Cross-Scale Coupling in Large-Systems

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Opportunities in Plasma Astrophysics
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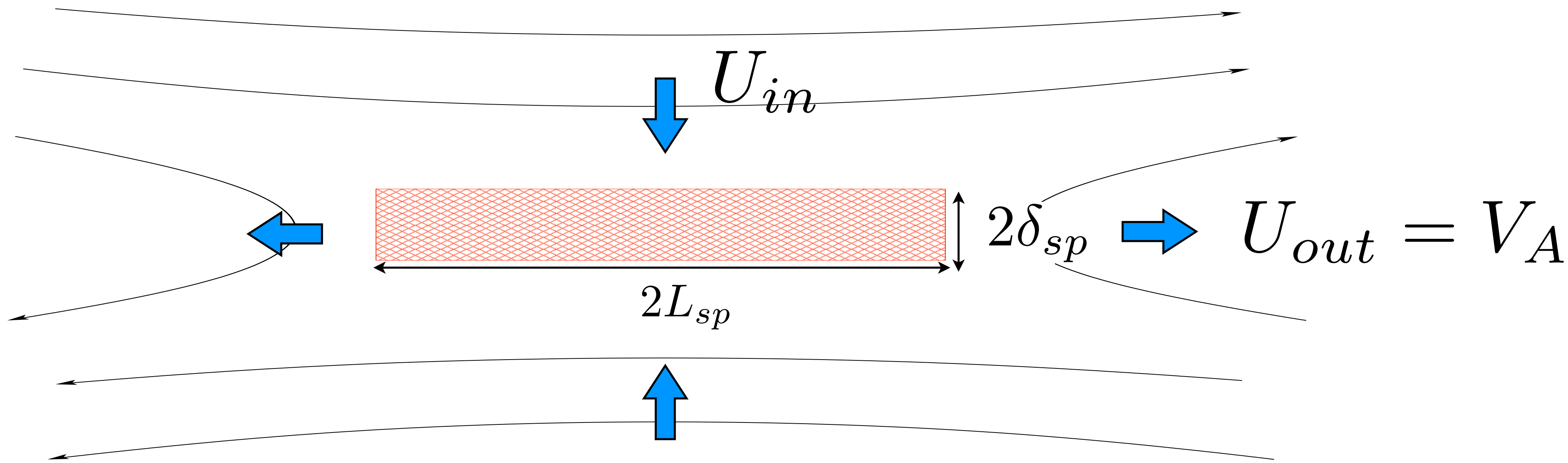
Much progress has been in understanding reconnection in systems of modest scale



$\delta_{sp} \quad > \quad d_i \longrightarrow$ Collisional Regime $\quad \frac{\mathbf{U}_{in}}{V_A} = \frac{\delta_{sp}}{L_{sp}} = \frac{1}{S^{1/2}}$

$\delta_{sp} \quad \leq \quad d_i \longrightarrow$ Kinetic Regime $\quad \frac{\mathbf{U}_{in}}{V_A} \sim 0.1$

Many uncertainties remain to extrapolate to large systems

Huge Separation of Scales in Astrophysical Plasmas

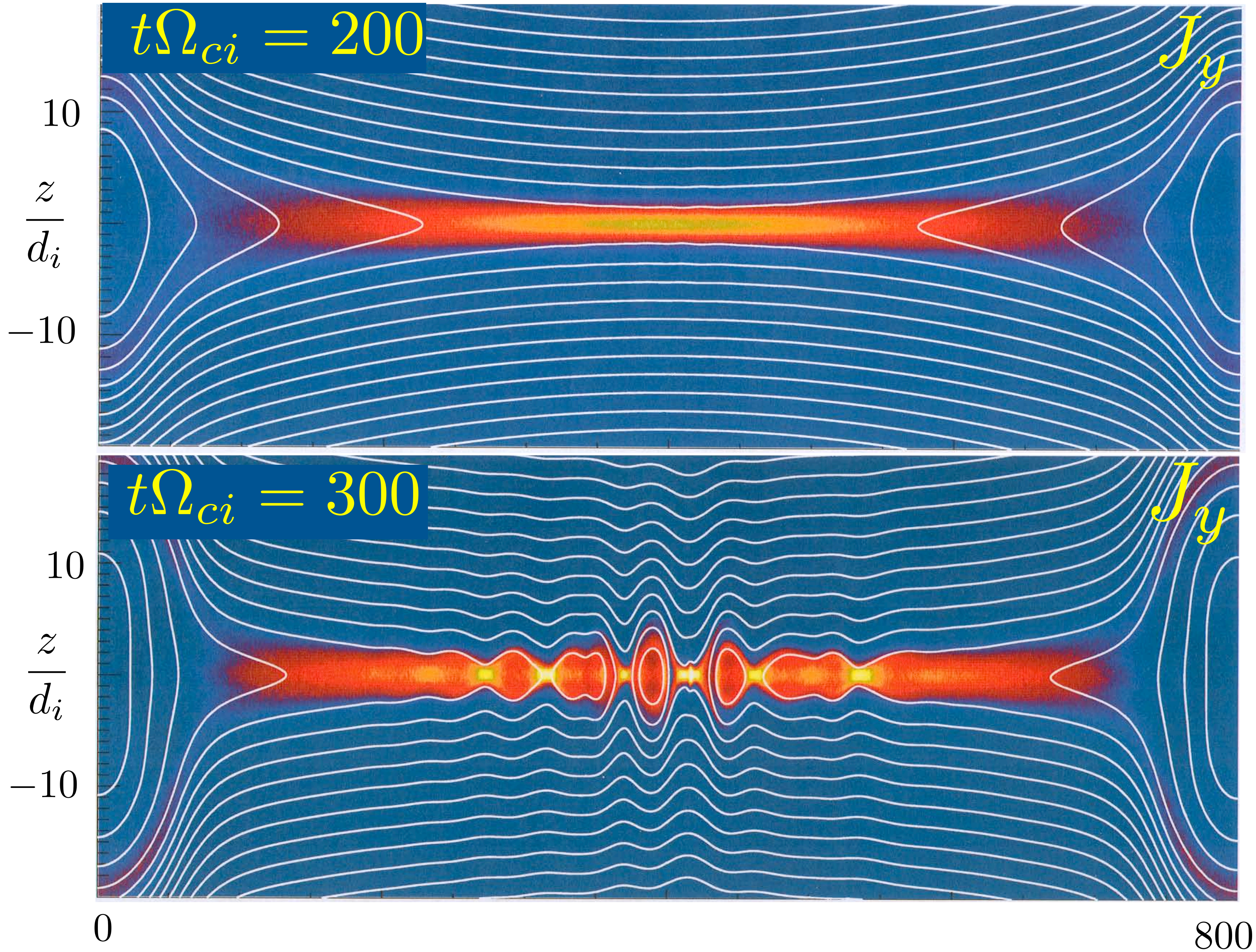
	Lundquist - S	L/d_i
Earth's magnetosphere	∞	$\sim 10^3$
Solar Corona & Stellar Flares	$\sim 10^{14}$	$\sim 10^8$
accretion disks, magnetars	$\sim 10^{18}$	$\sim 10^{10}$
Computer Simulations	$< 10^5$	< 400
Laboratory Experiments	< 1000	~ 10

Real challenge to extrapolate physics

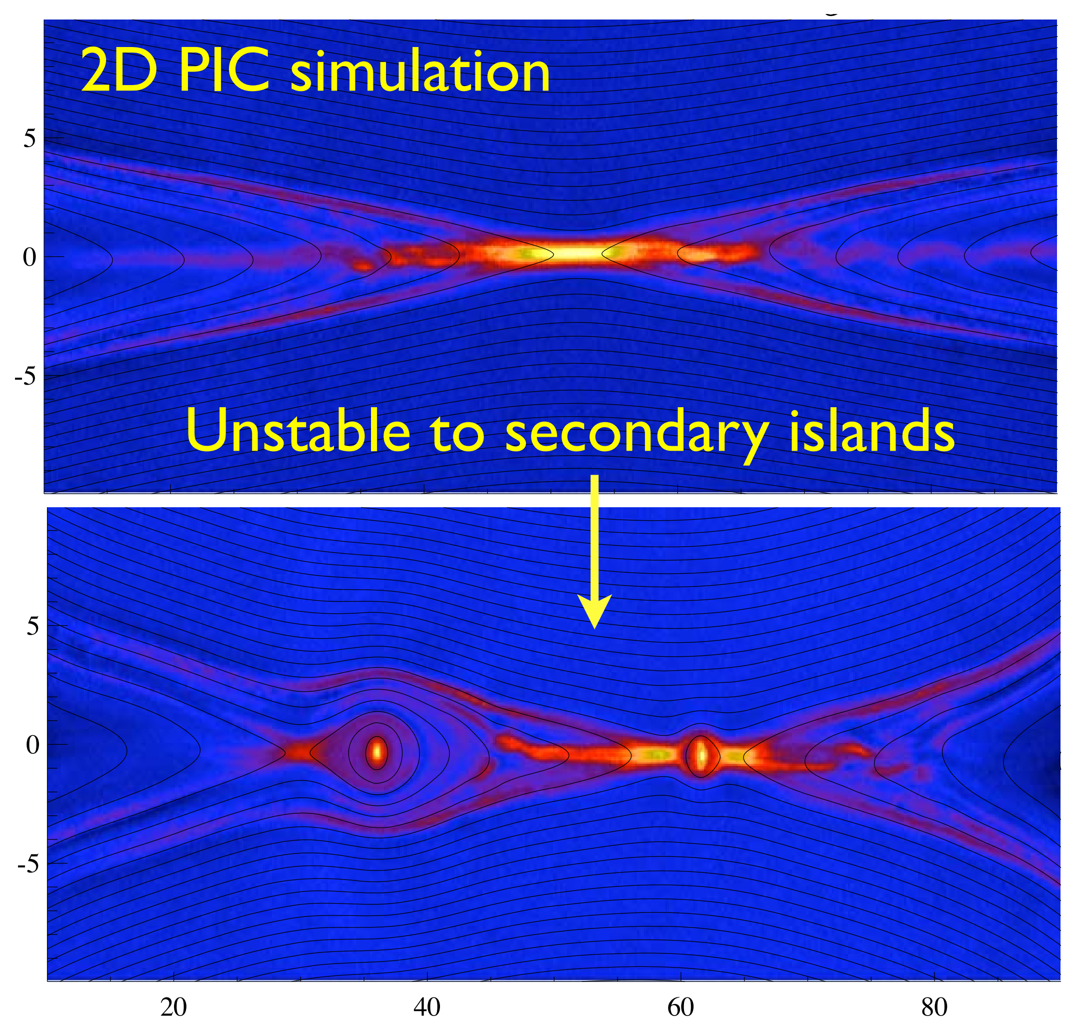
Do collisional or kinetic mechanisms dominate?

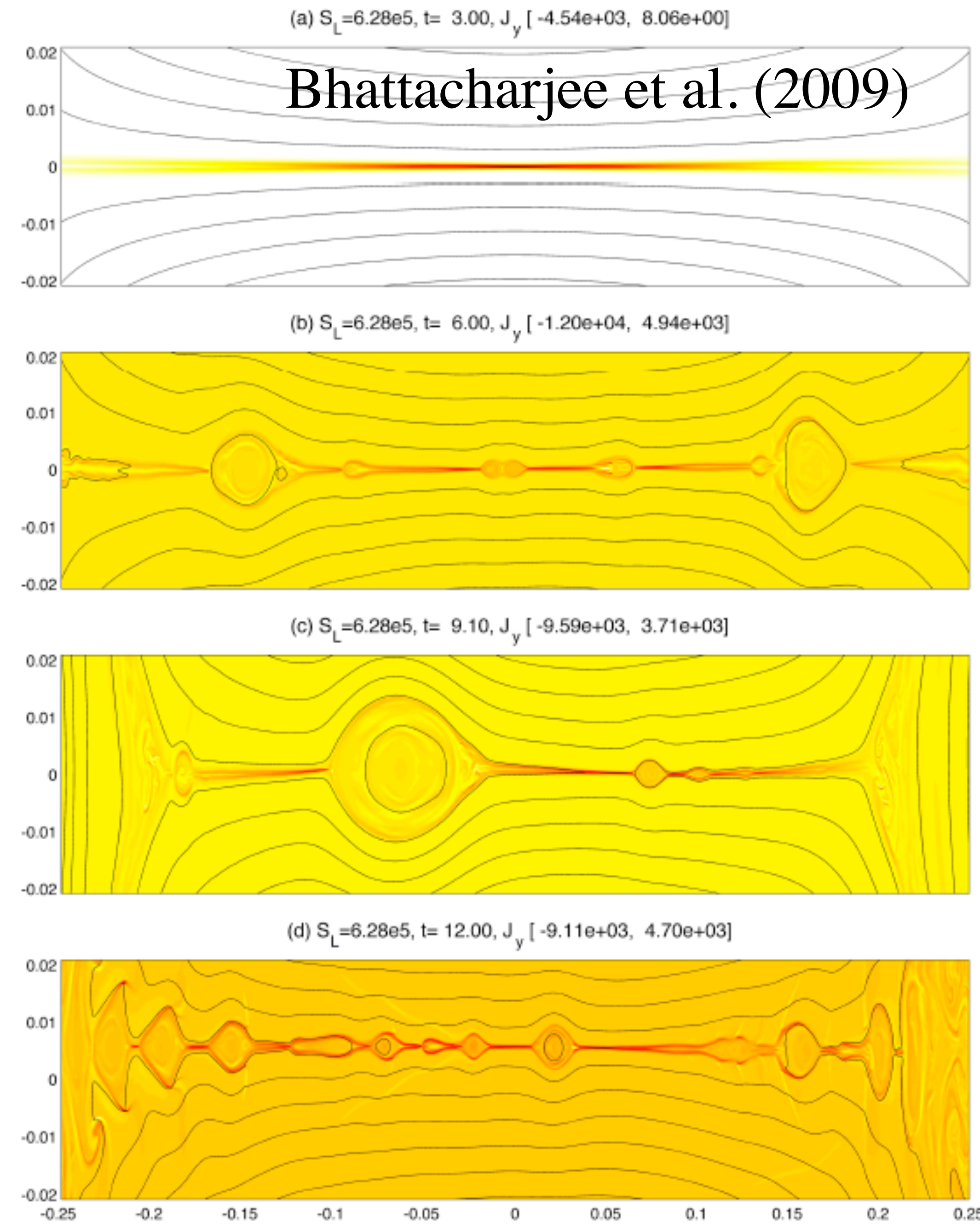
One Key Issue to "Scale-Up" the Dynamics

In both collisional and kinetic regimes, the non-linear evolution of reconnection produces elongated current layers, which are unstable to secondary magnetic islands (plasmoids)



Many new efforts exploring these ideas





Samtaney et al. (2009)

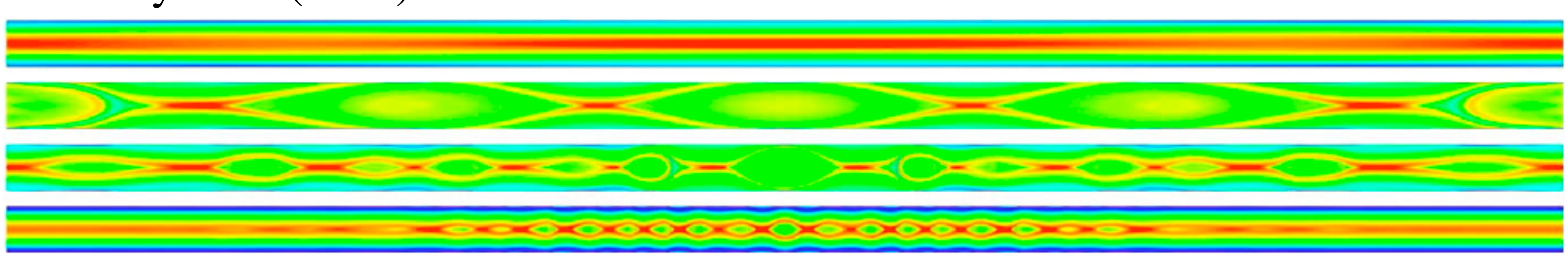


FIG. 2 (color online). Current density for $S = 10^4$, $S = 10^5$, $S = 10^6$ and $S = 10^7$. $S = 10^8$ is shown in Fig. 1.

Why does this matter ?

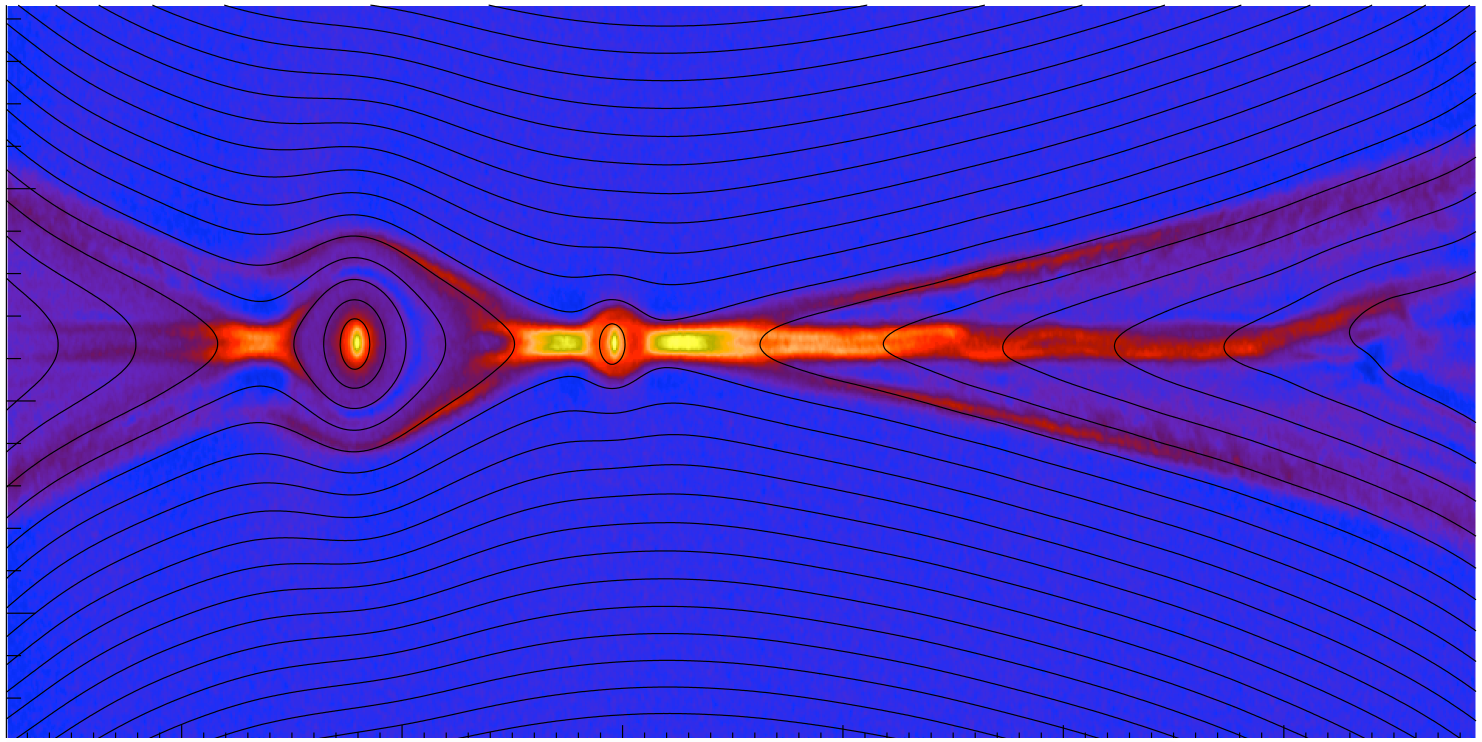
Collisional Regimes:

- The number of islands and growth rate increase with S
- May permit faster reconnection than Sweet-Parker
- Can also push evolution towards kinetic scales

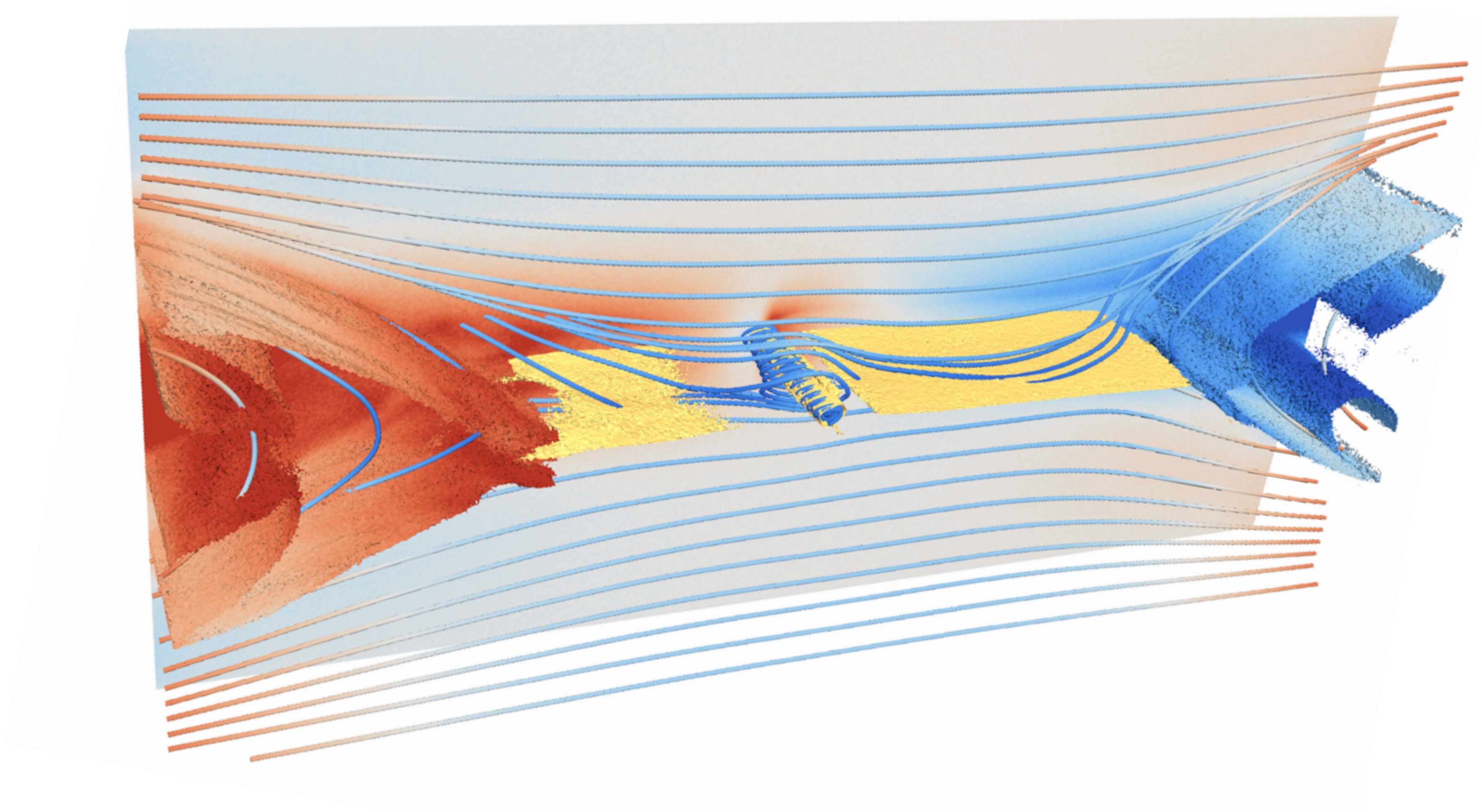
Kinetic Regimes:

- Do islands influence scaling of reconnection rate ?
- Could also be important in the energy partition and particle acceleration process ?

In real 3D world, magnetic islands are flux ropes



Collisionless
2D neutral sheet



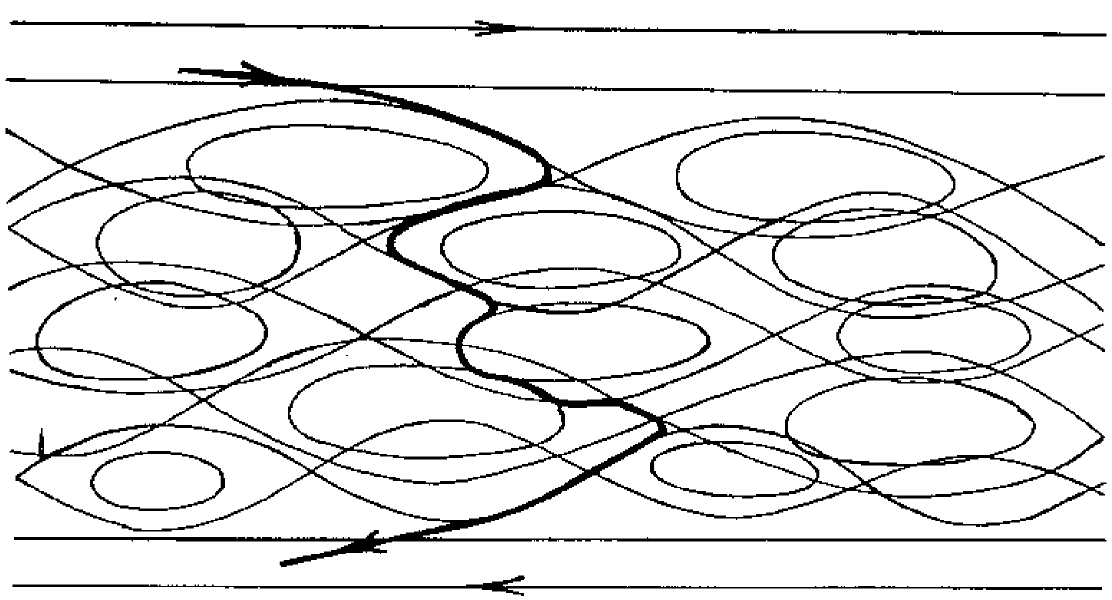
Collisionless
3D neutral sheet

Island formation can be complicated in 3D

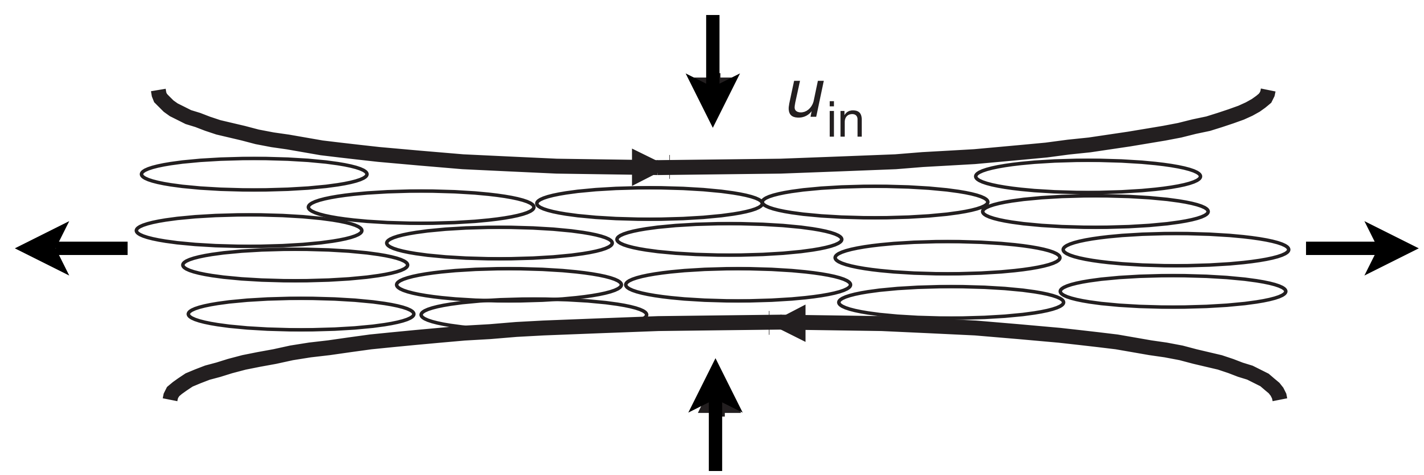
Drift Tearing - Coppi et al, 1979, Catto et al, 1974, Gladd, 1990, Daughton et al, 2005

Percolation - Galeev, Kuznetsova, Zeleny, 1986

Volume filling islands - Drake et al, Nature, 2006

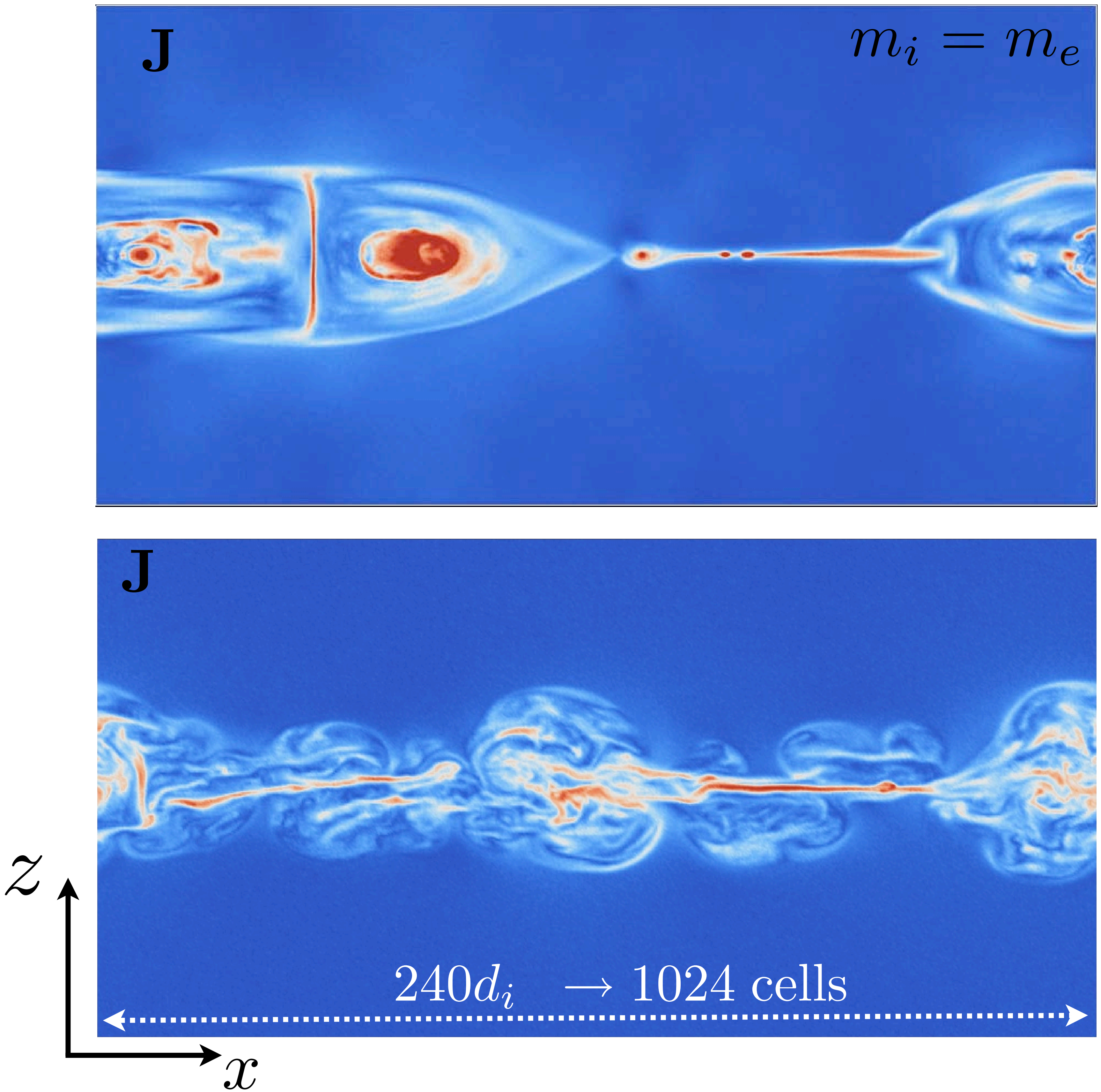


Galeev et al, 1986



Drake et al, 2006

2D vs 3D Dynamics is Quite Different



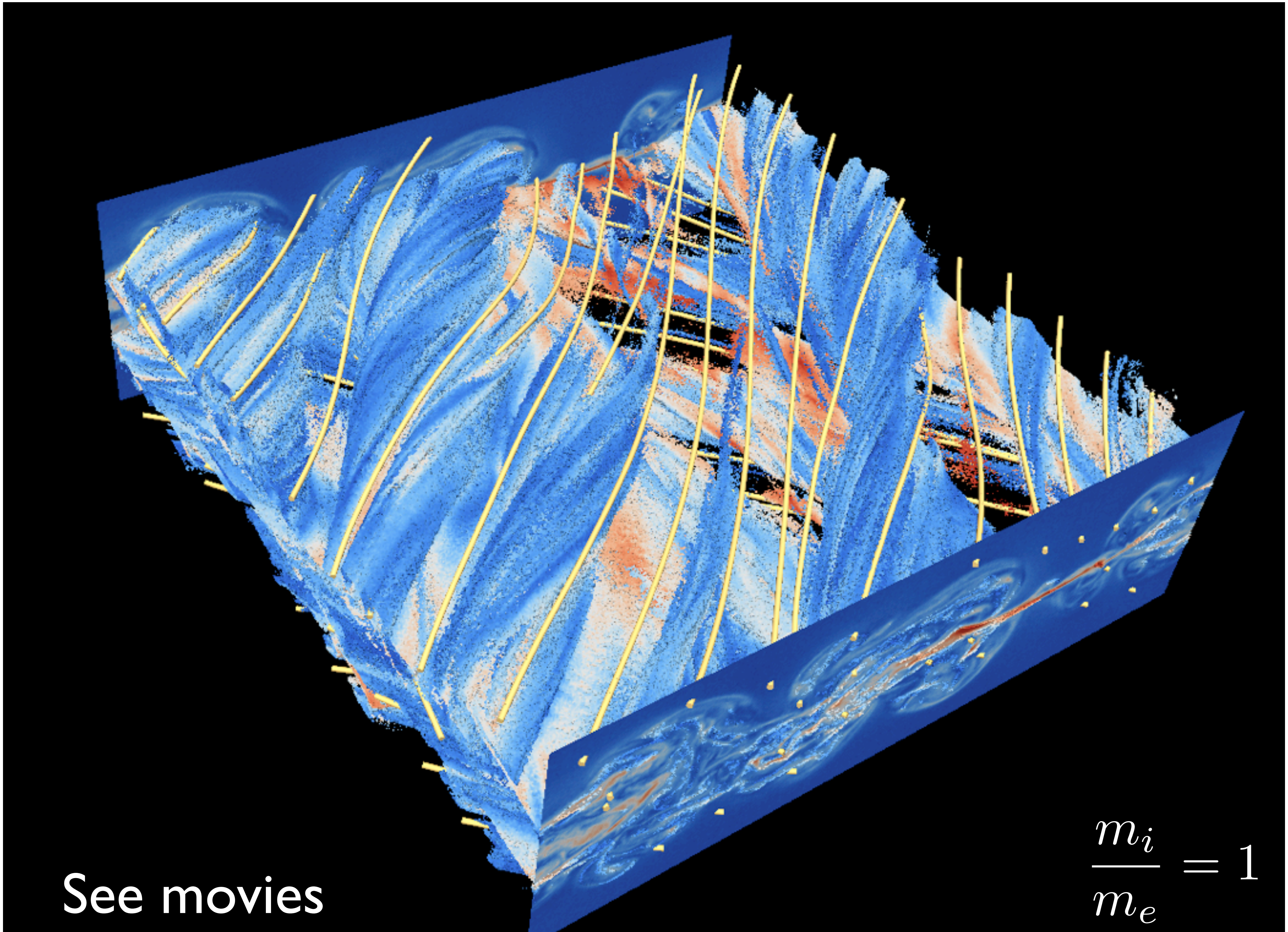
2D

$\sim 10^6$ cells

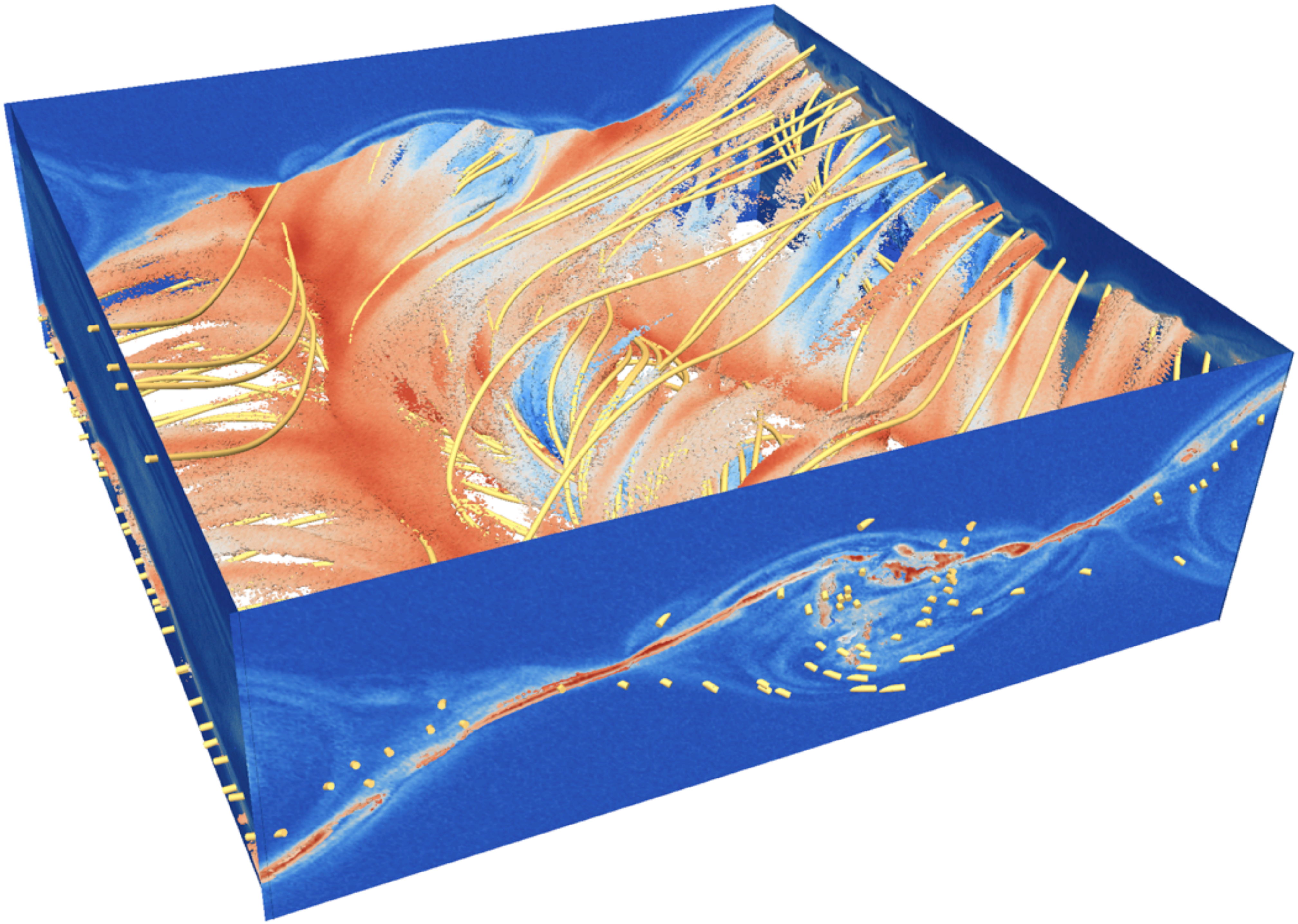
3D cut

$\sim 10^9$ cells

Primary & secondary islands form a spectrum interacting oblique flux ropes



Under certain conditions, theory & simulations suggest a spectrum of oblique flux ropes



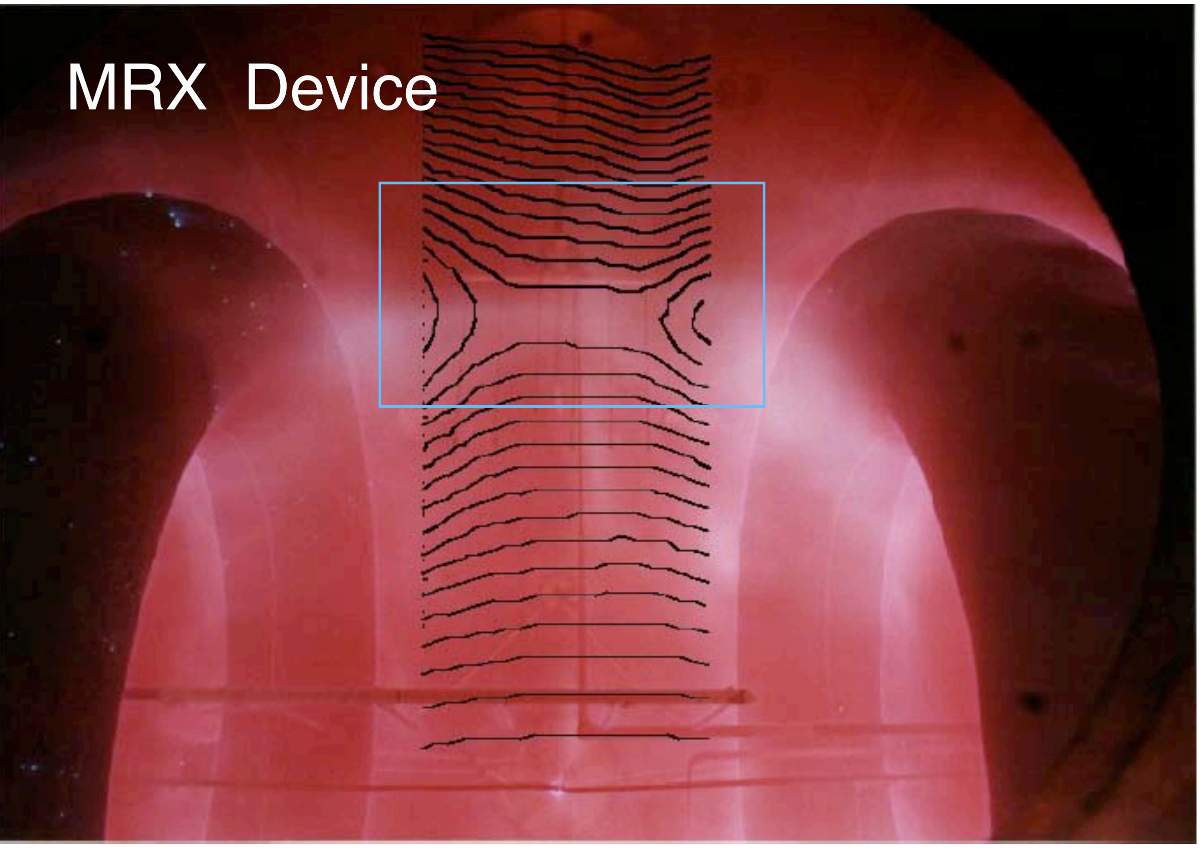
Flux ropes may interact differently than islands in 2D models

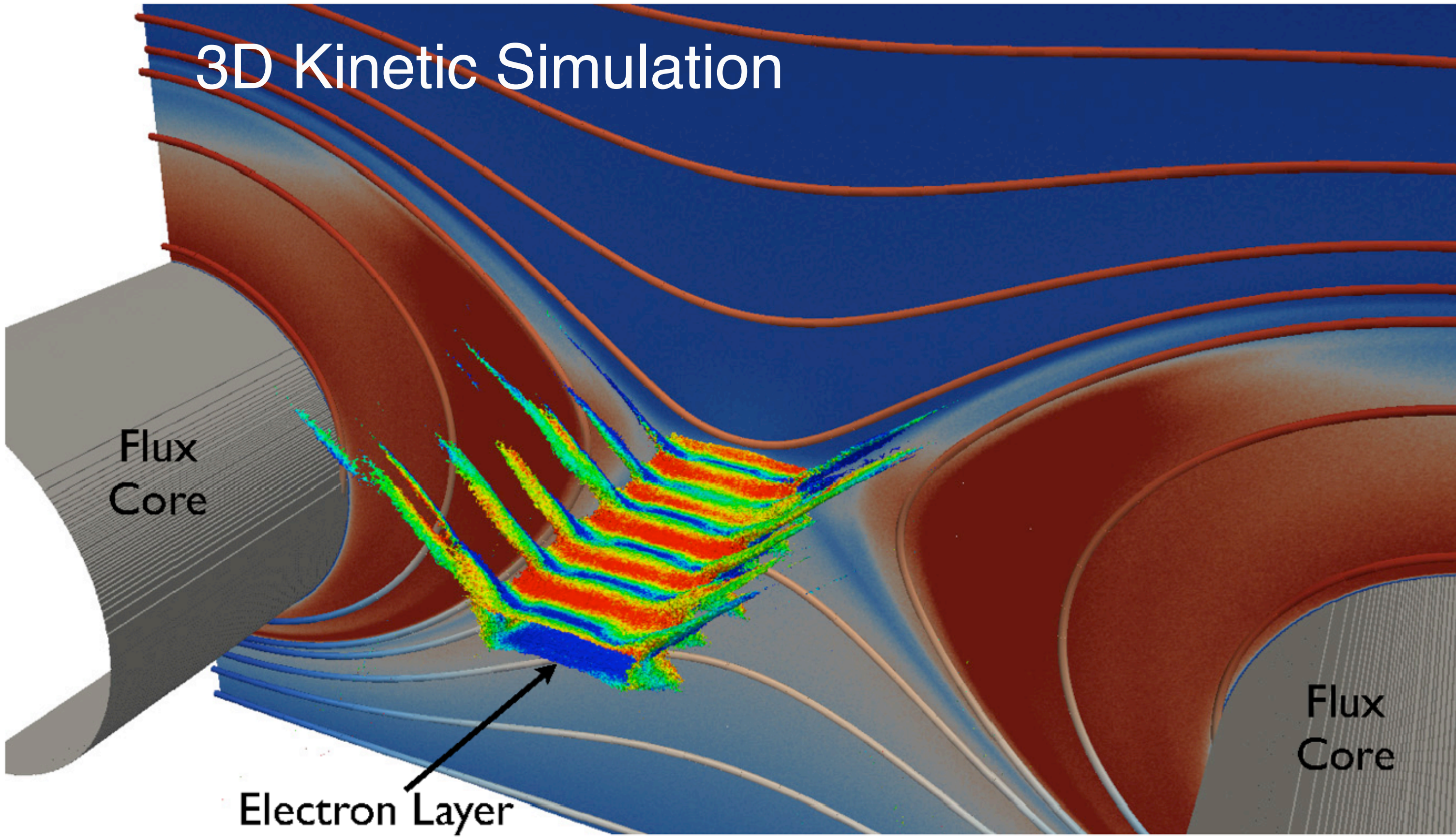
Variety of waves and instabilities may also influence reconnection process

- Pre-existing turbulence (MHD or kinetic)
- Buneman - streaming instabilities
- Lower-hybrid drift instability
- Lower-hybrid waves
- Temperature anisotropy modes
- Velocity shear instabilities
- Nonlinear structures - phase space holes

Can these produce anomalous dissipation, or influence larger scale evolution ?

Some of these instabilities are being examined with laboratory experiments & simulations





- Extrapolate experimentally validated results to other regimes
- Need for new experiments to address issue of secondary islands

Progress on these issues will benefit from increased interactions between:

- Satellite observations - magnetosphere & solar wind
- Solar observations
- Laboratory experiments
- Theory & simulations - both fluid and kinetic

Increased understanding will allow more realistic application of magnetic reconnection to astrophysical problems.