THEMIS SWG, 14 September, 2011

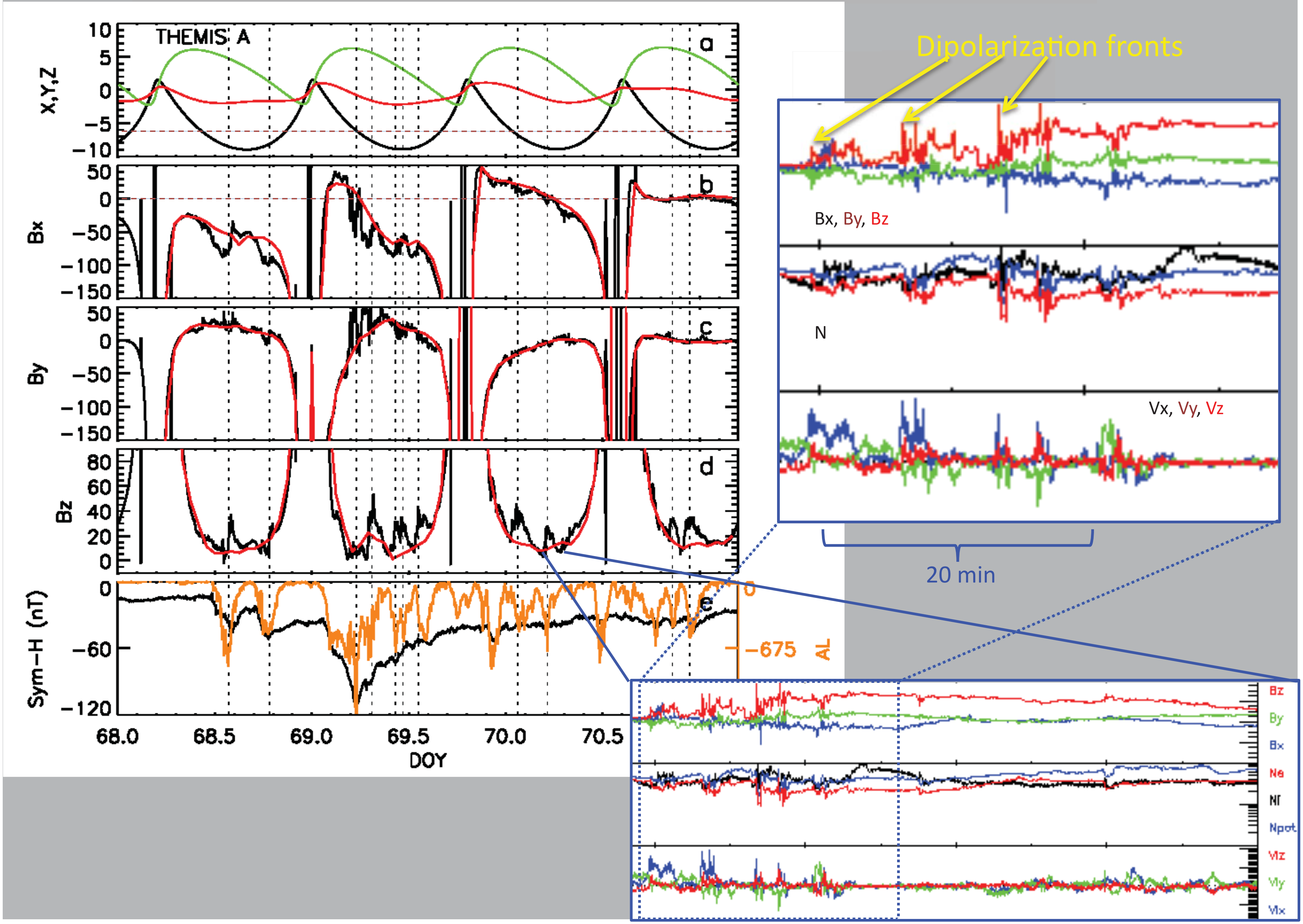
Dipolarization Fronts and Onset of Reconnection in the Magnetotail

M. I. Sitnov[1] and M. Swisdak[2]

[1]) Johns Hopkins University Applied Physics Laboratory, USA

[2]) University of Maryland, College Park

March 8-11, 2008 magnetic storm including substorms and BBFs

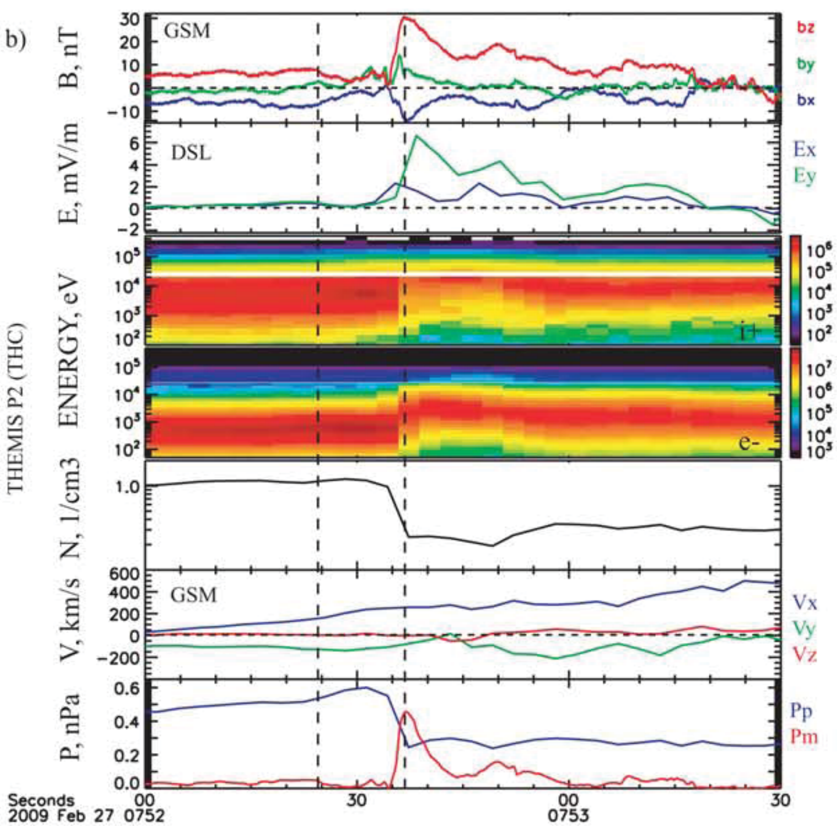


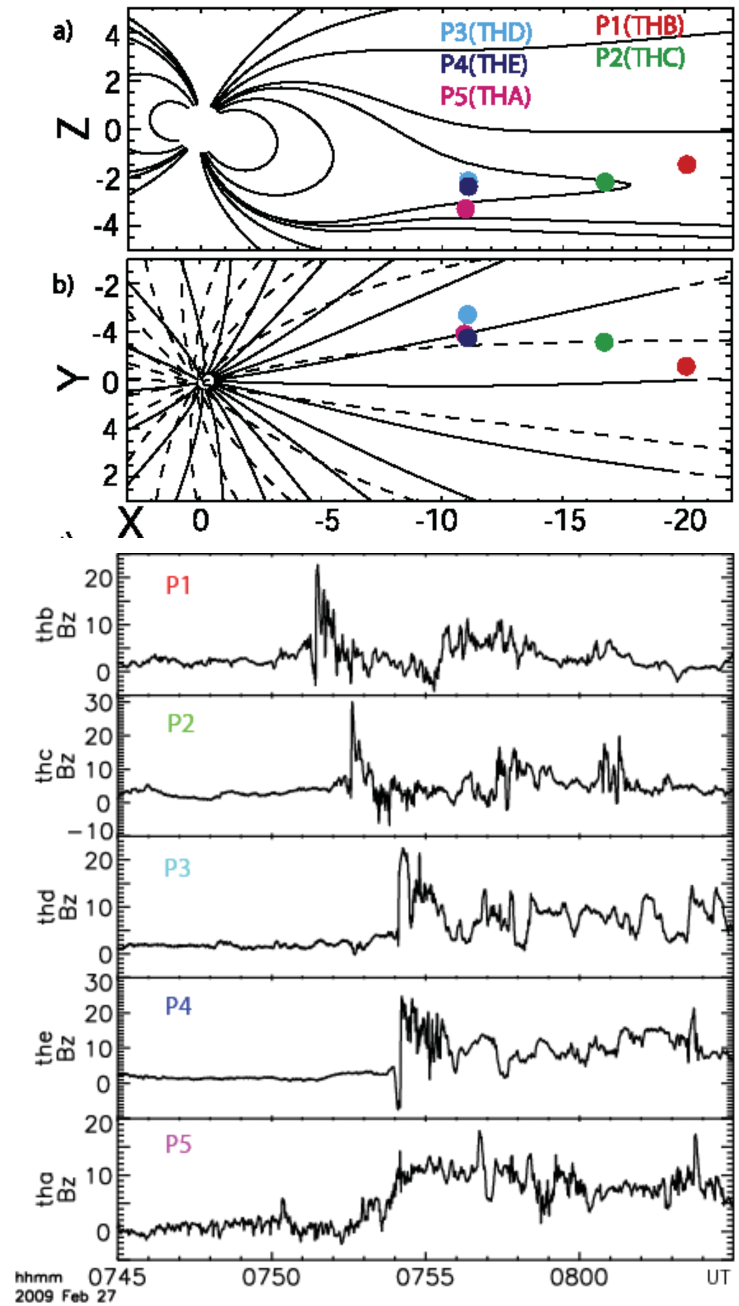
Dipolarization front observations

Runov et al. (2009)

THEMIS studies (e.g., Runov et al., 2009, 2011) showed that DFs couple active processes in the midtail with similar activity in its near-Earth region

Multi-probe high-resolution observations showed that DFs are microscopic structures (~1ρ_{0i}) that propagate over macroscopic distance (~10R_E).



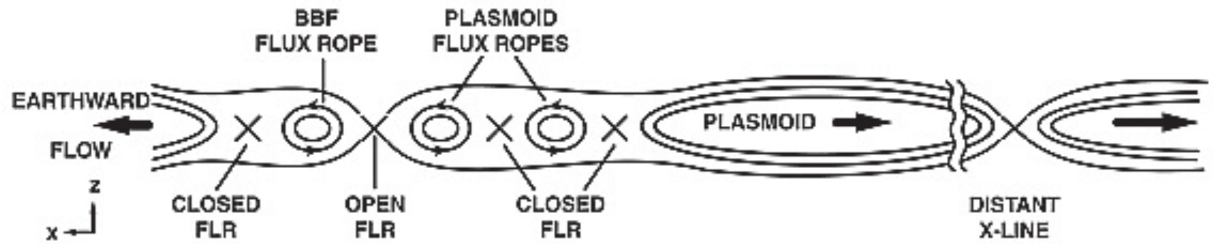


Dipolarization front simulations and interpretations

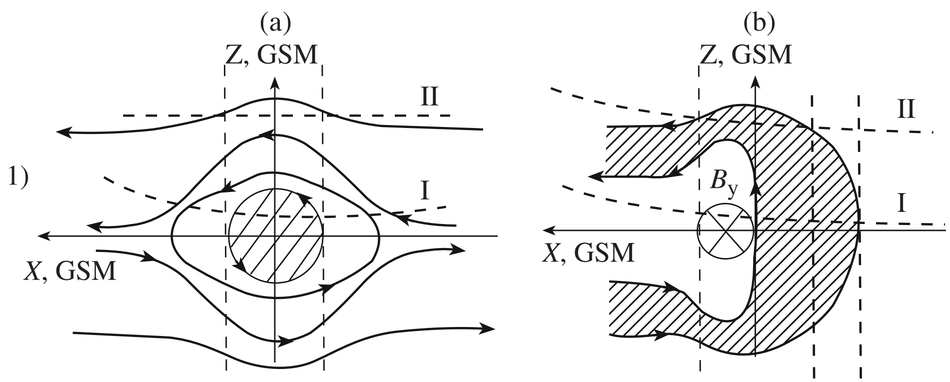
Understanding of the DF mechanism may be a key to understanding of substorms.

It may also help better understand more fundamental plasma physics processes such as magnetic reconnection.

Secondary plasmoids
(Slavin et al., 2003)



Nightside Flux Transfer Events (Sergeev et al., 1992; Sormakov and Sergeev, 2008; Semenov et al., 2005)

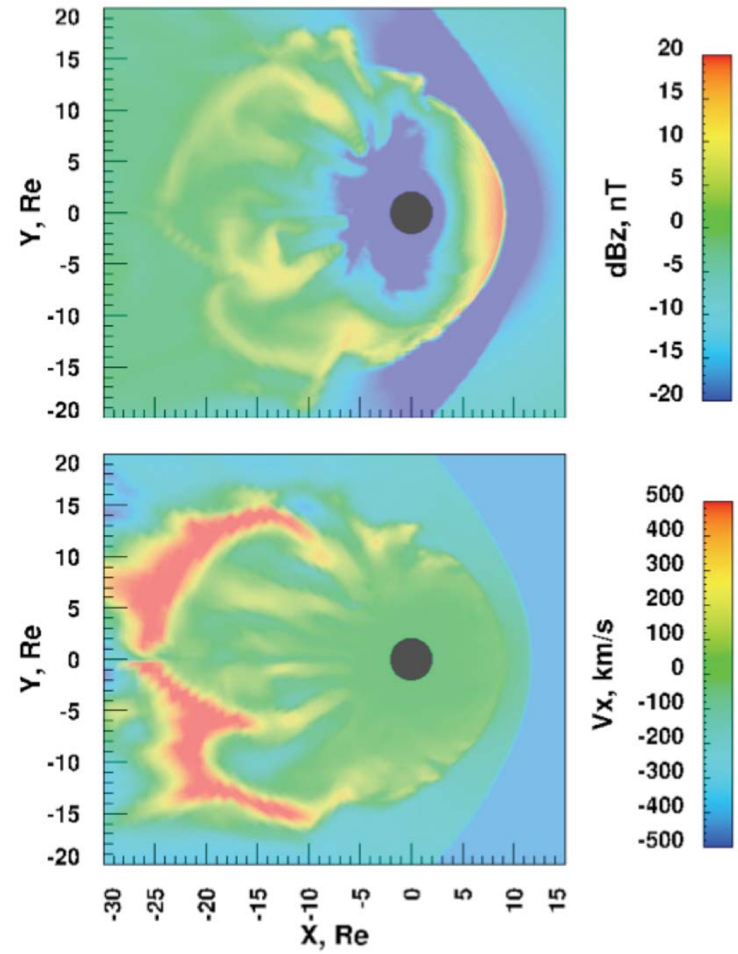


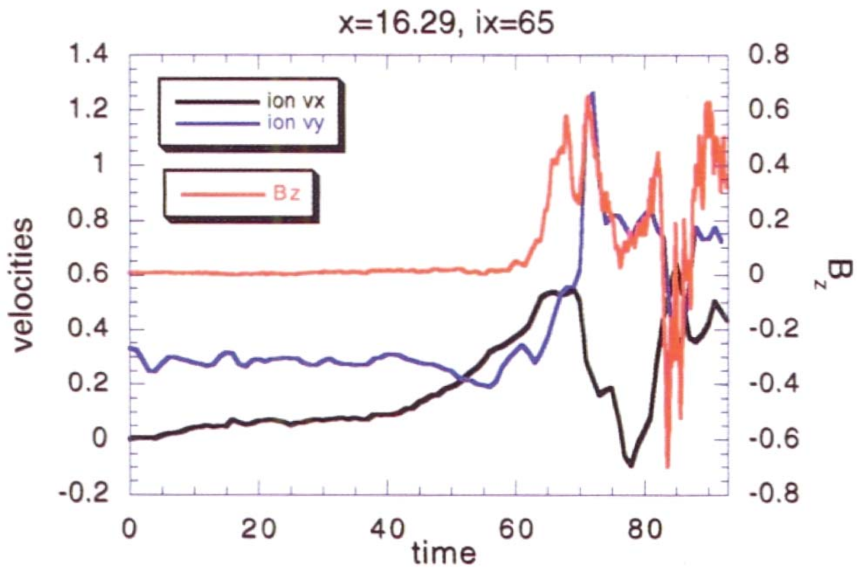
Plasmoid NFTE

Dipolarization front simulations and interpretations

DFs are reproduced in MHD and hybrid simulations of magnetic reconnection (Fujimoto et al., 1996; Hesse et al., 1998; Wiltberger et al., 2000; Nakamura et al., 2002; Krauss-Varban and Karimabadi, 2003; Ashour-Abdalla et al., 2010; Birn et al., 2011) when it is triggered by a localized resistivity

Merkin (2010)



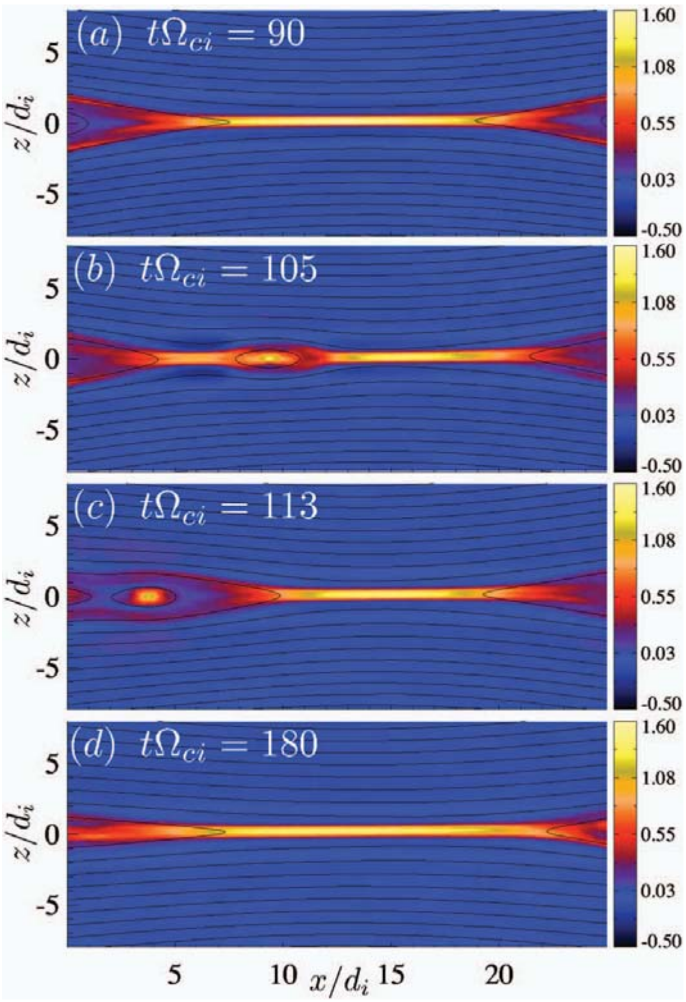


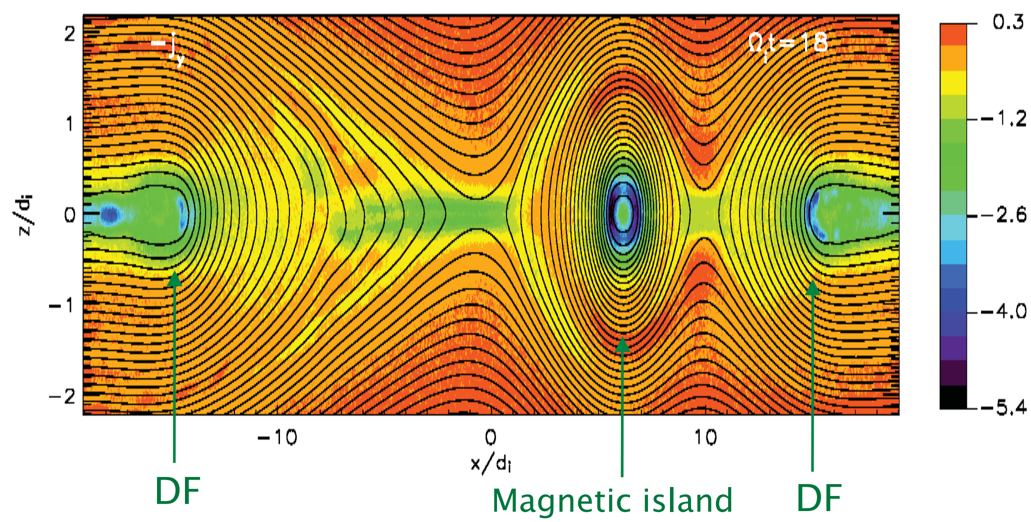
Hesse et al. (1998)

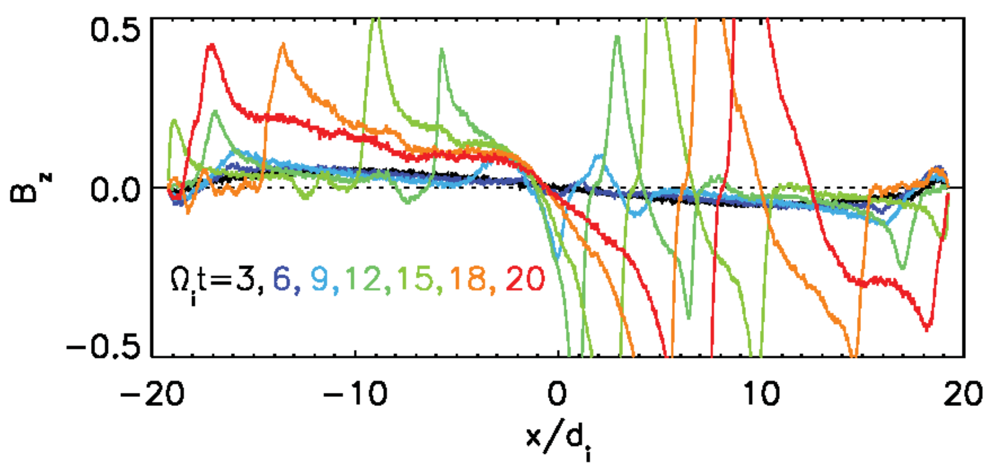
DFs are largely not seen in PIC simulations

Unsteady reconnection with secondary plasmoids (Daughton et al., 2006). Initial state: Perturbed 1D Harris equilibrium (GEM Reconnection Challenge (Birn et al., 2001)

Few exceptions: DFs are observed in 2D equilibria with external driving field strongly localized in X within few ion inertial lengths (Pritchett, 2005, 2010) and for relatively strong perturbations of 1D sheet (Sitnov et al., 2009)



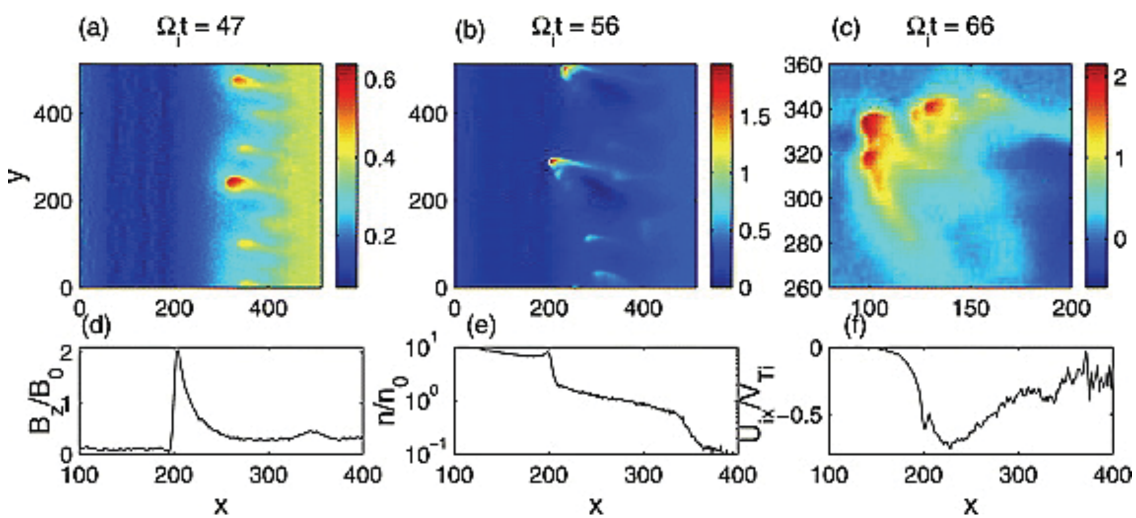


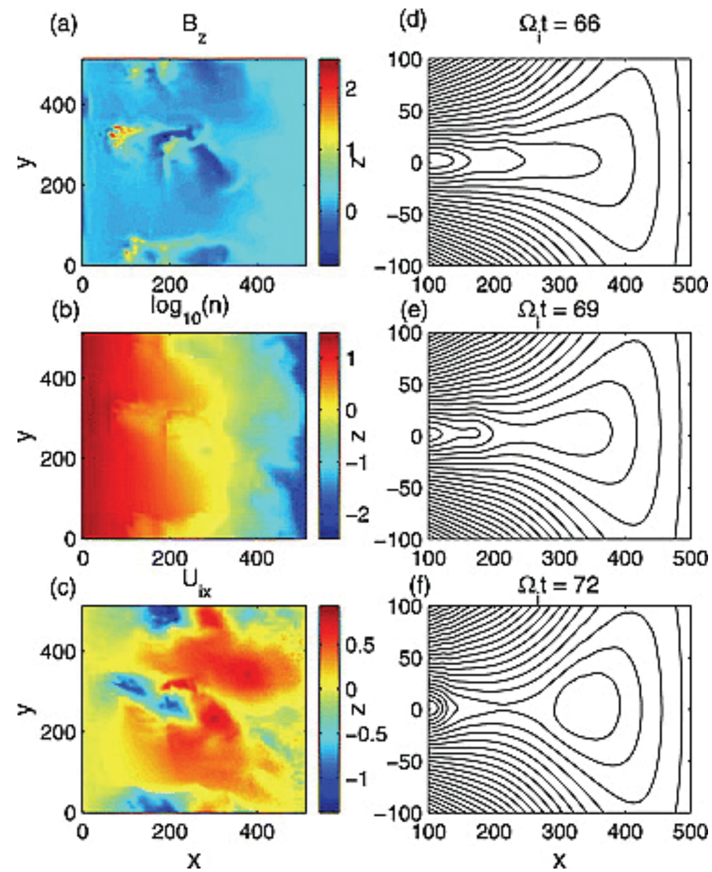


Dipolarization front simulations and interpretations

DF formation can be alternatively explained in terms of the ballooning-interchange instability (Zhu et al., 2009; Yang et al., 2011; Hu et al., 2011; Pritchett and Coroniti, 2011) where reconnection appears as its nonlinear consequence (bubble-blob pair formation)

Pritchett and Coroniti (2011): 3D full-particle simulations with closed X-boundaries



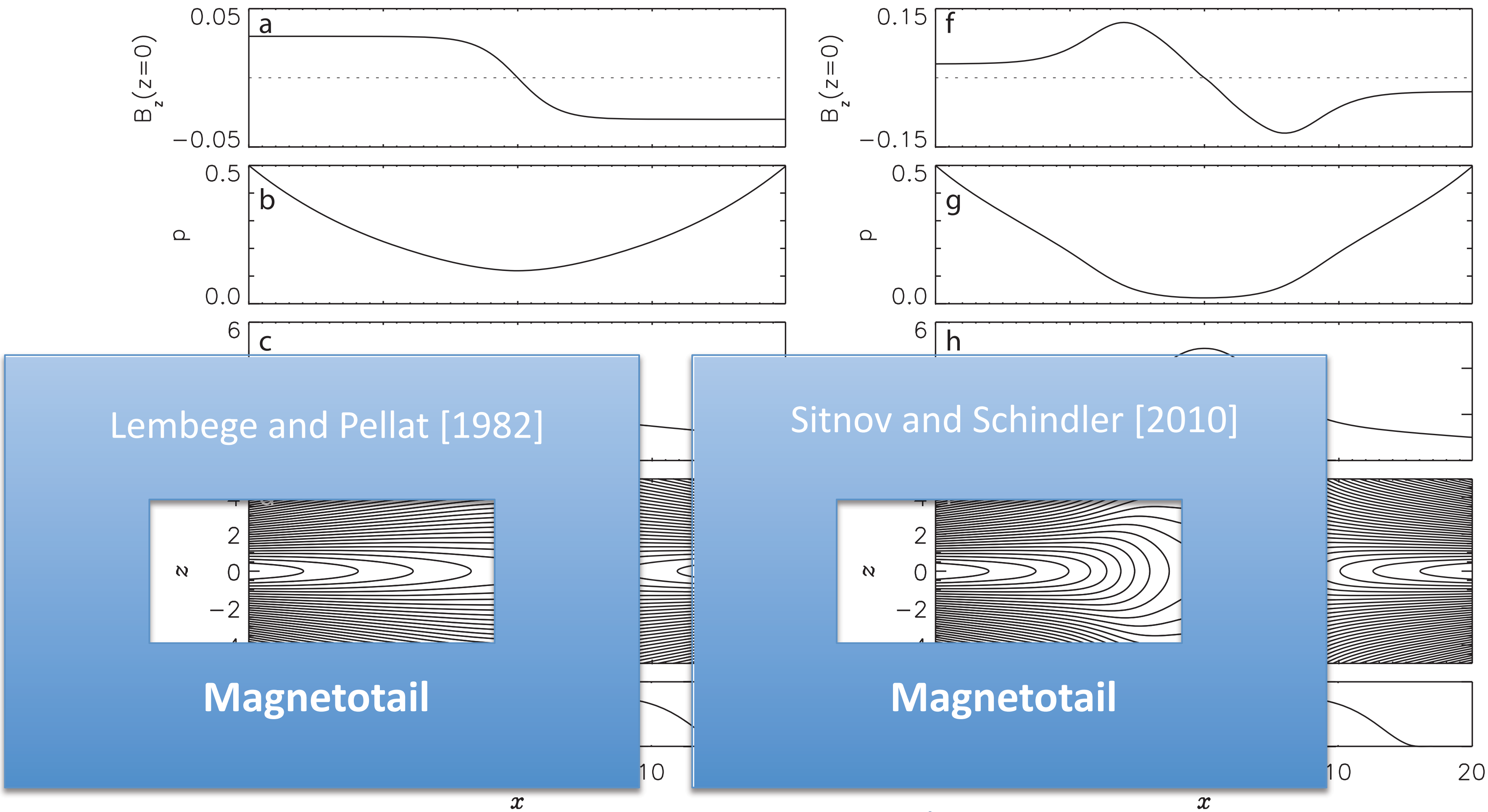


Dipolarization front simulations and interpretations

Can the DF formation be explained by the onset of spontaneous reconnection in the tail (tearing instability)?

X-line separating conventional tearing-stable magnetotail equilibria

X-line separating multiscale magnetotails that may be potentially tearing-unstable



With broadly distributed driving/convection electric field

Boundary conditions: Particles

Open boundaries are needed

- to allow the elongation and disruption of the electron diffusion region
- to avoid cutting the flux tube integral, which plays the key role in the tearing stability

$$\frac{\partial n^{(\alpha)}}{\partial x} = 0 \qquad \frac{\partial \mathbf{V}^{(\alpha)}}{\partial x} = 0 \qquad T^{(\alpha)} = T^{(\alpha)}(t=0), \quad \alpha = e,i$$

Contradicts force balance across the boundary for 2D equilibria

$$j_y B_z \neq 0$$

Additional particle injection:

$$\delta n^{(\alpha)} \propto (\partial/\partial x) n^{(\alpha)}(t=0)$$

Boundary conditions: Fields

Outflow (X)

$$\frac{\partial E_x}{\partial x} = 0 \qquad \frac{\partial E_y}{\partial x} = 0 \qquad E_z = 0 \qquad \frac{\partial B_x}{\partial x} = -\frac{\partial B_z}{\partial z} \qquad \frac{\partial B_y}{\partial x} = 0 \qquad B_z = B_z(t=0)$$

Provide free propagation of magnetic flux [Pritchett, 2001]

Inflow (Z) $\quad E_y^{(dr)} = 0.2$

Multiscale current sheet model

(Sitnov and Schindler, 2010)

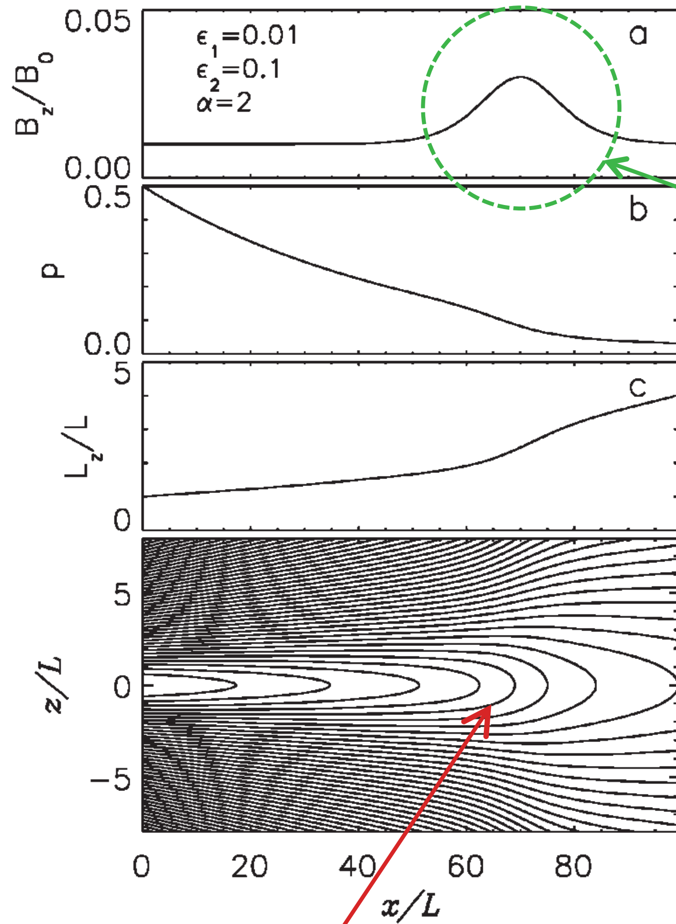
Lembege-Pellat tearing stability criterion

$$\frac{kL_z}{\pi b} > \left(\frac{VB_z}{\pi L_z}\right)^2 \equiv C_d^2$$

$$C_d > 1$$

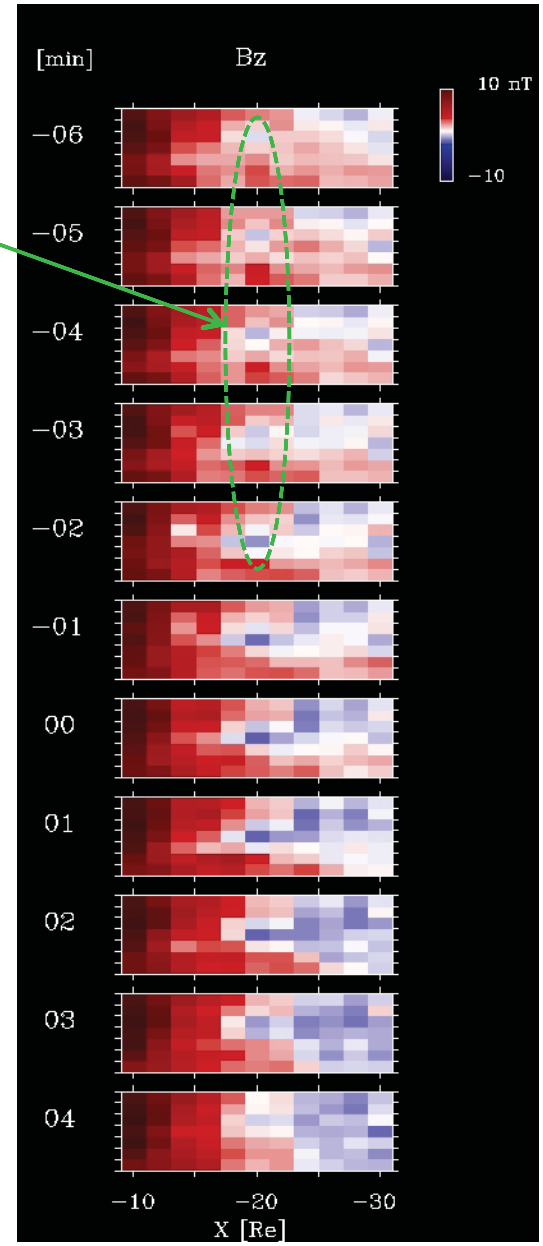
For current sheets with Bz increasing at the tailward end of the thin current sheet

- Potentially tearing unstable



flux accumulation region at the tailward end of the extended thin current sheet

Machida et al. [2009]

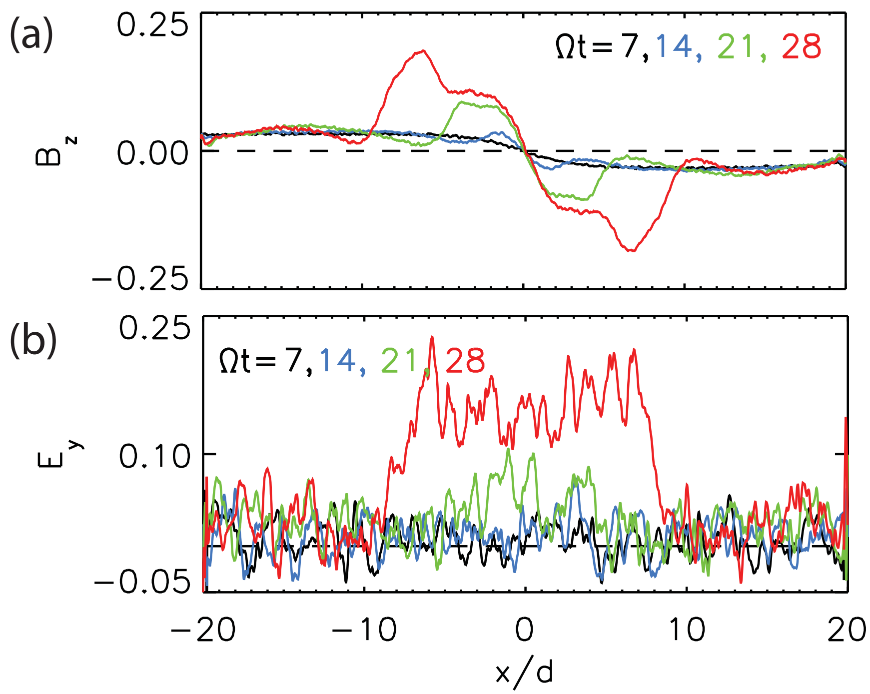


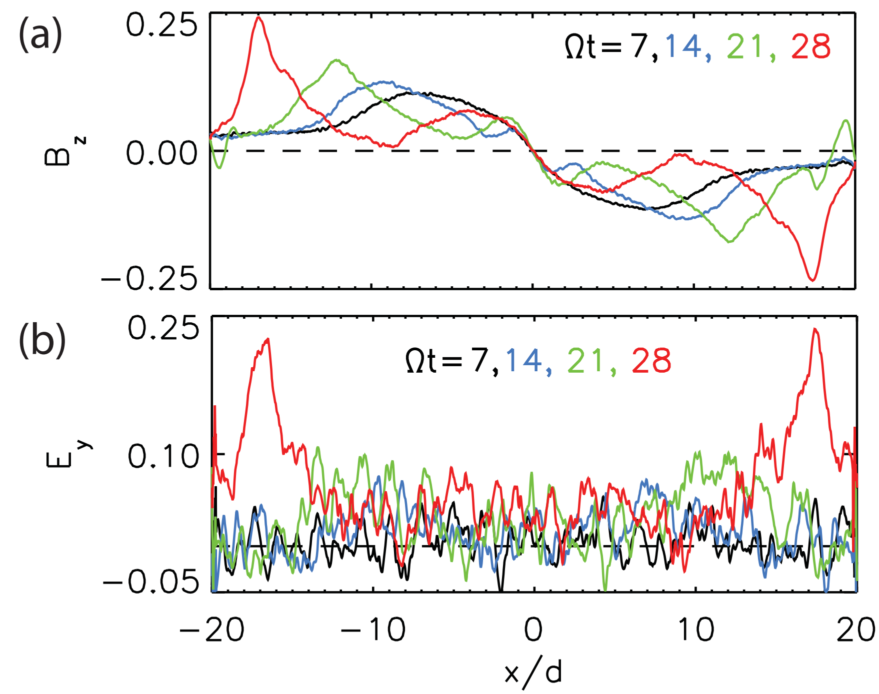
Two different reconnection stories

Lembege-Pellat tails

Multiscale tails

Normal magnetic field B_z inside the current sheet



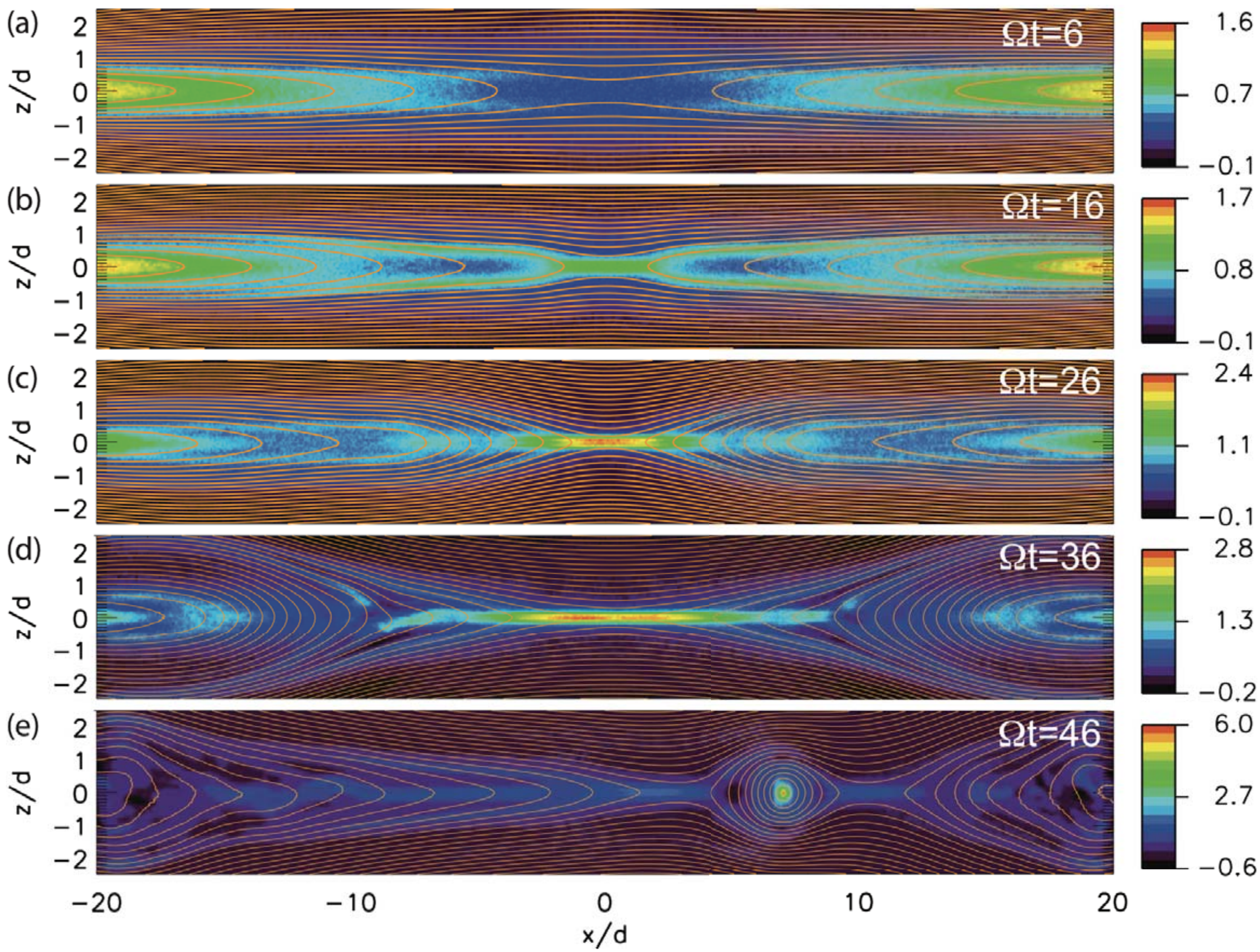


Reconnection electric field E_y inside the current sheet

$E_y^{(dr)}=0.2$

Reconnection onset with Lembege-Pellat magnetotails

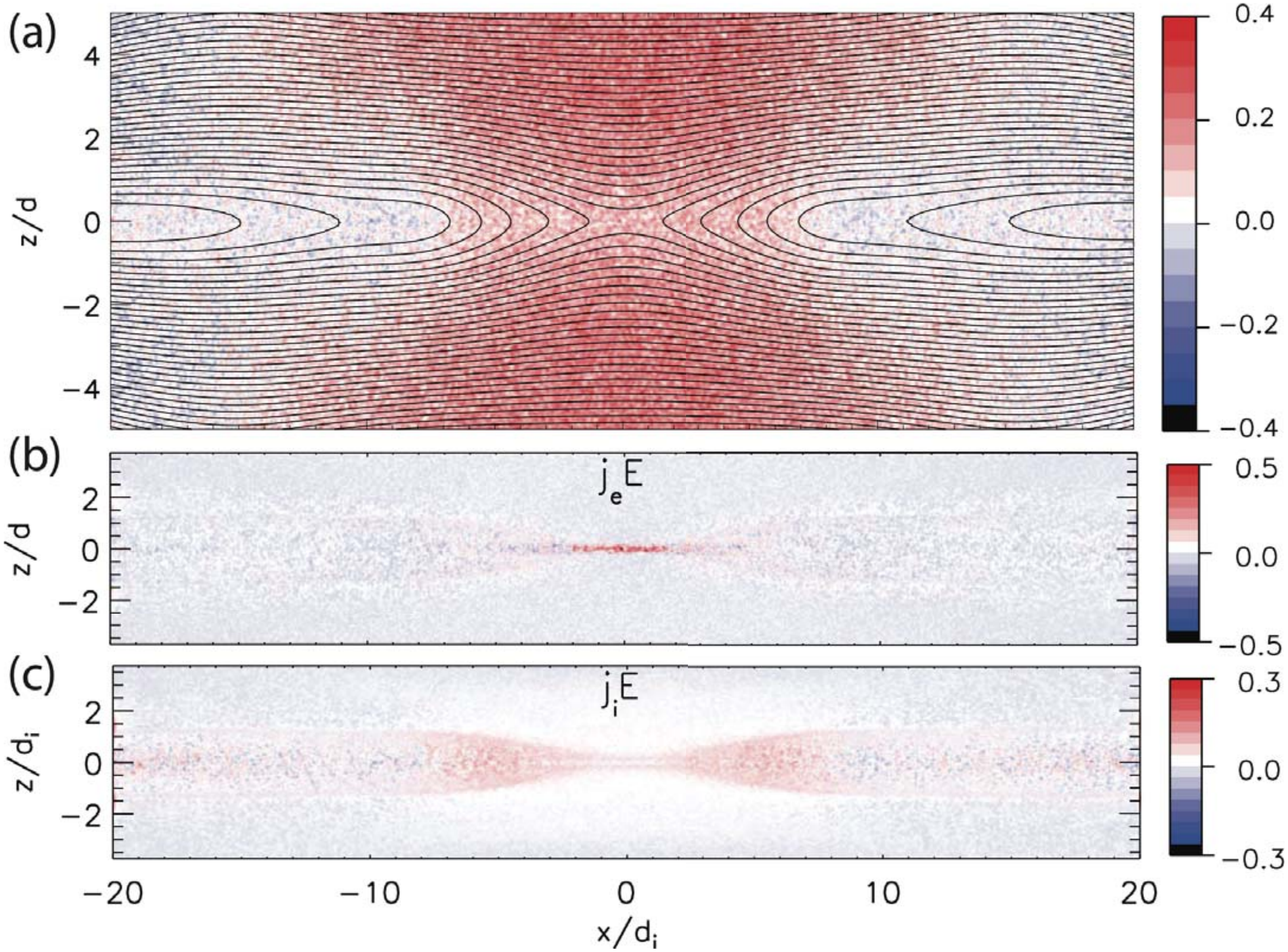
Total current density



$m_i/m_e=128$, $T_i/T_e=3$, $L=0.75\ c/\omega_{pi}$, $E_y^{(dr)}=0.2$

Reconnection onset with Lembege-Pellat magnetotails

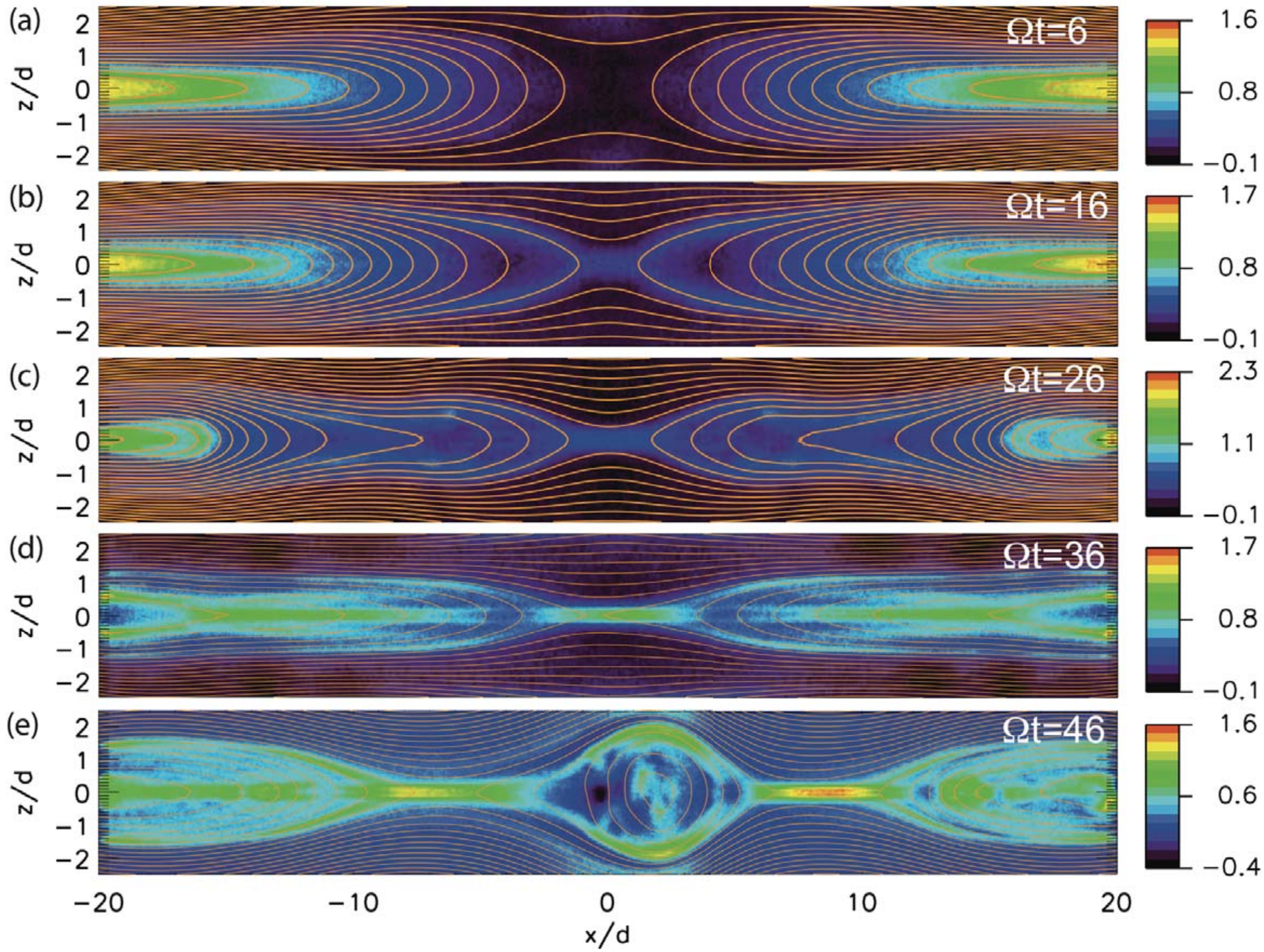
Electric field and energy dissipation



$E_y^{(dr)}$=0.2

Reconnection onset with multiscale magnetotails

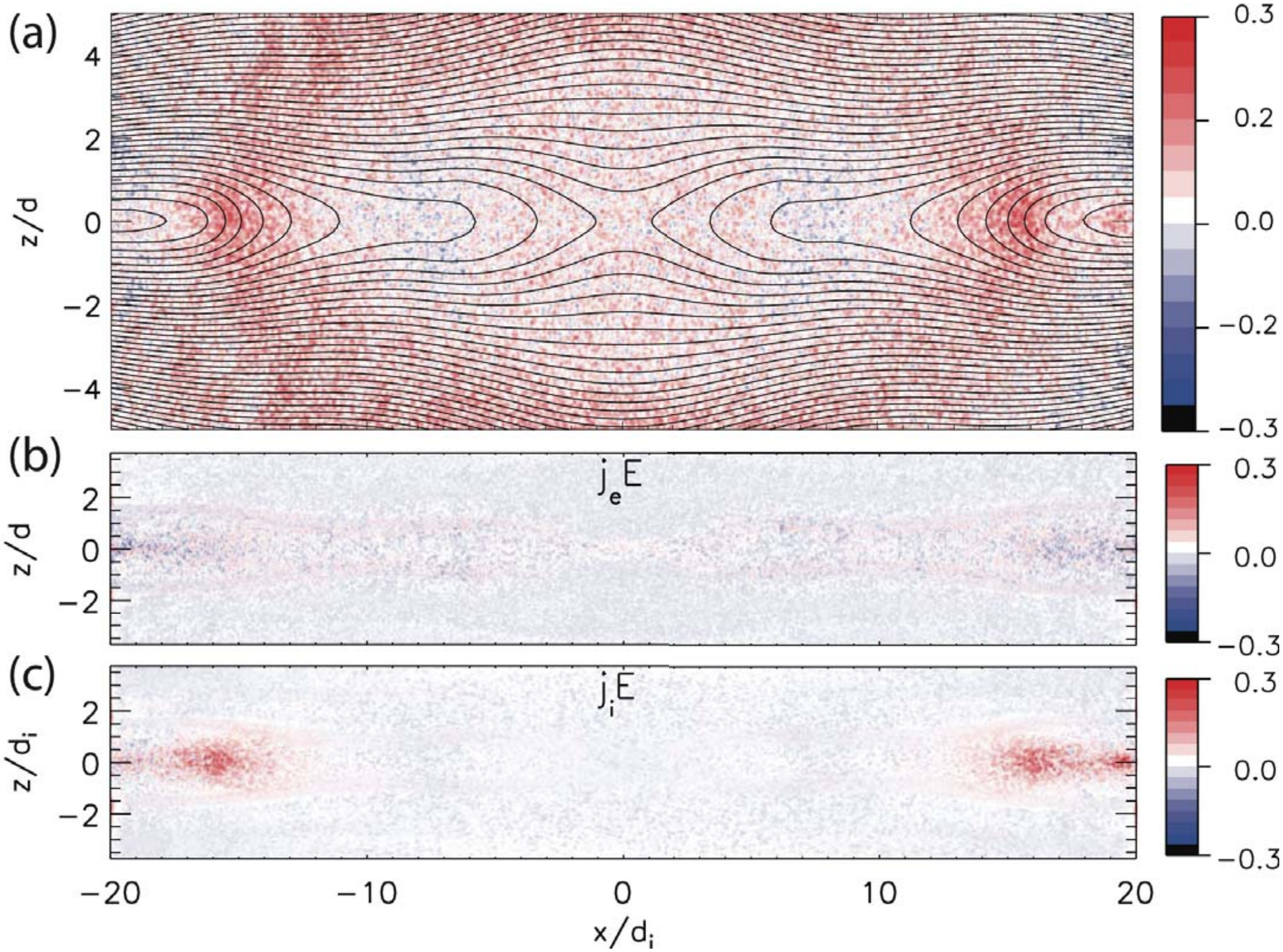
Total current density



$E_y^{(dr)}=0.2$

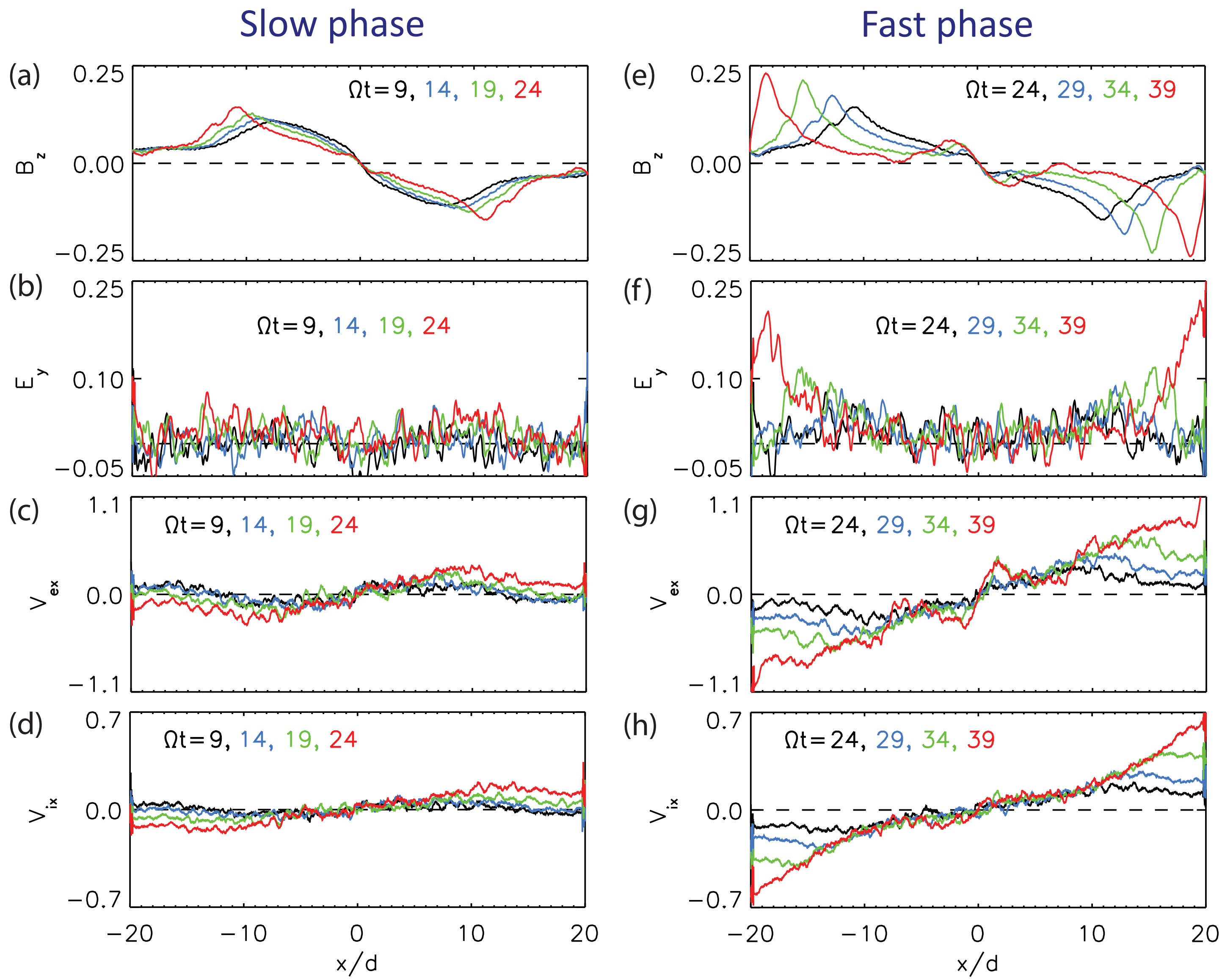
Reconnection onset with multiscale magnetotails

Electric field and energy dissipation



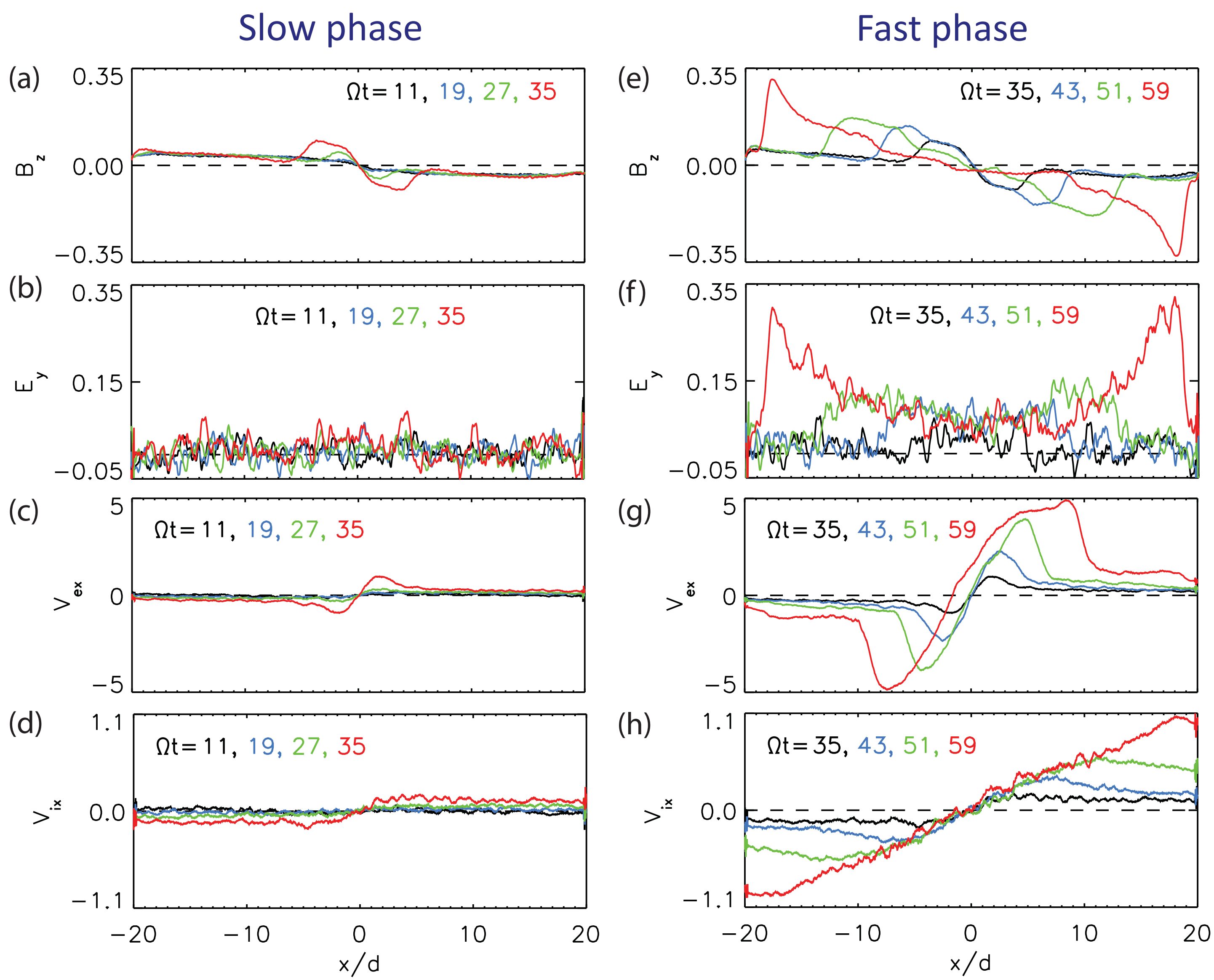
$E_y^{(dr)}$=0.2

Metastable current sheet evolution: Multiscale tails



Reduced driving electric field $E_y^{(dr)}$=0.05

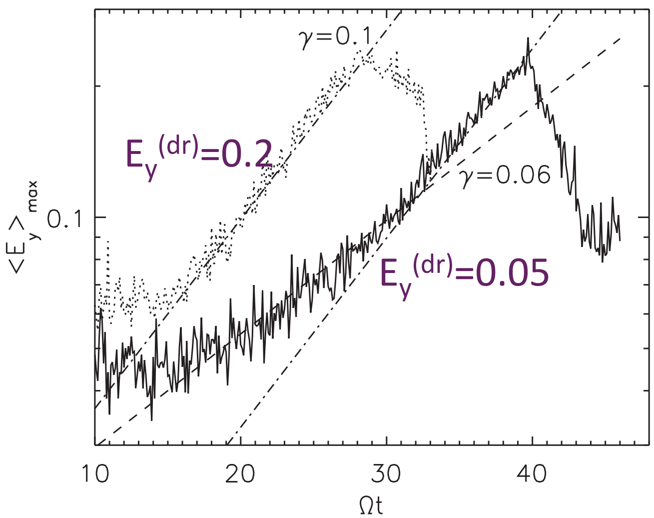
Metastable current sheet evolution: Lembege-Pellat tails



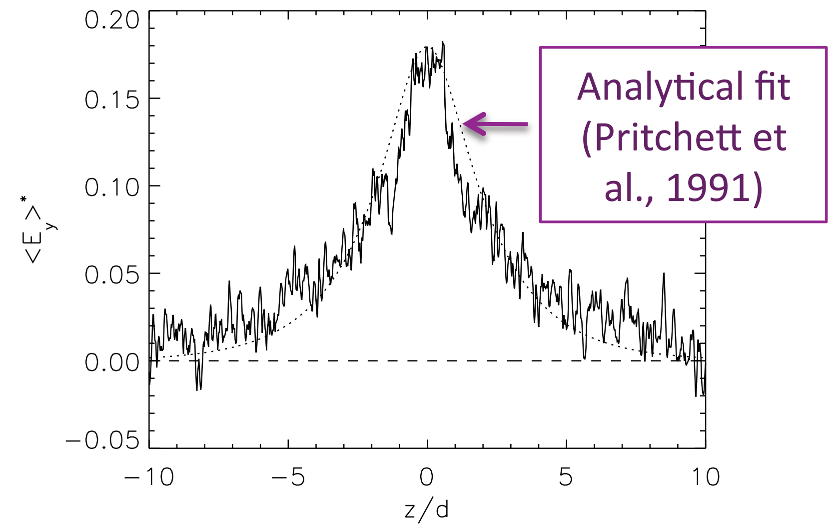
Reduced driving electric field $E_y^{(dr)}$=0.05

Transition from slow to fast phase: Is it caused by the ion tearing instability?

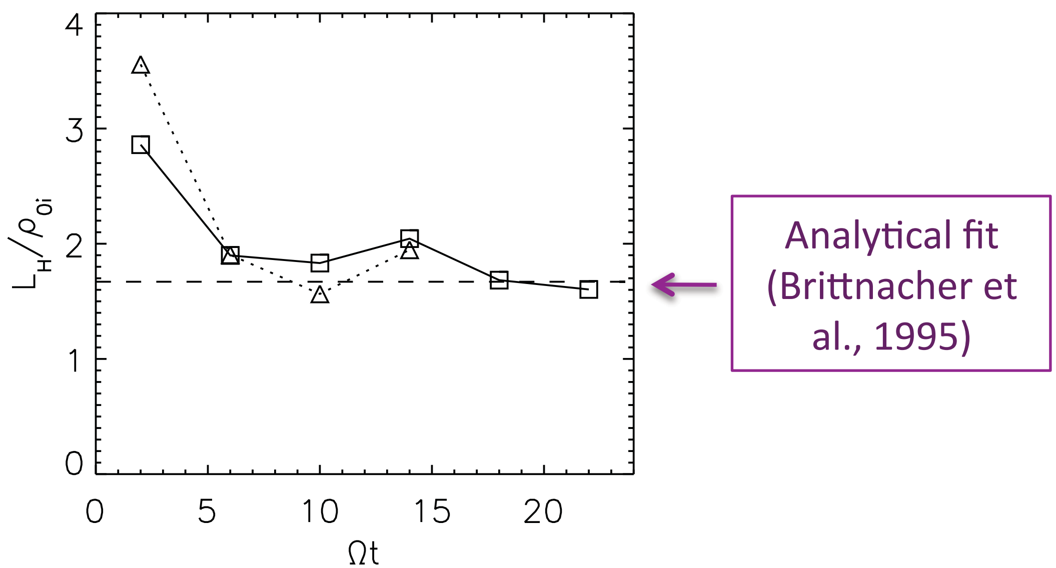
DF amplitude growth



DF electric field profile across the current sheet

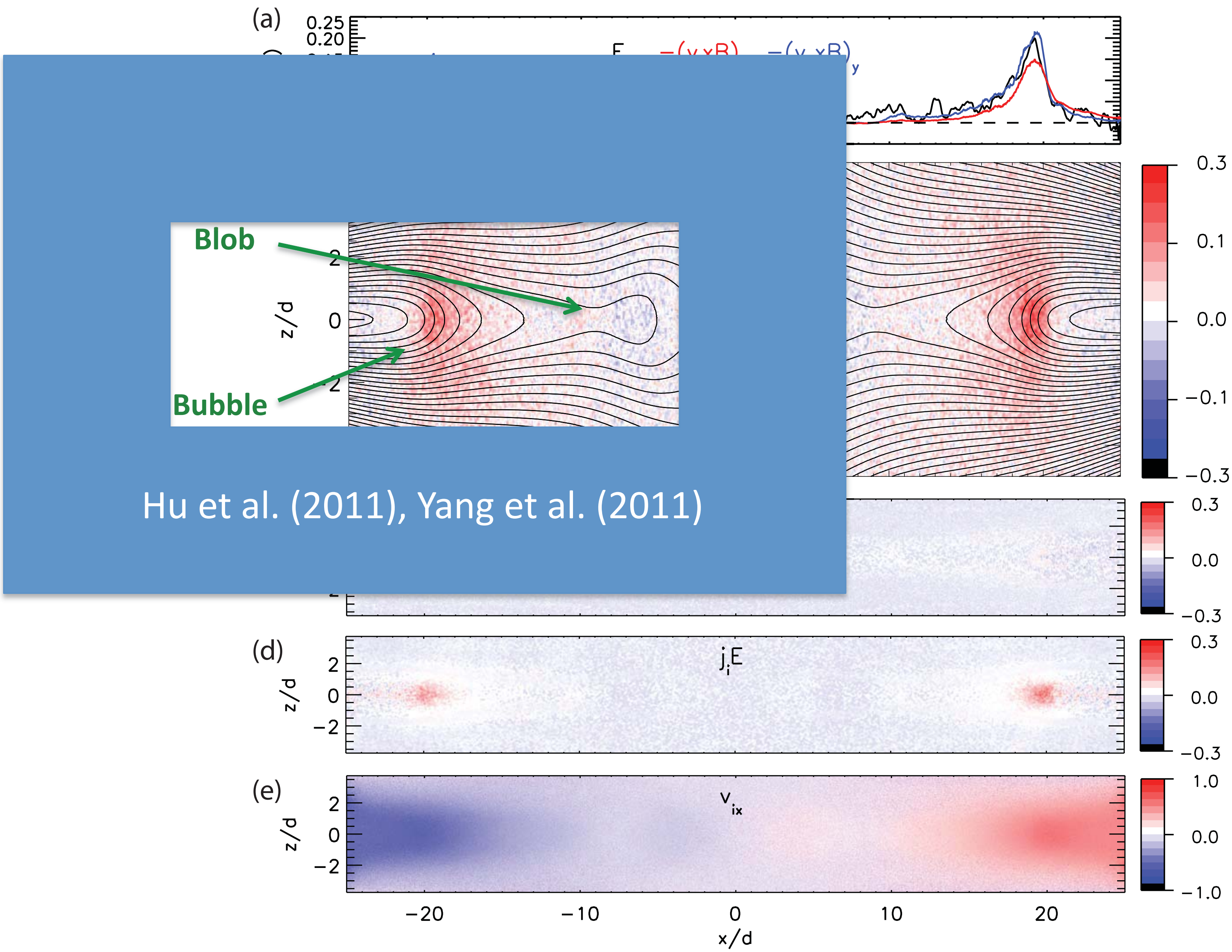


Critical current sheet thickness



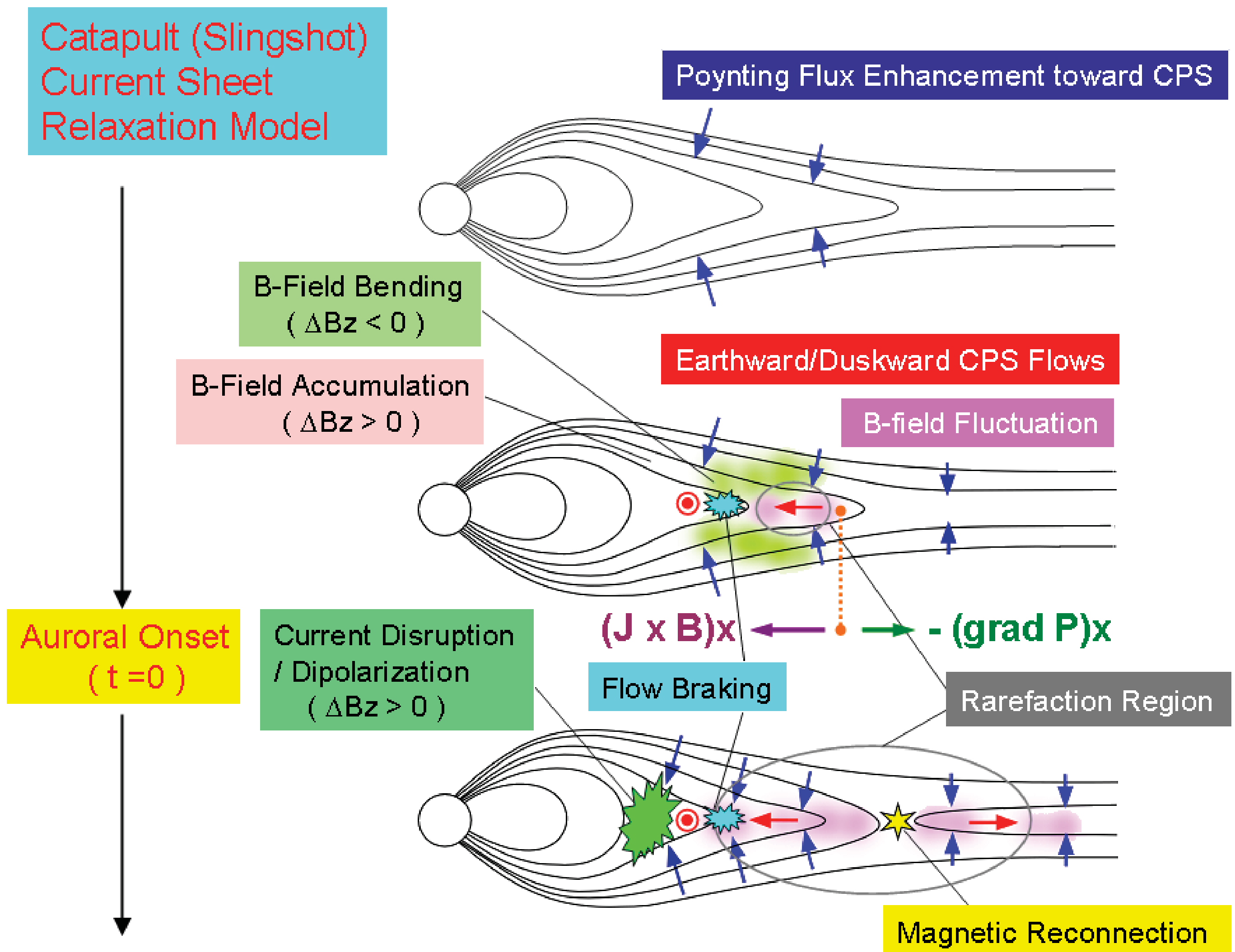
The onset process if consistent with the tearing stability theory

Bubble-blob formation



Hu et al. (2011), Yang et al. (2011)

Catapult current sheet relaxation substorm scenario [Machida et al., 2009]



Conclusion

- **Spontaneous reconnection is possible in the magnetotail and it may be a mechanism of substorms** (consistent with the outside-in scenario)

- **However the main distinctive feature of the magnetotail reconnection onset is the formation of DFs rather than a change of magnetic topology** (consistent with one of the main ideas of the current disruption theory)

- **New X-lines and their EDRs may form consistent with the bubble-blob pair mechanism** (before and after the formation of DFs)