Investigation of the Transition from Secondary Island to Hall Magnetic Reconnection

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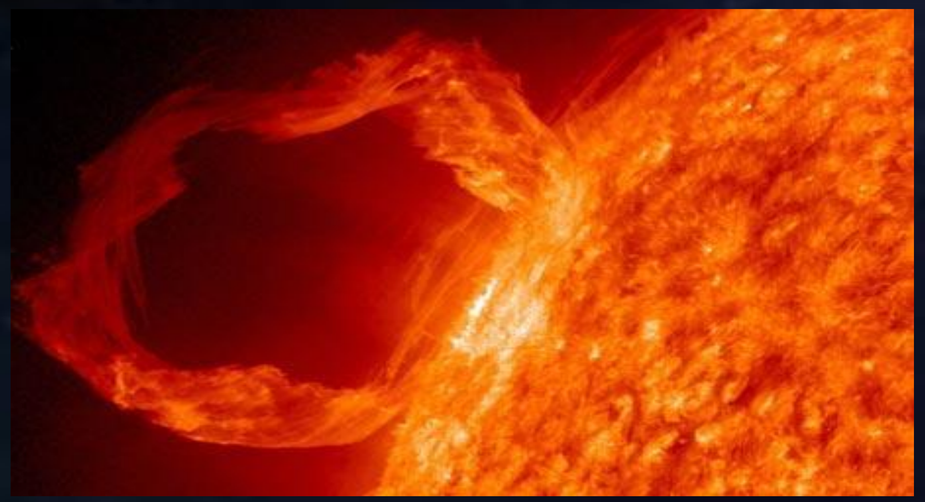
Motivation



- Magnetic reconnection is thought to be the primary mechanism driving solar flares.
- Bistability of reconnection provides a clue to the onset problem for flares in the solar corona.
- Presence of secondary islands significantly shifts the resistivity at which the system transitions to Hall reconnection.

MHD Equations

Mass Continuity: $$\frac{\partial \rho}{\partial t} + \nabla\cdot\rho\mathbf{v} = 0$$

Ampere's Law: $$\mathbf{J} = \frac{c}{4\pi}\nabla\times\mathbf{B}$$

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

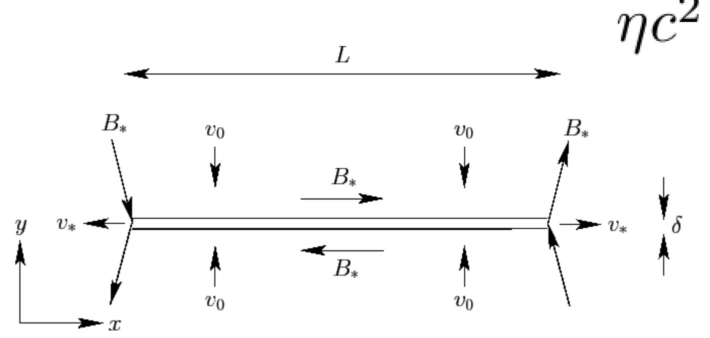
No divergence of magnetic field: $$\nabla\cdot\mathbf{B} = 0$$

Generalized Ohm's Law:

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

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

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

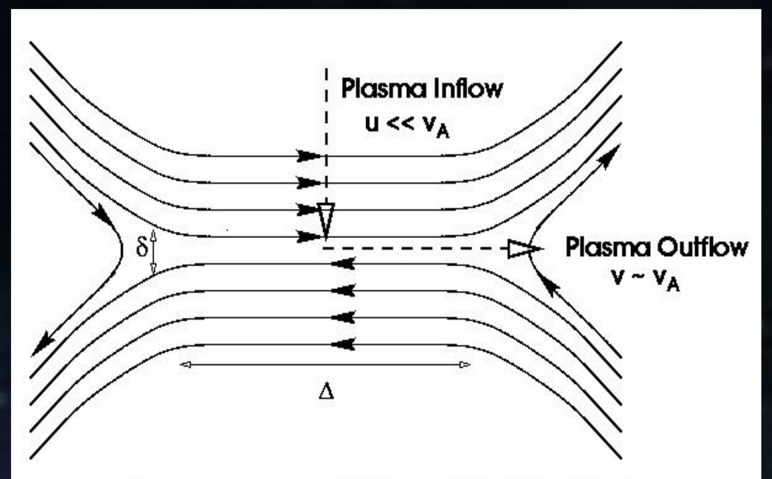


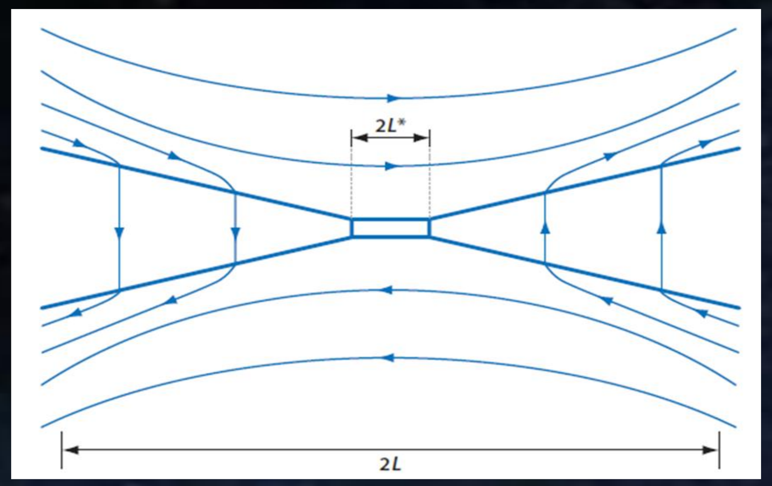
$$\rho_{in} v_{in} L = \rho_{out} v_{out} \delta$$

$$\rho_{in} \approx \rho_{out} \Rightarrow$$

$$\frac{v_{in}}{v_{out}} \approx \frac{\delta}{L} \approx \frac{1}{\sqrt{S}}$$

Reconnection Solutions





Sweet-Parker Reconnection

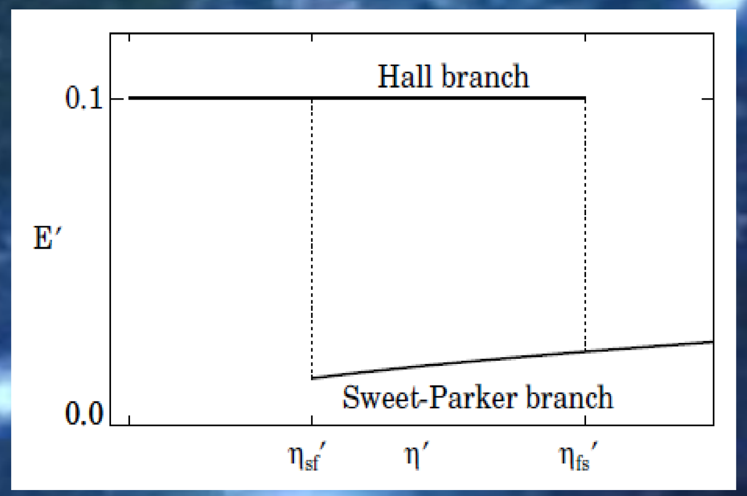
- Long current sheet with length set by system size
- Reconnection occurs too slowly to explain explosive phenomena such as solar flares
- Occurs as a result of simple resistive MHD

Hall Reconnection

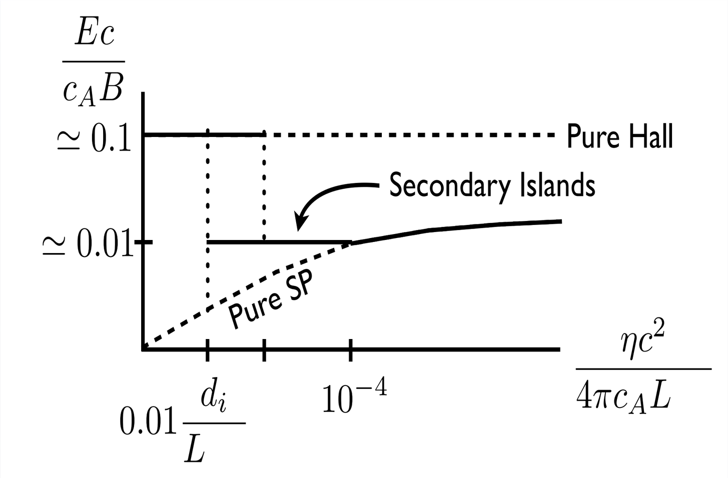
- Petschek configuration with short current sheet
- Reconnection rate is large enough to explain observations in solar flares
- Enabled by nonlinear whistler waves which occur due to Hall term

Bistability

Without secondary islands



With secondary islands



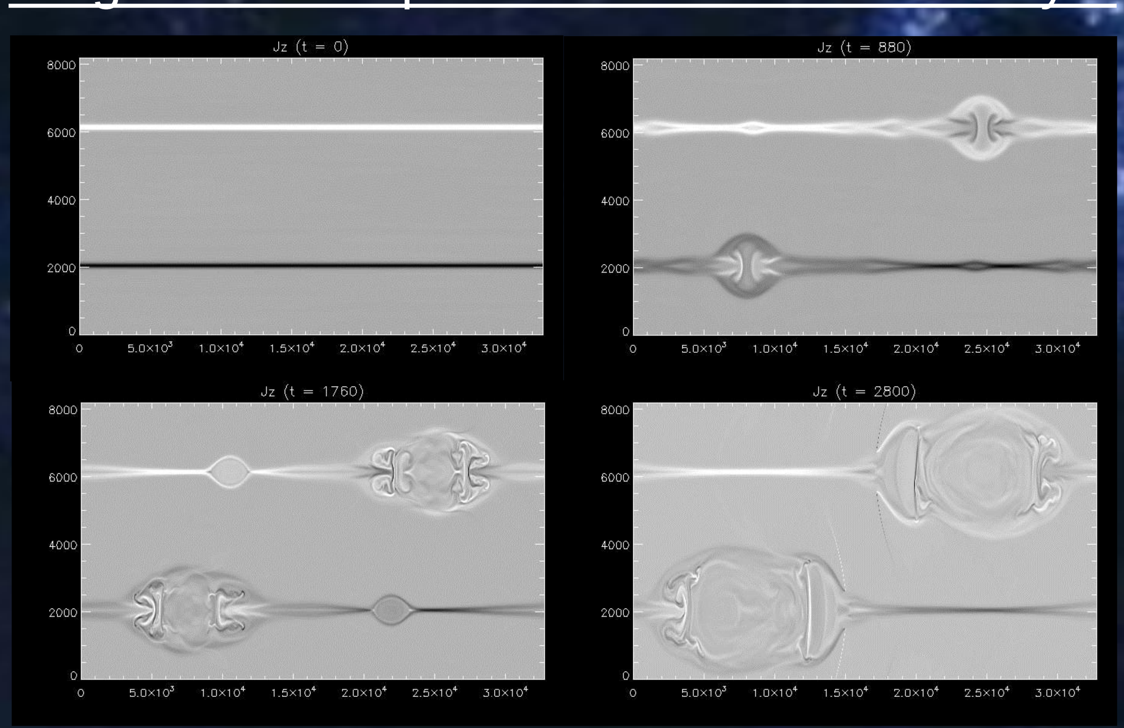
- Reconnection rate scales as $\eta^{1/2}$ along Sweet-Parker branch
- At low Lundquist number, Sweet-Parker transitions directly to Hall reconnection at a critical resistivity
- Hysteresis

- At higher Lundquist number, the Sweet-Parker layer is unstable to secondary island formation
- Some theorize oscillation between secondary island phase and Hall reconnection (we feel otherwise)

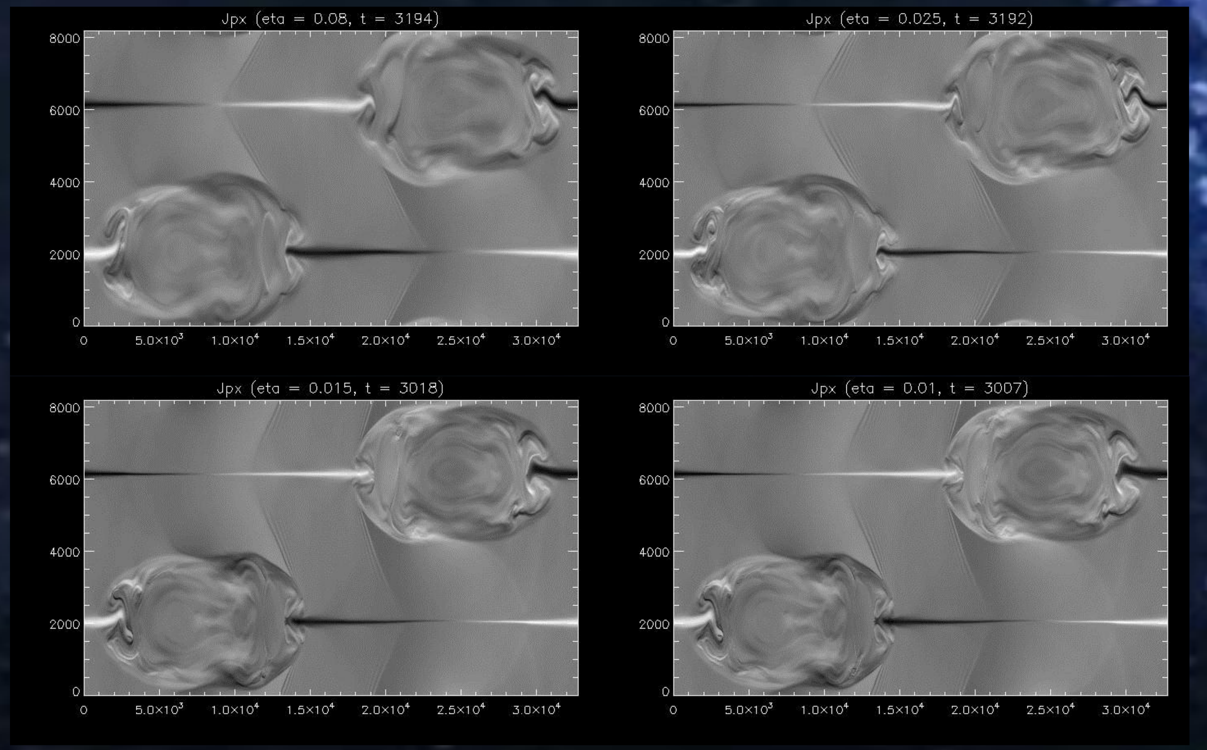
Numerical Results

- Simulations run using fluid code on hopper, a Cray XE6 massively parallel supercomputer at NERSC with over 153,000 processors

Stage 1: Development of Sweet-Parker Layer



Stage 2: Enabling the Hall term and Running at Various Resistivities



Conclusions and Future Work

- Runs with lower resistivity clearly have thinner current sheets and some have widths approaching the ion inertial length
- No runs have yet transitioned to Hall reconnection or developed secondary islands
- Runs need more time to develop, but flux is running out. A larger box might be necessary, with more flux to reconnect

If you can read this, you are too close to the poster.