





Plasmoid-Induced Turbulence



Plasmoid formation

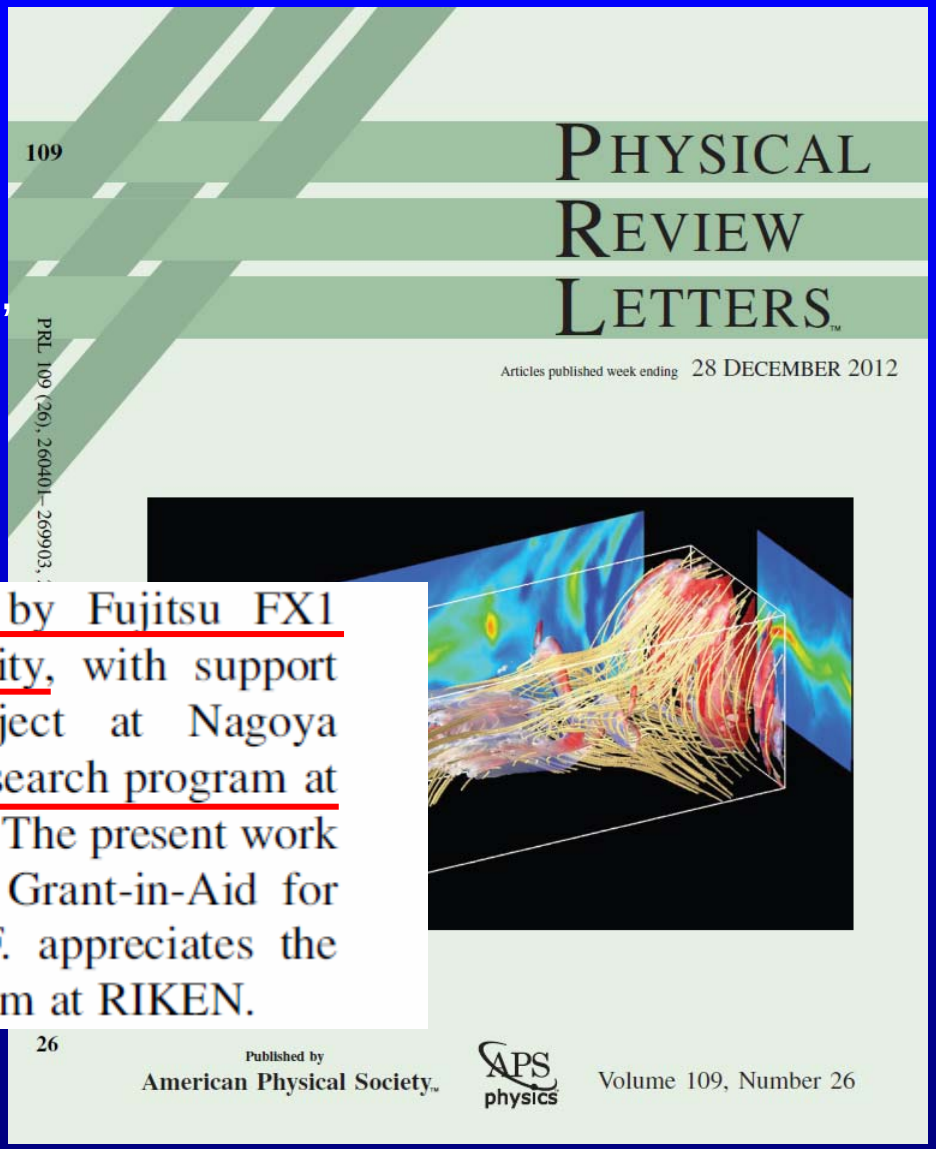
Wave amplification

Local turbulence enhancement

Propagation along the field line

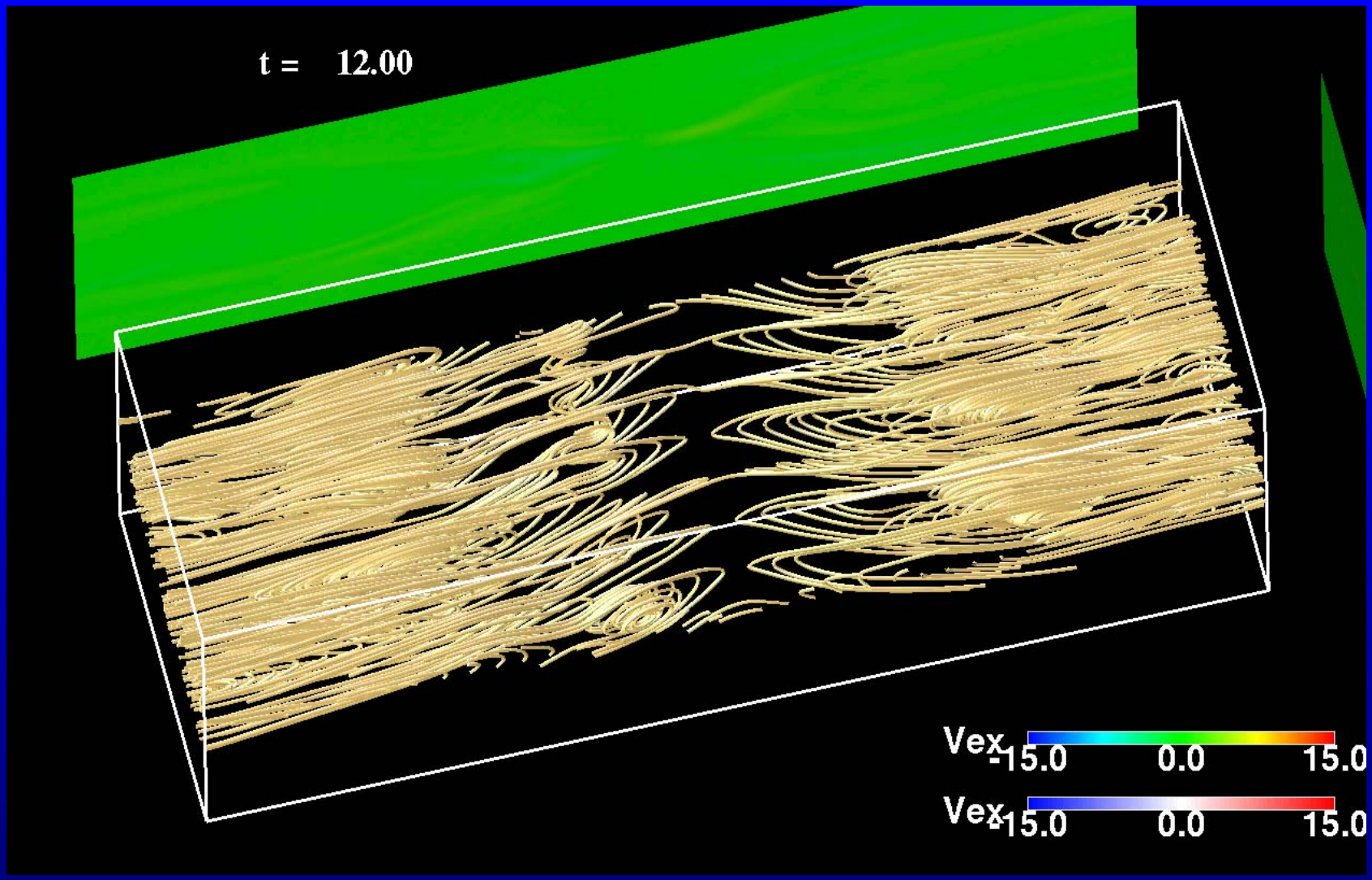
Intensified turbulence at the x-line

K. Fujimoto & RD. Sydora,
Plasmoid-induced turbulence in collisionless magnetic reconnection,
PRL, **109**, 265004, 2012

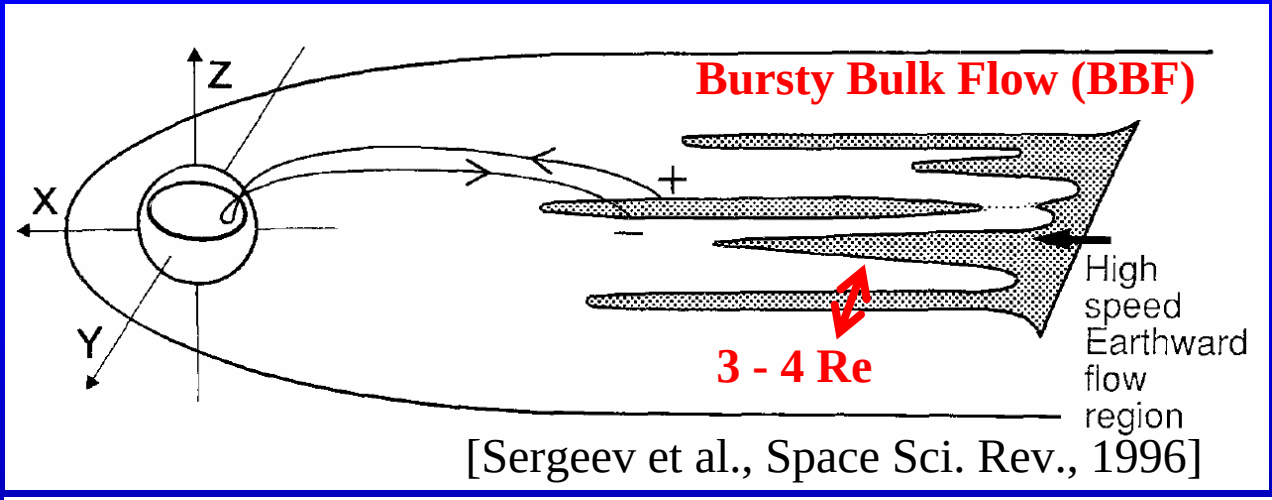


The simulations were carried out by Fujitsu FX1 installed at the ITC, Nagoya University, with support from the HPC joint research project at Nagoya University and a computational joint research program at the STE Laboratory, Nagoya University. The present work has been also supported by the JSPS Grant-in-Aid for Young Scientists (B) (23740373). K. F. appreciates the Special Postdoctoral Researchers Program at RIKEN.

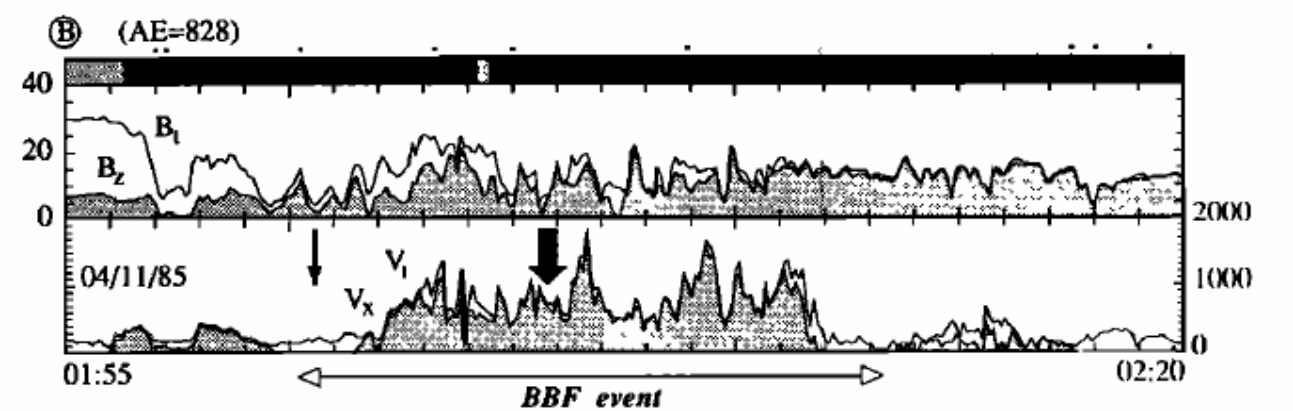
Surface: |Vex|, Line: Field line
Color on the surface:Vex, Cut plane：Vex



Observation in Earth Magnetotail



[Sergeev et al., Space Sci. Rev., 1996]



[Angelopoulos et al., 1992]

局所的、間欠的なプラズマ流。

磁気圏尾部におけるエネルギー輸送の大部分。

リコネクションとの関係？

まとめ

準定常リコネクションにおける異常磁気散逸機構を調べた。

問題設定： 反平行磁場、自発的、非相対論的

不安定性 → シアー不安定性（ドリフト、2流体モードではない）
（$\omega_{ci} < \omega_r < \omega_{lh}$, $k \propto (m_i/m_e)^{1/4}$, $\gamma \sim \omega_{ci}$）

散逸機構 → 電磁乱流による電子運動量の異常輸送

散逸の大きさ → プラズモイド形成によって増大。全磁気散逸の50%程度。波動の振幅に依存。

今後 ・・・ より大規模な計算を実現し、異常散逸過程が周辺領域に与える影響を調べる。