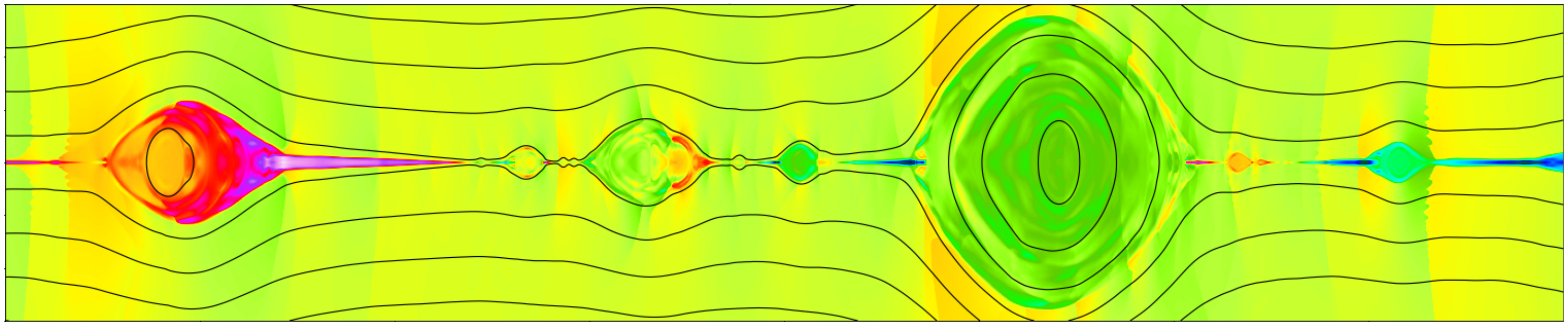

Plasmoid-dominated turbulent reconnection in a low-β plasma

[*Astrophys. J. Lett.*, 894, L7 (2020)]

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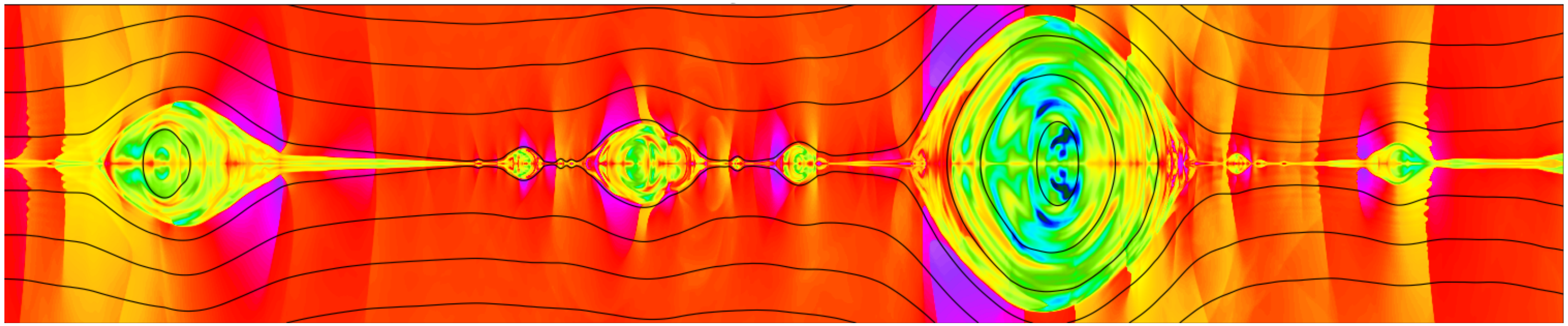
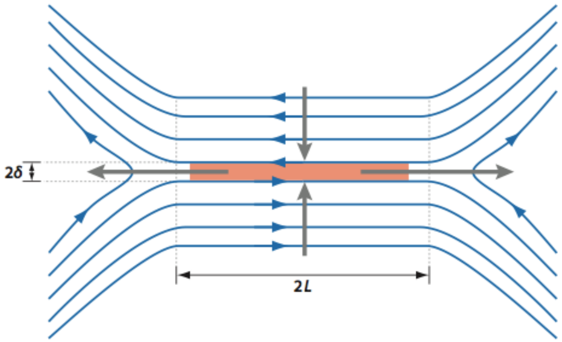
Takahiro MIYOSHI (Hiroshima U, Japan)



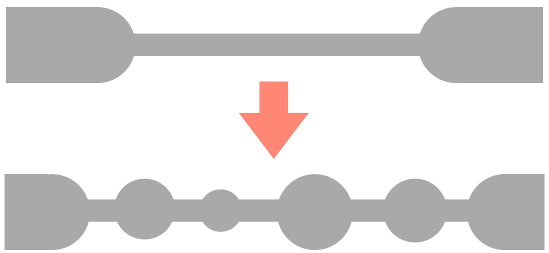
MHD models of magnetic reconnection

Sweet-Parker



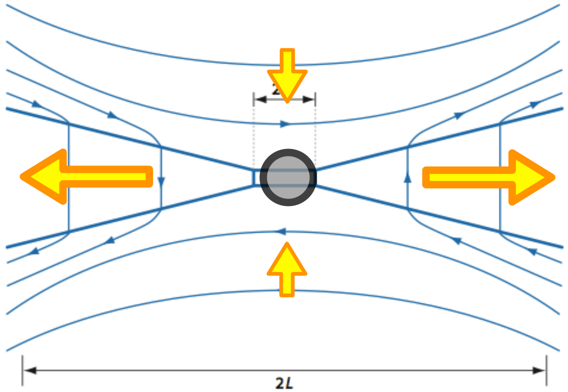
Sweet 1958, Parker 1957

plasmoid-dominated



Loureiro 2007, Bhattacharjee+ 2009
Uzdensky+ 2010, Pucci+ 2014

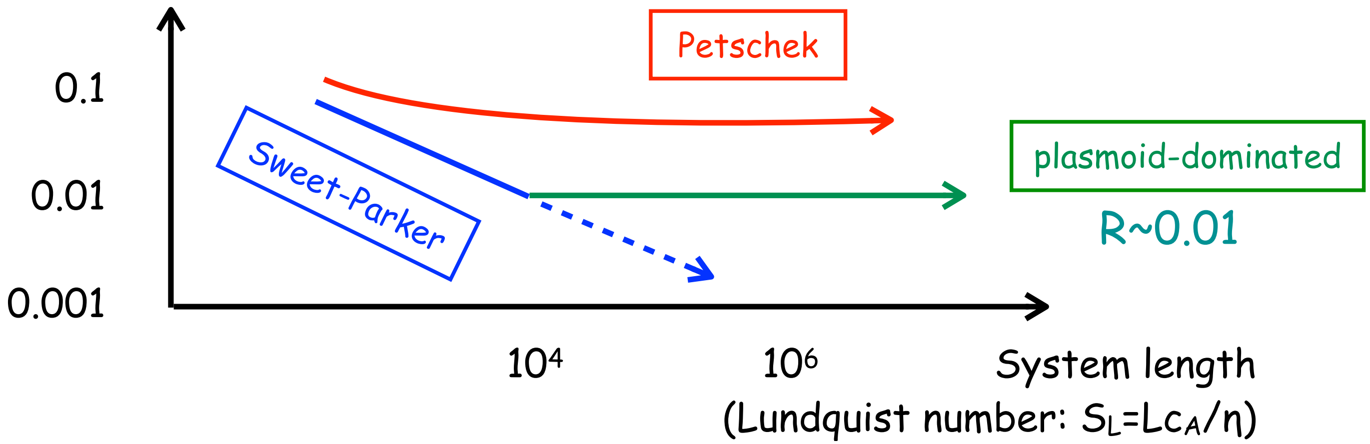
Petschek



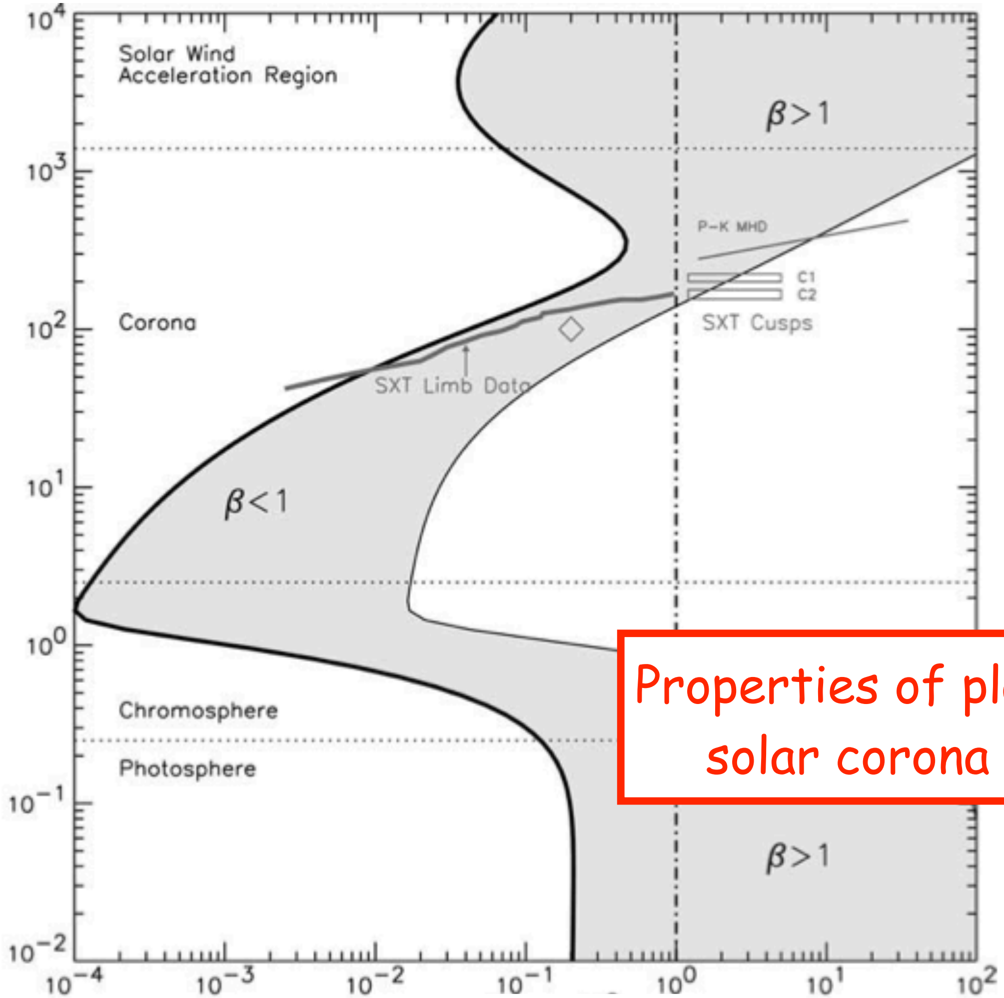
Petschek 1964

Reconnection rate

$$\mathcal{R} \equiv \frac{v_{in}}{c_A}$$



Solar corona: β<<1



Height

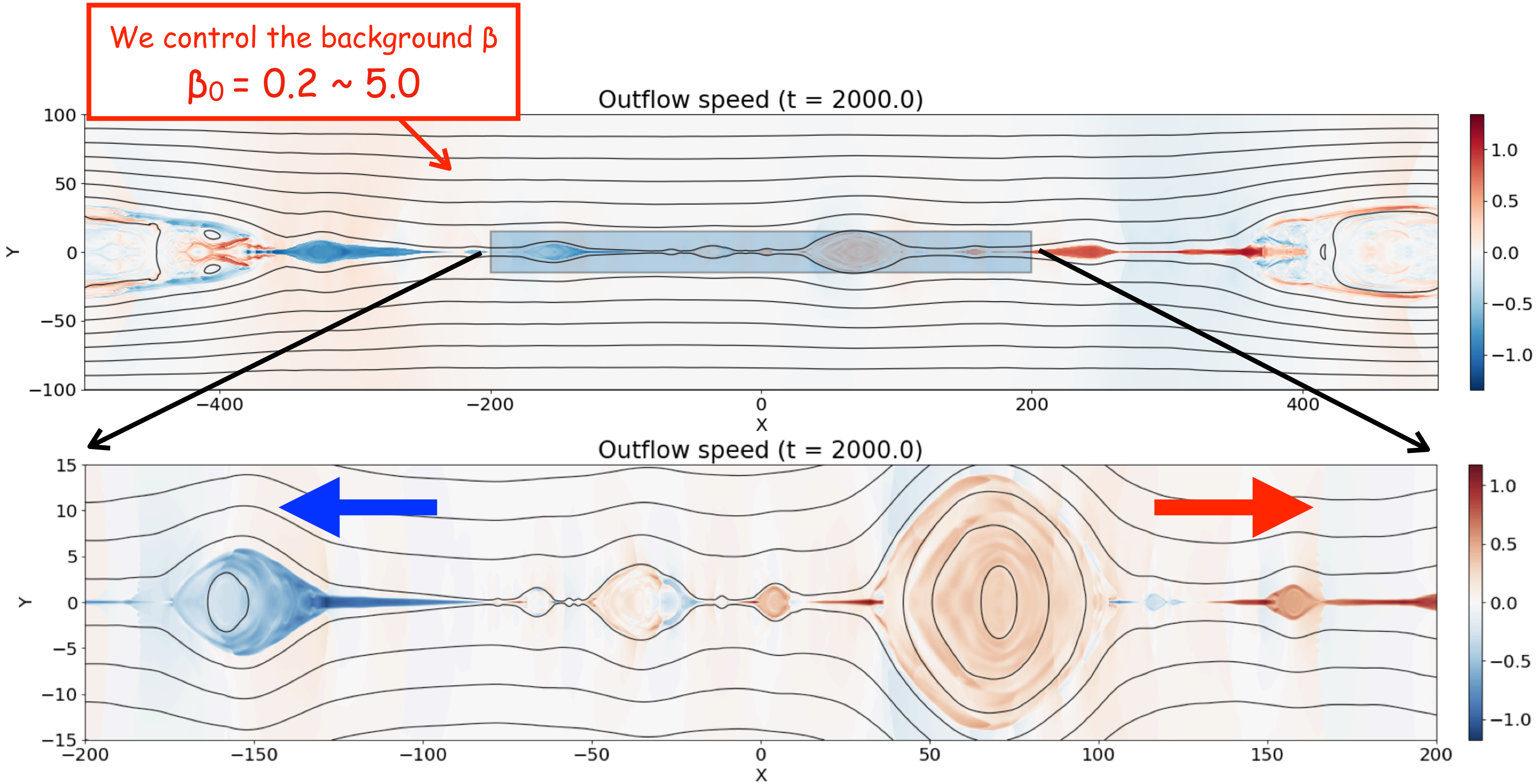
Plasma beta $\beta \equiv \frac{p_{\rm gas}}{p_{\rm mag}}$

Gary 2001

Properties of plasmoid-reconnection in a solar corona (β<<1) is largely unknown.

MHD simulation

MHD simulation

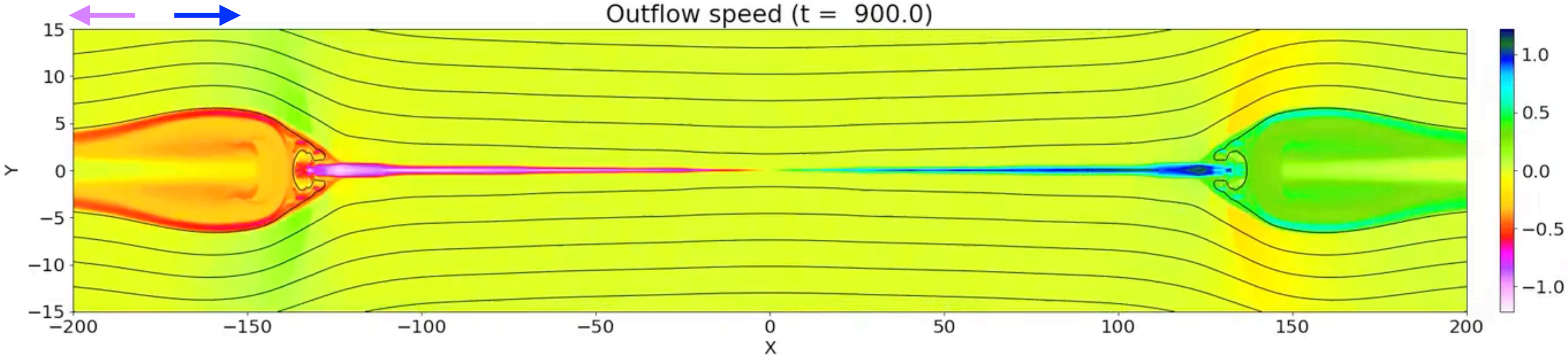


- η = 1/1000, S_L = 2.5 x 10^5 for L_{cs} = 250
- 30,000 x 3,000 (x 2) grid points
- 500 cores on a supercomputer or 1 GPU (NVIDIA A100)

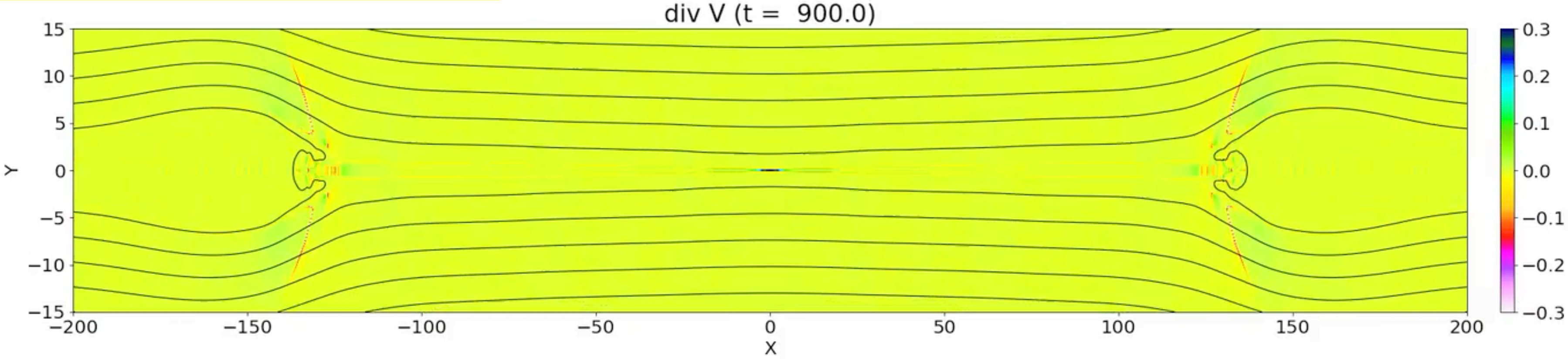
Simulation results (Movies)

- https://sci.nao.ac.jp/MEMBER/zenitani/files/b02_outflowB.mp4
- https://sci.nao.ac.jp/MEMBER/zenitani/files/b02_divvB.mp4

Outflow speed (V_x)



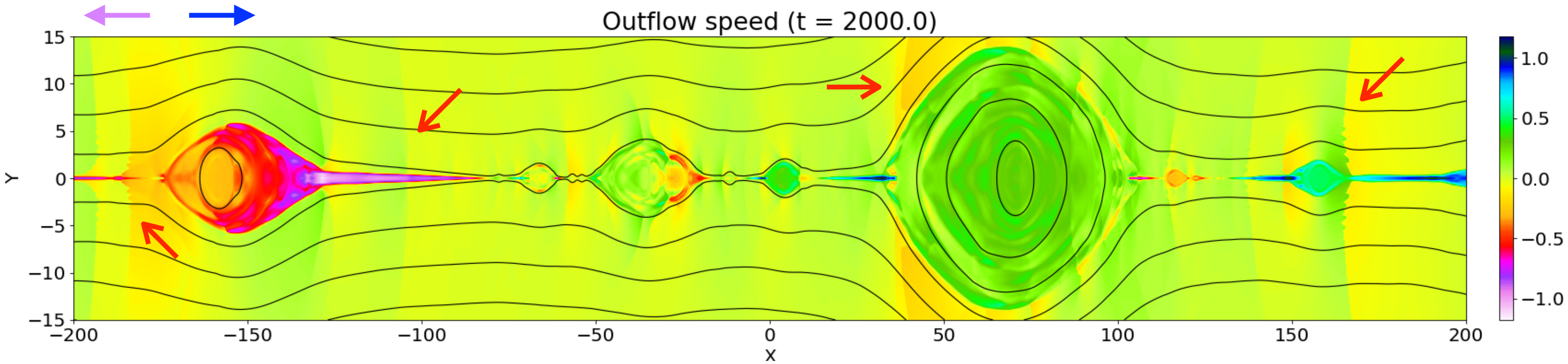
div V - Compression in red



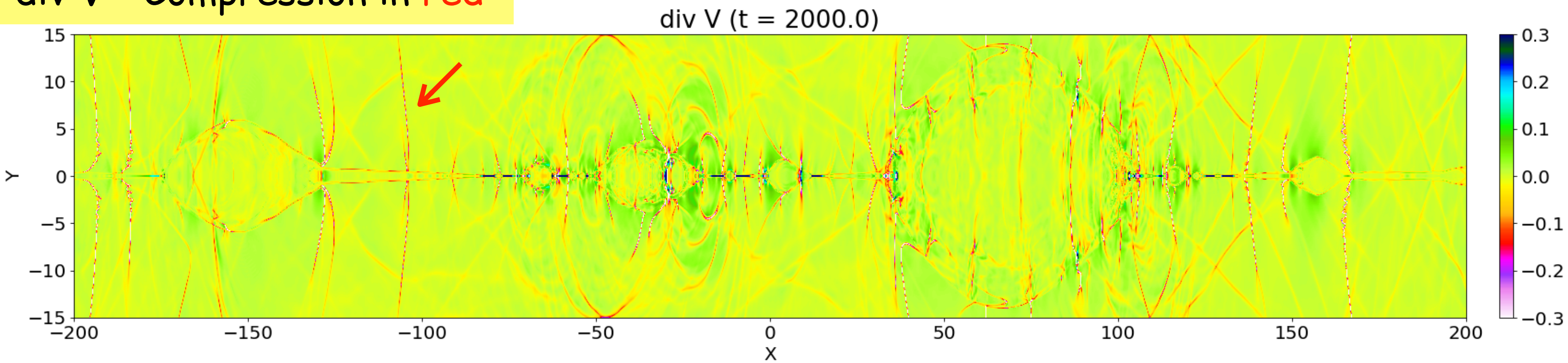
Normal slow shocks

- They travel in the left and right directions, even inside the plasmoids
- Potential particle scatterer/reflector?

Outflow speed (V_x)

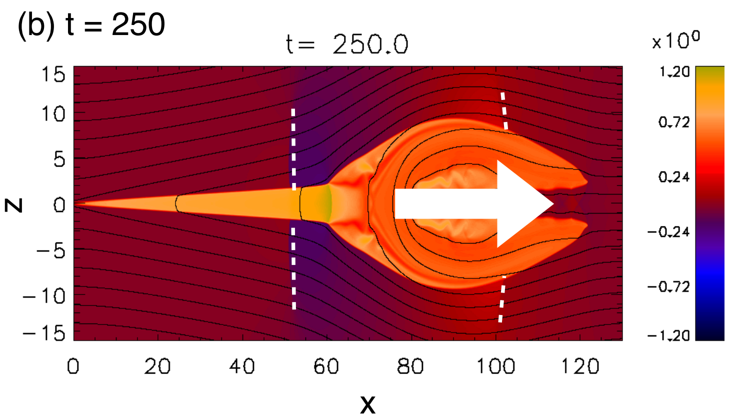


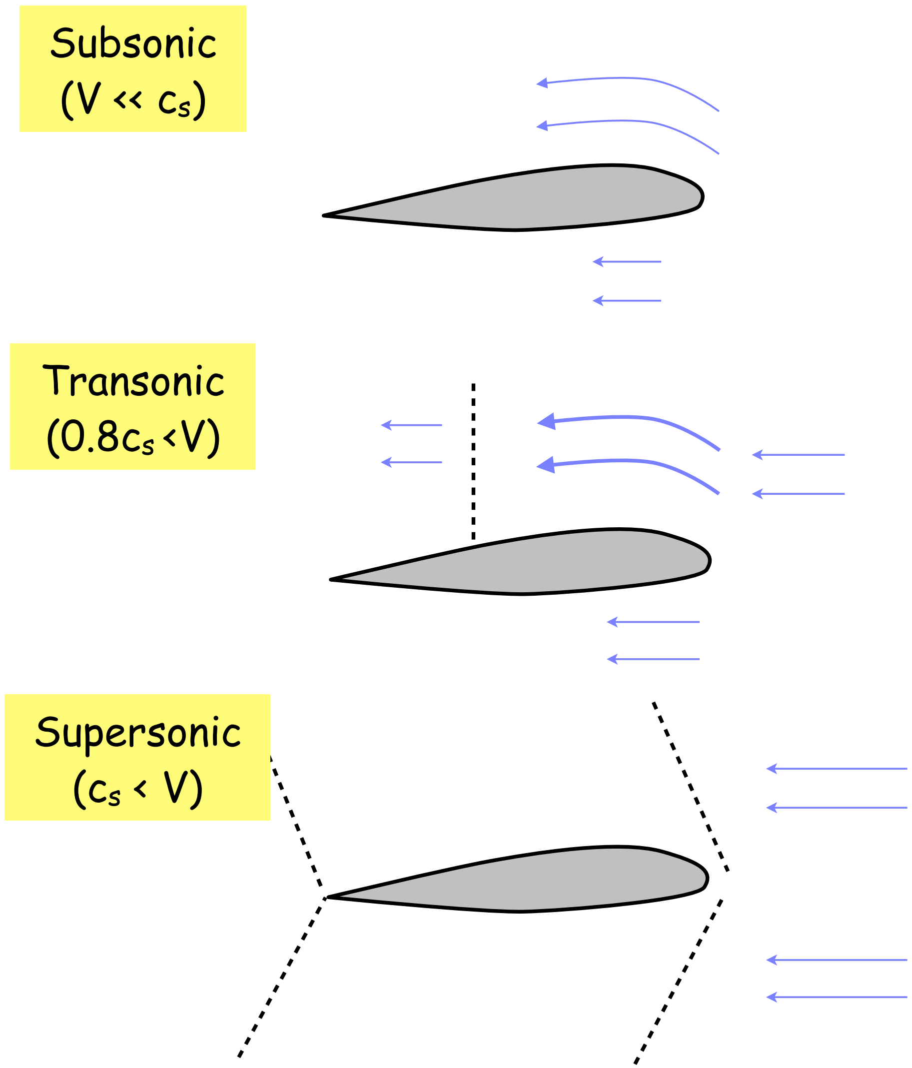
div V - Compression in red



Normal shocks: Analogy to wings

- Signatures of transonic/supersonic flow
- Plasmoid moves at Alfvén speed, which is transonic/supersonic in the β<<1 regime.

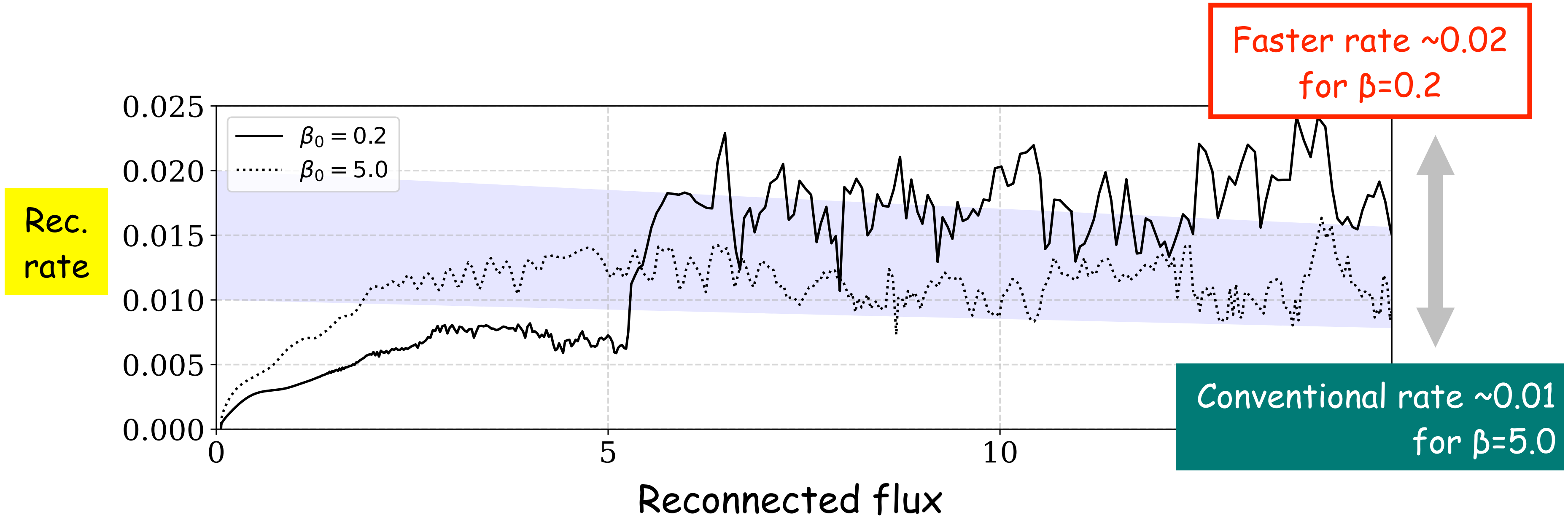


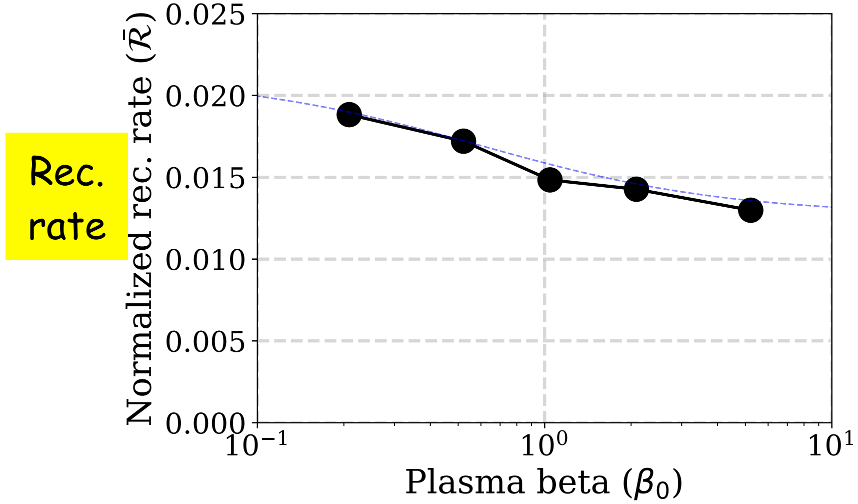


SZ & Miyoshi 2011, 2015

See also https://www.youtube.com/watch?v=8OIqfCTAZQo

Reconnection rate

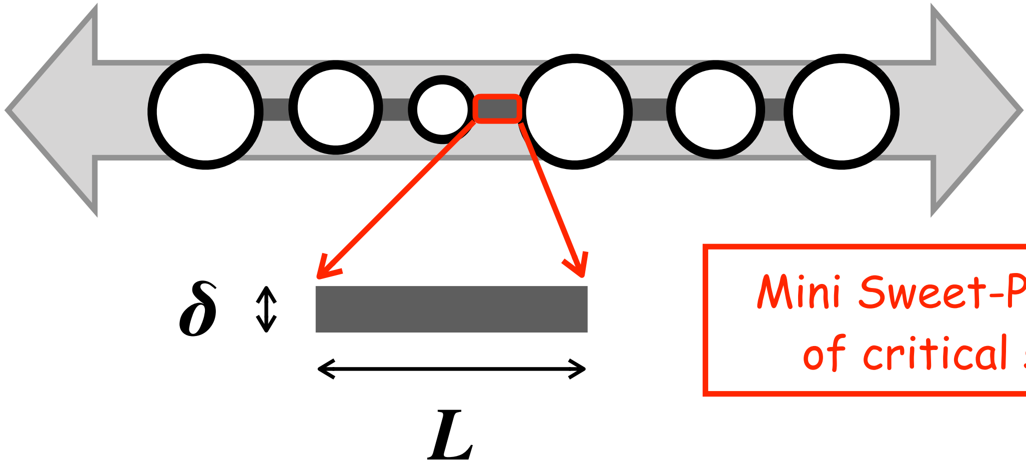




- Faster for lower-β cases

- For β<<1, the rate approaches R~0.02
- For β>>1, it approaches the conventional value of R~0.01

Estimating the reconnection rate



Mini Sweet-Parker (SP) layers of critical size (S_{crit} ~10^4)

- Rate of the mini S-P layer is controlled by the compression ratio and the aspect ratio (Hesse+ 2011)
- We assume that the typical aspect ratio is similar.
- Global reconnection rate should scale like the compression ratio.

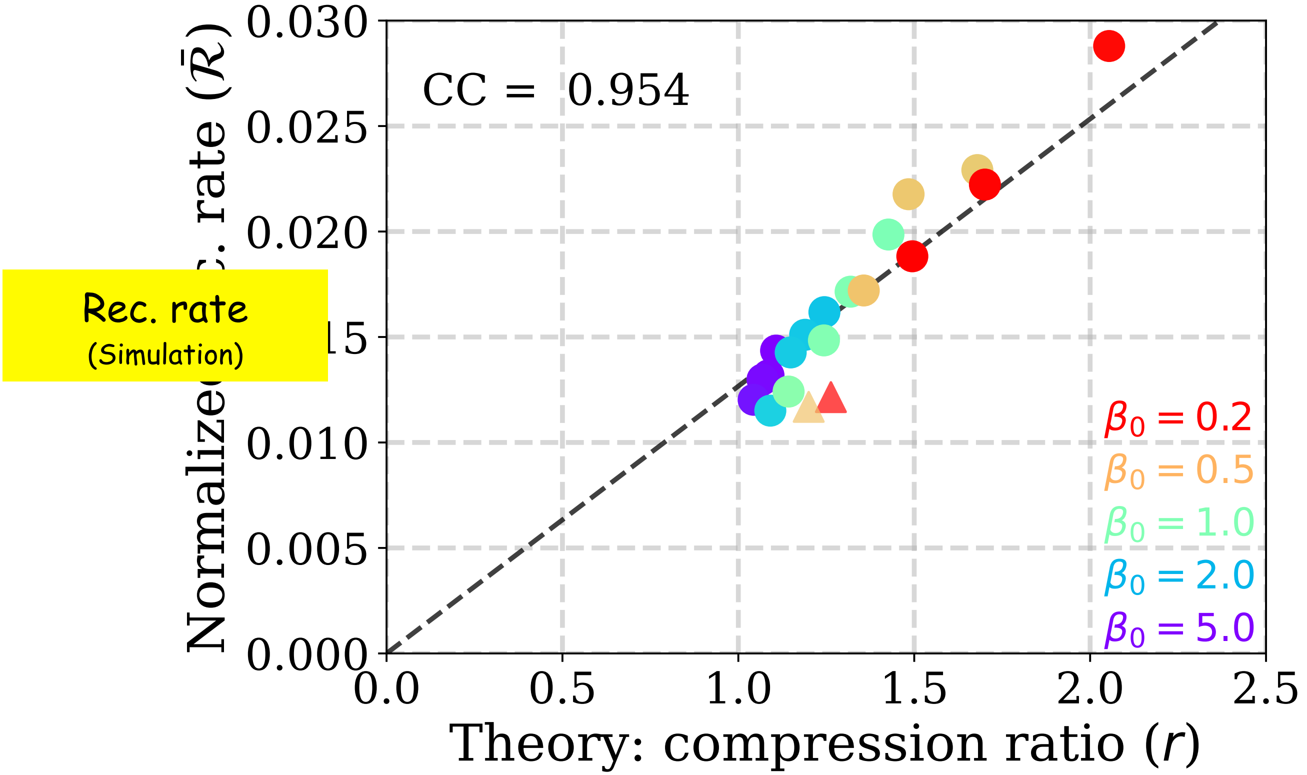
$$\mathcal{R}_{\rm sp} \equiv \frac{v_{in}}{c_A} = \frac{2\gamma(1+\beta)}{3(\gamma-1)+2\gamma\beta}\left(\frac{\delta}{L}\right)$$

$$\left(\frac{\delta}{L}\right) \approx S_{\rm crit}^{-1/2} = \text{const.}$$

$$\langle\mathcal{R}\rangle \sim \mathcal{R}_{\rm sp} \propto \frac{2\gamma(1+\beta)}{3(\gamma-1)+2\gamma\beta}$$

Simulation vs Theory

- Compression ratio (theoretical prediction) is a function of (β, γ)
- Numerical survey for β=[0.2, 0.5, 1.0, 2.0, 5.0], γ=[1.33, 1.5, 1.67, 2.0]
- Rec. rate (simulation) is proportional to the compression ratio

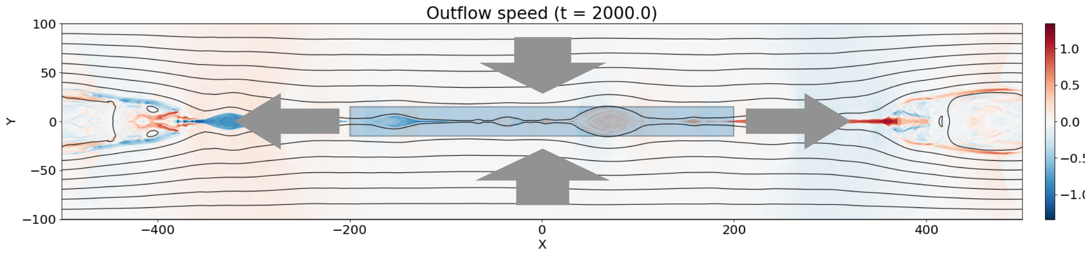


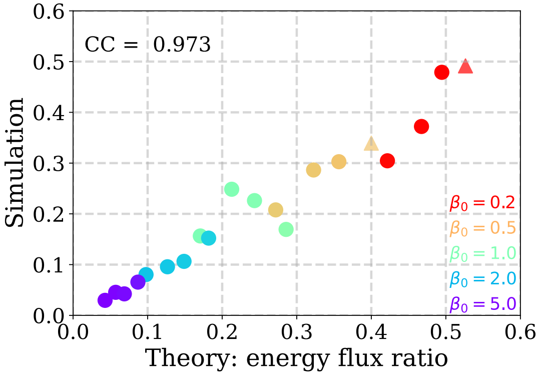
SZ & Miyoshi 2020

Energy budget

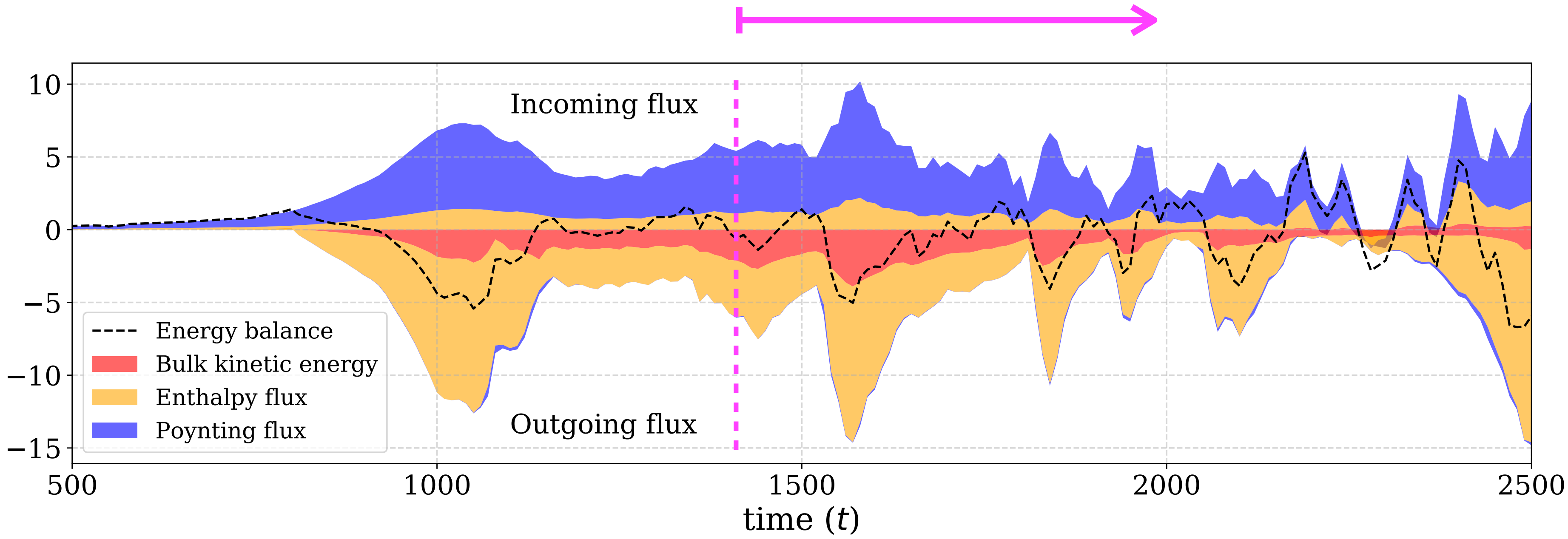
Theory vs Simulation

Ratio of (Bulk kinetic energy) : (enthalpy flux) in the outgoing energy flow





Plasmoid-dominated stage



Summary

- Plasmoid-dominated reconnection for $\beta \ll 1$
  - Visible signature: Normal slow shocks
  - Higher reconnection rate
    - Rec. rate can be accelerated to ~0.02 in the $\beta \to 0$ limit
  - Energy balance: quasi-periodic behavior

- Reference
  - Zenitani & Miyoshi, ApJL, 894, L7 (2020)
  - GPU-ready simulation code is available --- Search "OpenMHD"