Progress on 2D Anomalous Magnetic Reconnection

Leonid Malyshkin, Timur Linde and Russell Kulsrud

August 4, 2004, Madison WI

Theoretical Background

Magnetic resistivity is enhanced by onset of plasma instabilities:

$$\eta(j) = \eta_0 + \eta_\star \max\{j - j_{crit}, 0\}/j_{crit}.$$

Russell Kulsrud's reconnection model (Kulsrud, 2000):

- Anomalous Sweet-Parker reconnection:

$$L' = L, \qquad V_R L = V_A \delta, \qquad \eta j_0 = V_R B_0 \Rightarrow \eta(j_0)\, j_0^2 = V_A B_0^2/L.$$

- Anomalous "Petschek" reconnection

$$\delta << L' << L, \qquad \delta = B_0/j_c, \qquad V_R L' = V_A \delta, \qquad V_R = \eta(j_0)/\delta,$$

$$\frac{dB_x}{dt} = \frac{V_R - V_R'}{L'} B_0 - \frac{V_A}{L'} B_x = 0 \Rightarrow B_x = -\frac{B_0^2 \eta_\star}{\delta^2 V_A j_c} \frac{L'^2}{L^2}, \qquad V_R = \frac{|B_x|}{\sqrt{4\pi\rho}},$$

$$\frac{V_R}{V_A} = \left(\frac{B_0}{L j_{crit}} \frac{\eta_\star}{L V_A} \right)^{1/3}$$

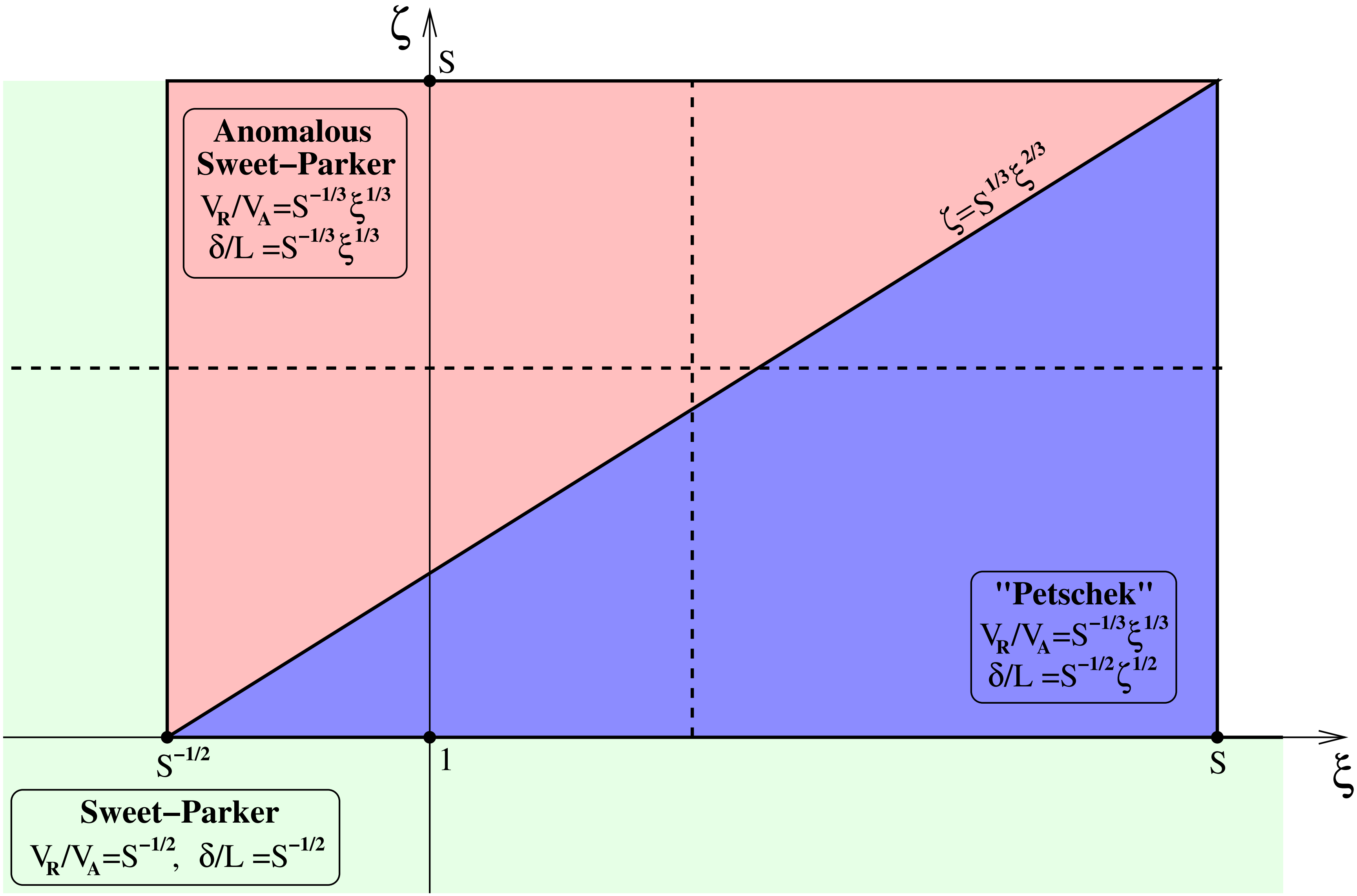


Figure 1: $S \equiv LV_A/\eta_0 >> 1$, $\zeta \equiv SB_0^2/L^2 j_{crit}^2$ and $\xi \equiv SB_0\eta_\star/V_A L^2 j_{crit}$.

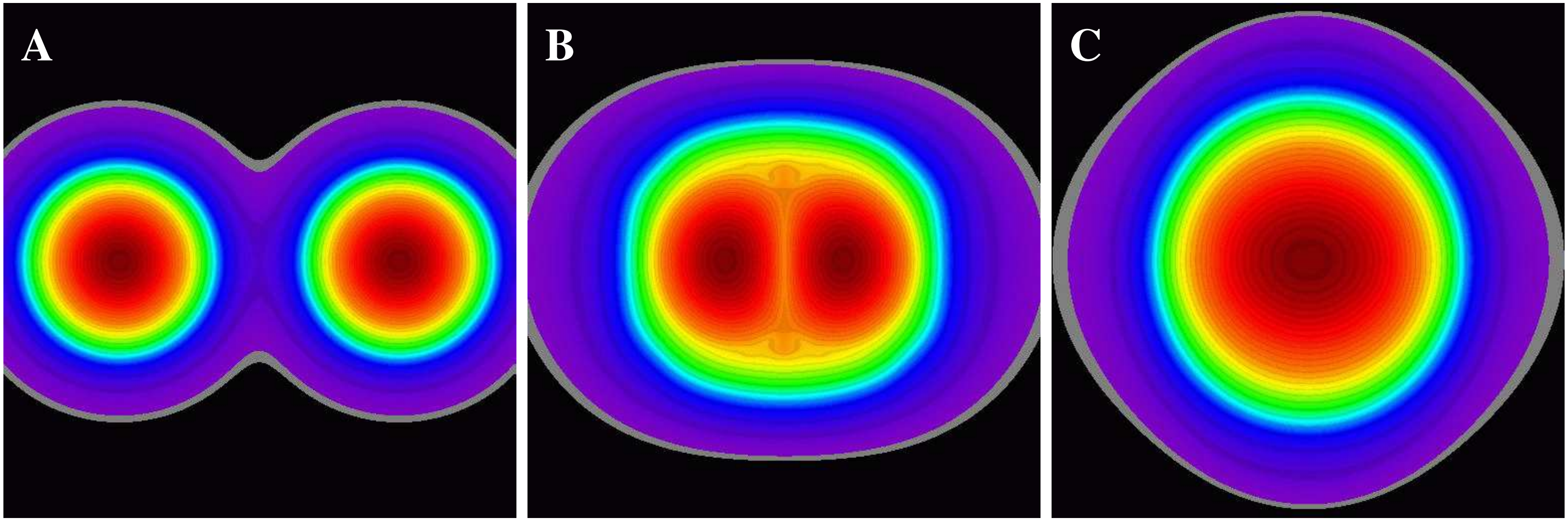
Simulation Setup

Two flux tubes $\Psi = \Psi_0 \left[\exp\left(-r_+^2/2\sigma^2\right) + \exp\left(-r_-^2/2\sigma^2\right)\right]$,

$$r_\pm^2 = (x \mp d)^2 + y^2.$$

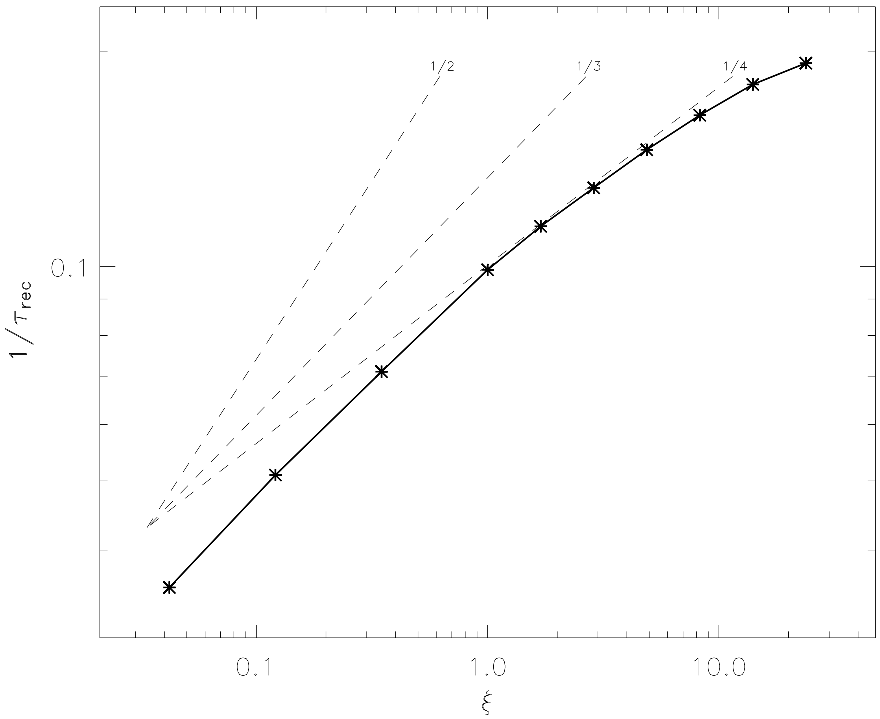
Parameters: $\sigma = L = 1.0$, $d = 2.7162$ (5% of initially reconnected flux), $\max\{B\} = B_0 = 1.0$ ($\Psi_0 = B_0 \sigma \sqrt{e}$), $\rho = 1$ and $B_z = 0$.

FLASH adaptive mesh: zero field boundary conditions at $x, y = \pm 25$.



Results

For moderate Lundquist numbers, $S \lesssim 10^4$, confirm Kulsrud's model.



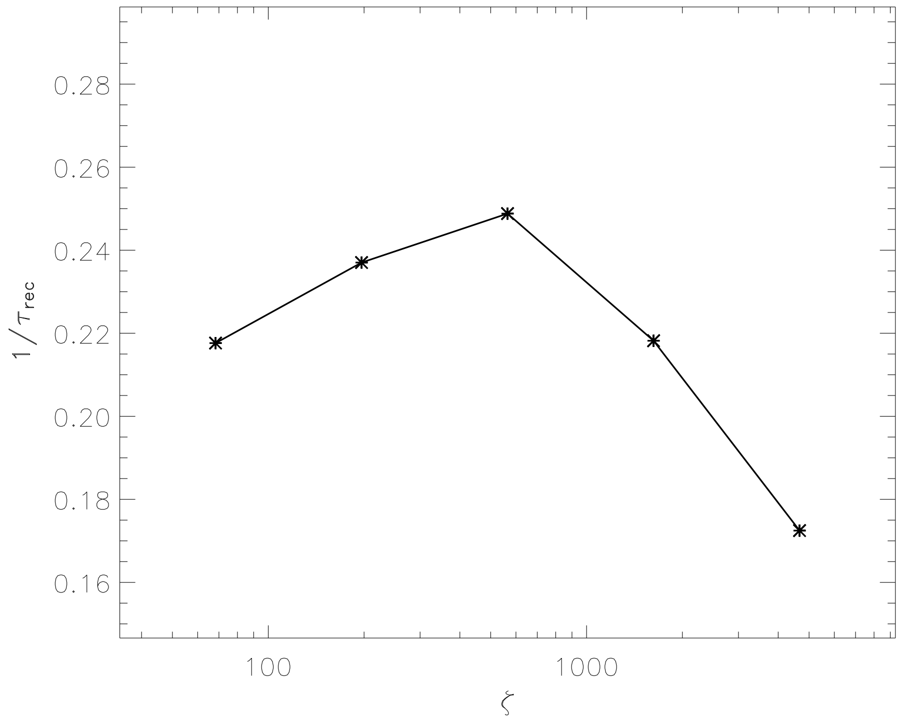


Figure 2: $S \sim 1.3 \times 10^4$. LEFT: fixed $\zeta = S^{5/9}$. RIGHT: fixed $\xi = S^{1/3}$.

For high Lundquist numbers, $S \gtrsim 10^4$, tearing-mode instability destroys the reconnection layer, resulting in reconnection over resistive time scale.

Future Work

- Finish studies of dependence of reconnection time and **reconnection layer thickness $\boldsymbol{\delta}$** on parameters ξ and ζ, i.e. on $\eta_\star/j_{crit}$ and j_{crit}.
- Possible refined theoretical model for the reconnection layer:

$$\partial/\partial z \equiv 0 \;\Rightarrow\; (\partial A/\partial t) = -V_\alpha(\partial A/\partial x_\alpha) - \eta(j)j = -E_z$$

$$t_A/t_{rec} << 1 \;\Rightarrow\; \text{const} \approx E_z = \eta j - V_x B_y + V_y B_x \approx \eta j(x) - V_x(x)B_y(x)$$

$$V_x \approx -\alpha x \;\Rightarrow\; \eta(j)\frac{dB_y}{dx} + \alpha x B_y(x) = -\eta_0 j_0.$$

This differential equation depends on α and a single parameter that is combination of $\eta_\star$ and j_{crit}.

For example, if $\eta_\star = 0$, then we have Sweet-Parker and $\alpha = V_A/L$, $t_{rec}^{-1} = 1.31\, t_A^{-1} S^{-1/2}$.