Investigation of the Transition from Sweet-Parker Magnetic Reconnection with Secondary Islands to Hall Reconnection

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Magnetohydrodynamics (MHD) Primer

Basic Equations:

$$\frac{\partial \rho}{\partial t} + \nabla\cdot\rho\mathbf{v} = 0 \qquad \nabla\cdot\mathbf{B} = 0$$

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\,\mathbf{v}\right) = -\nabla p + \frac{\mathbf{J}\times\mathbf{B}}{c} \qquad \mathbf{J} = \frac{c}{4\pi}\nabla\times\mathbf{B}$$

Generalized Ohm’s Law:

$$\mathbf{E} = -\frac{\mathbf{v}\times\mathbf{B}}{c} + \eta\mathbf{J} + \underbrace{\frac{\mathbf{J}\times\mathbf{B}}{nec}}_{\text{Hall term}} - \frac{\nabla\cdot\mathrm{P}_e}{ne} \underbrace{+ \frac{m_e}{ne^2}\left[\frac{\partial\mathbf{J}}{\partial t} + \nabla\cdot(\mathbf{J}\mathbf{v} + \mathbf{v}\mathbf{J})\right]}_{\text{Electron inertia term}}$$

Lundquist Number:

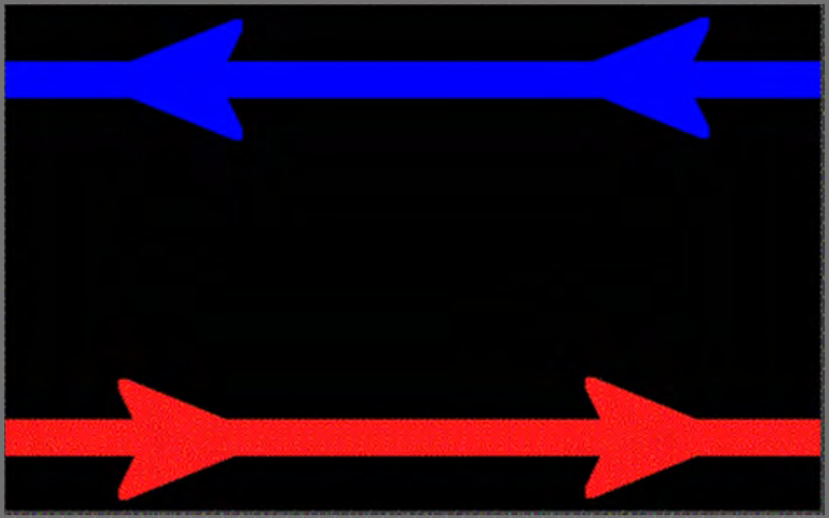
$$S = \frac{4\pi c_A L}{\eta c^2}$$

Alfvén speed:

$$c_A = \frac{B}{\sqrt{4\pi\rho}}$$

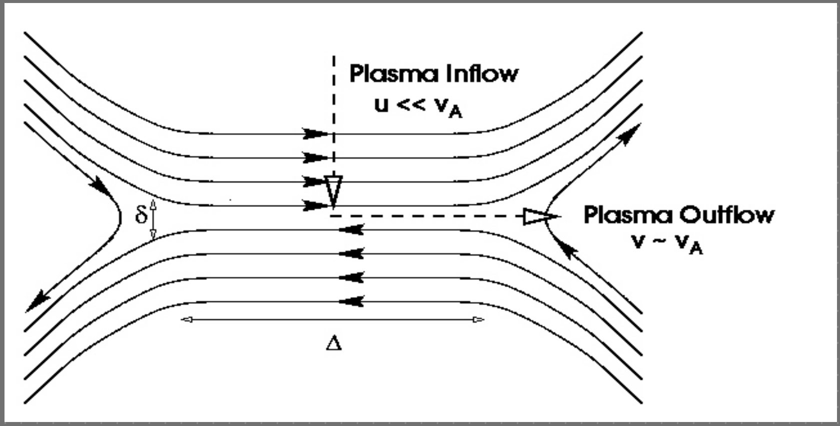
What Does Magnetic Reconnection Look Like?

- A topological change in a magnetic field configuration which allows rapid release of magnetic energy



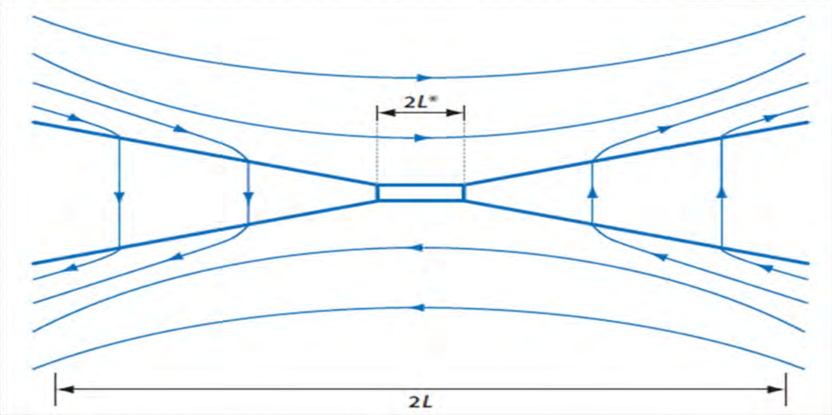
- Current sheet forms where oppositely directed magnetic fields meet, in accordance with Ampere's Law

Types of Magnetic Reconnection



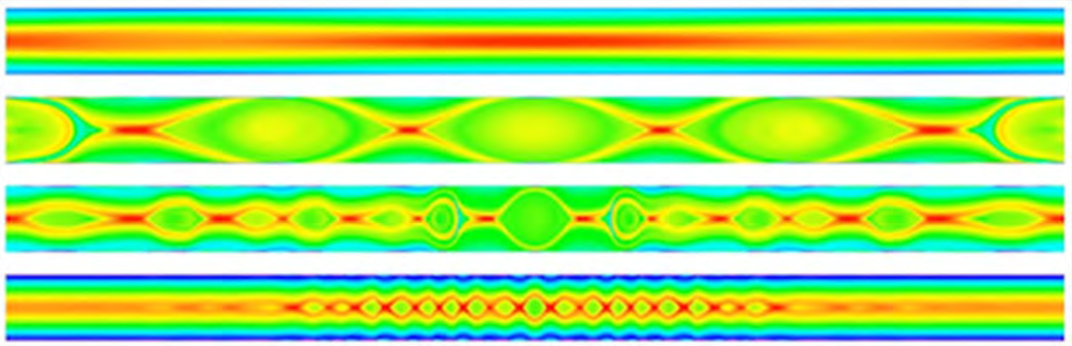
Sweet-Parker Reconnection

- Length of current sheet set by the size of the system
- Reconnection rate too slow to explain energy release of solar flares
- Present in resistive MHD (i.e. without Hall or electron inertia terms)
- Unstable to secondary island formation at high Lundquist numbers →



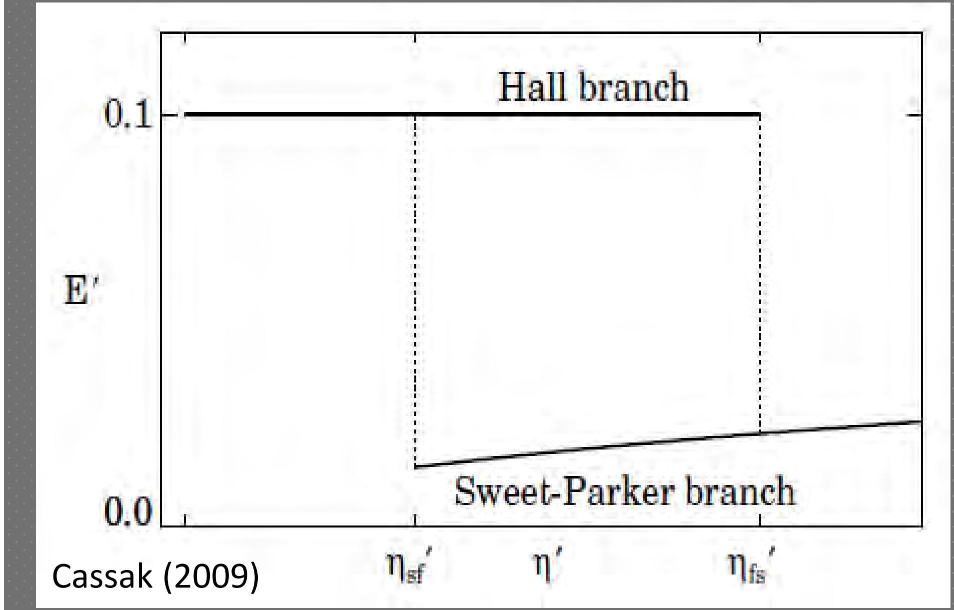
Hall Reconnection

- Petschek configuration with short current sheet
- Reconnection rate is fast enough to explain energy release in solar flares
- Enabled by nonlinear whistler waves which occur due to Hall term

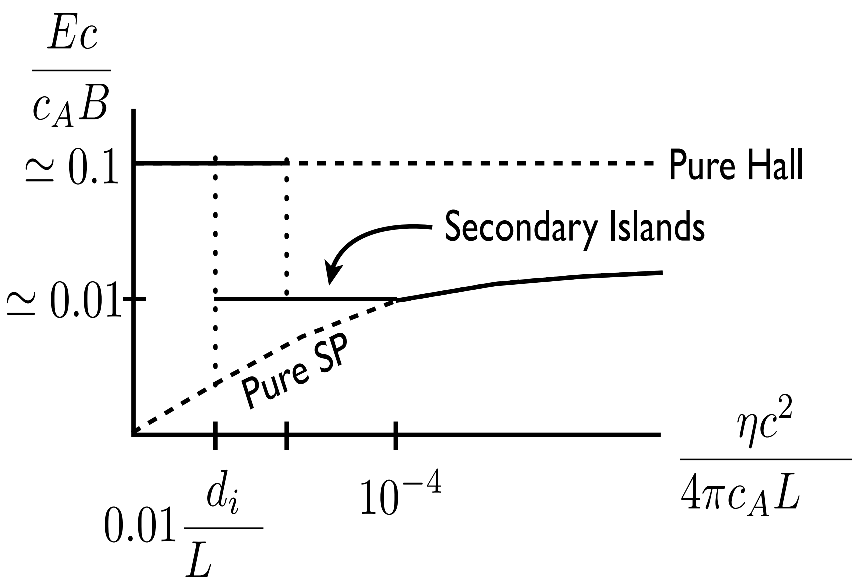


Samtaney, et al. (2009)

Bistability of Reconnection



Cassak (2009)



Without Secondary Islands

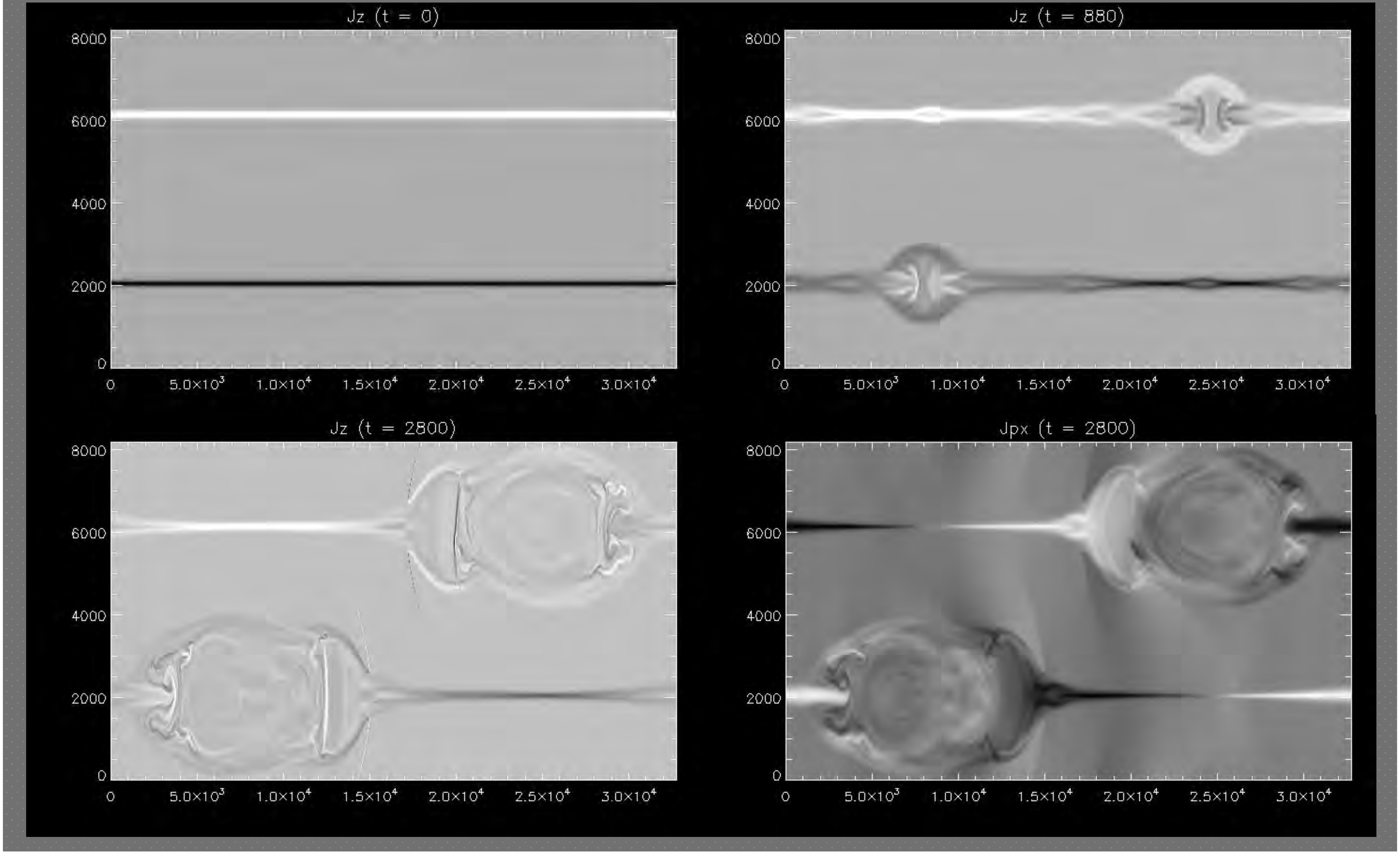
- At low Lundquist numbers, system is stable to secondary islands
- Sweet-Parker reconnection transitions directly to Hall reconnection at critical value of resistivity
- Reverse transition occurs at higher resistivity, resulting in hysteresis

With Secondary Islands

- At higher Lundquist numbers, system is unstable to island formation
- Secondary islands level off reconnection rate and raise the transition to Hall reconnection
- Some propose oscillation exists between secondary island phase and Hall reconnection (we feel otherwise)

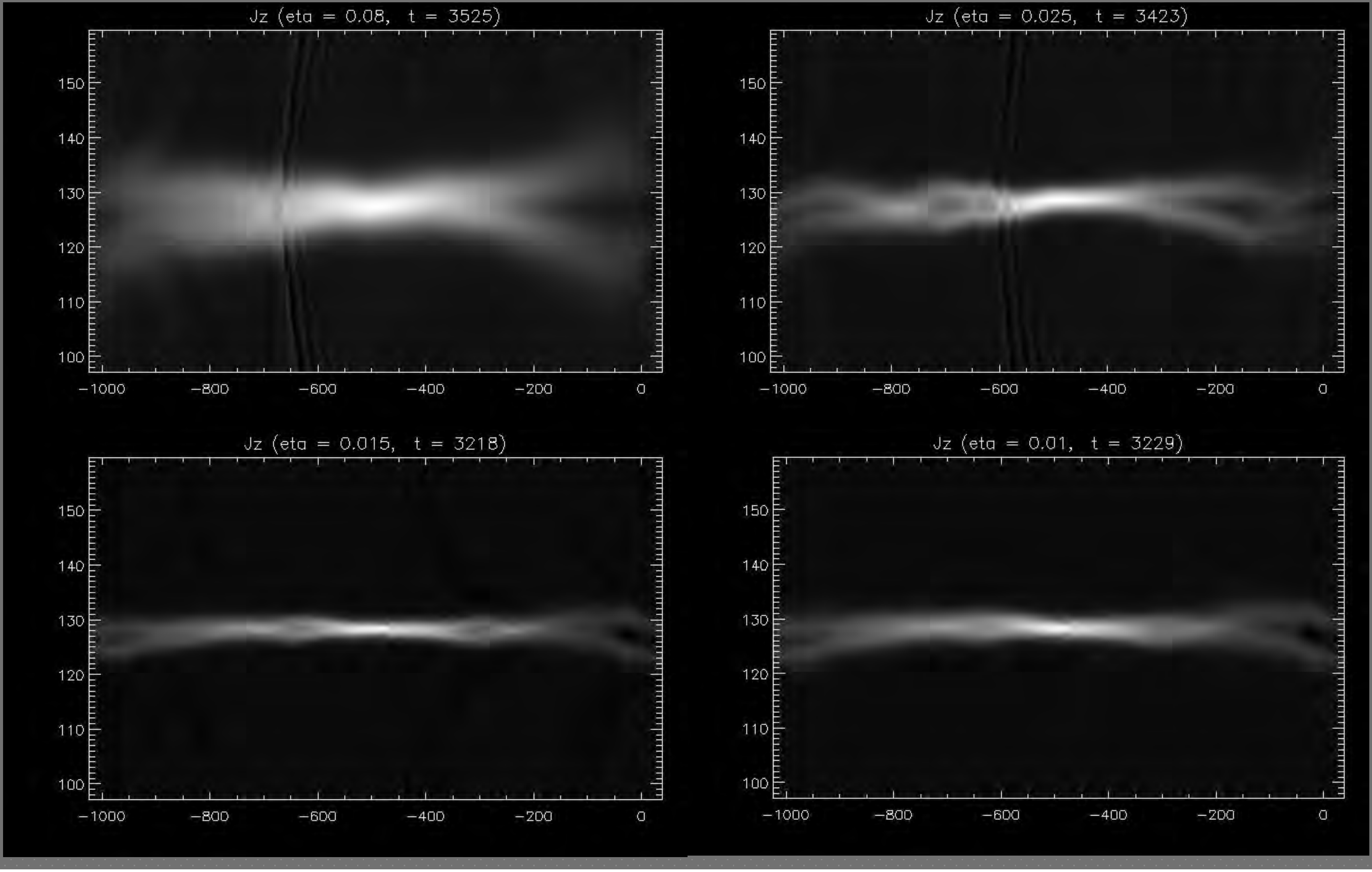
Stage 1: Developing Sweet-Parker Current Sheet

$$\mathbf{E} = -\frac{\mathbf{v}\times\mathbf{B}}{c} + \eta\mathbf{J} + \cancel{\frac{\mathbf{J}\times\mathbf{B}}{nec}} - \frac{\nabla\cdot\mathrm{P}_e}{ne} + \cancel{\frac{m_e}{ne^2}\left[\frac{\partial\mathbf{J}}{\partial t} + \nabla\cdot(\mathbf{J}\mathbf{v}+\mathbf{v}\mathbf{J})\right]}$$



Stage 2: Continue Simulation with Hall Term Enabled at Various Resistivities

$$\mathbf{E} = -\frac{\mathbf{v} \times \mathbf{B}}{c} + \eta \mathbf{J} + \frac{\mathbf{J} \times \mathbf{B}}{nec} - \frac{\nabla \cdot \mathsf{P}_e}{ne} + \frac{m_e}{ne^2}\left[\frac{\partial \mathbf{J}}{\partial t} + \nabla \cdot (\mathbf{J}\mathbf{v} + \mathbf{v}\mathbf{J})\right]$$



Conclusions and Future Work

- Runs with lower resistivity have developed secondary islands, while the run with highest resistivity still has an intact Sweet-Parker layer
- None of the runs at lower resistivity have transitioned to Hall, even though the Hall branch is stable at these parameters
- Results lend support to idea that there are no oscillations between Hall and secondary island reconnection, but system must be run out to longer times to know for sure

References

- Samtaney, R. et al. “Formation of Plasmoid Chains in Magnetic Reconnection” Phys. Rev. Lett. 103 (2009)
- Cassak, P. “Catastrophe Model for the Onset of Fast Magnetic Reconnection” Ph.D. Thesis (2006)