The onset and dynamics of the plasmoid instability during asymmetric inflow reconnection

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Motivation

- Most simulations of the plasmoid instability assume reconnection with symmetric upstream fields
  - Simplifies computing and analysis
  - Plasmoids interact with each other and outflows in one dimension
- Asymmetry affects the scaling and dynamics of the plasmoid instability
- In 3-D, flux ropes twist and writhe and sometimes bounce off each other instead of merging
  - Asymmetric inflow reconnection simulations offer clues to 3-D dynamics

NIMROD simulations of asymmetric plasmoid formation

- Reconnecting magnetic fields are asymmetric:

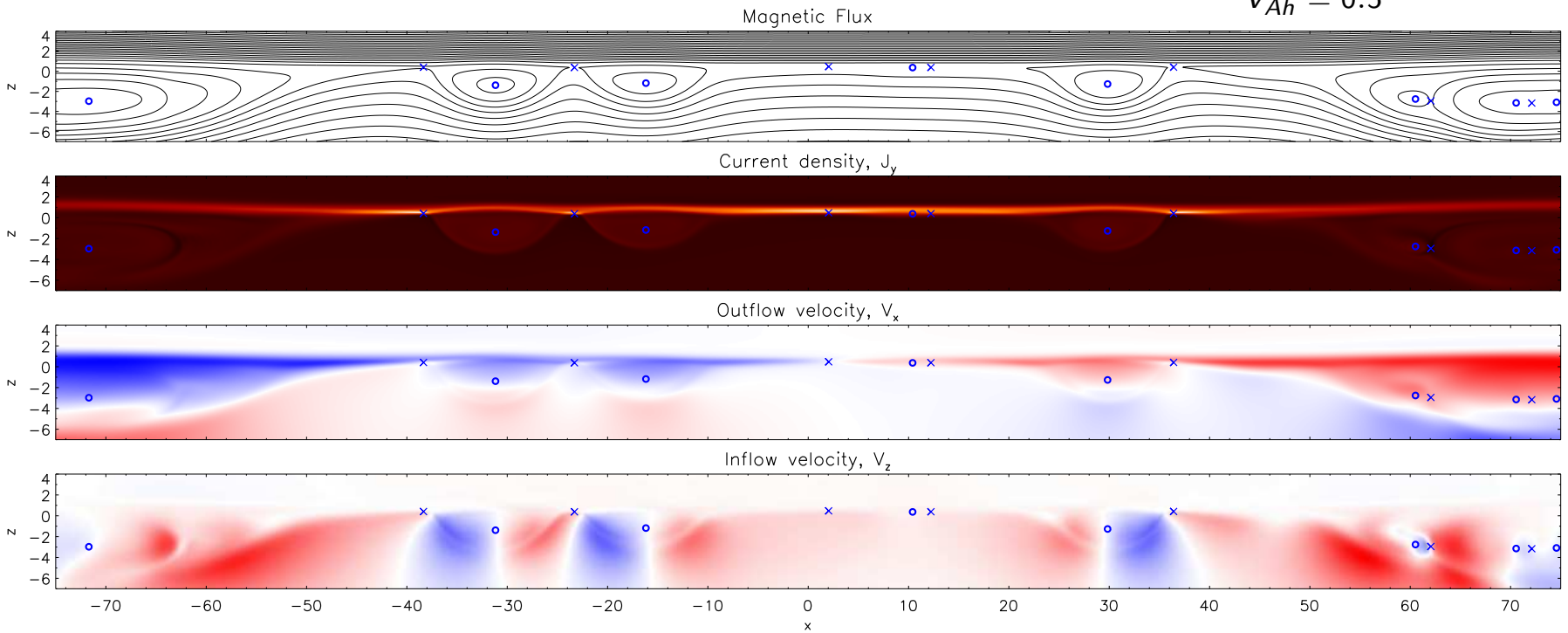
$$B_y(x) = \frac{B_0}{1+b} \tanh\left(\frac{x}{\delta_0} - b\right) \tag{1}$$

- Initial perturbations placed asymmetrically near center of domain
- Magnetic field ratio: 0.25 (density is symmetric)
- $\beta_0 = 1$ in higher magnetic field upstream region
- $-12 \leq x \leq 12$, $-150 \leq y \leq 150$
- Periodic BCs in outflow direction
- Conducting wall BCs in inflow direction
- High resolution is required because because
  - X-lines drift along inflow direction
  - Outflowing plasmoids eventually merge
- More details on the setup and numerical method in Murphy (2010) and Murphy et al. (2012)

NIMROD simulation results

Magnetic field ratio = 0.25

$S \sim 5 \times 10^4$ using $L \sim 50$
$V_{Ah} = 0.5$



$V_x \in [-0.31, 0.31]$ blue $\longrightarrow$ negative
$V_z \in [-0.07, 0.07]$ red $\longrightarrow$ positive

- X-lines offset from each other in inflow direction
- Islands develop preferentially into weak magnetic field region
- Islands propagate somewhat slowly and have net vorticity
- Indications that X-line formation is less efficient

Ongoing and future work

- Dynamics of secondary reconnection when plasmoids merge
  - Asymmetric outflow
  - Slower/less effective than in the symmetric case?
- Scaling study to determine how asymmetry impacts the onset and dynamics of plasmoid formation
- Asymptotic matching analysis do determine the onset criterion of the linear asymmetric plasmoid instability

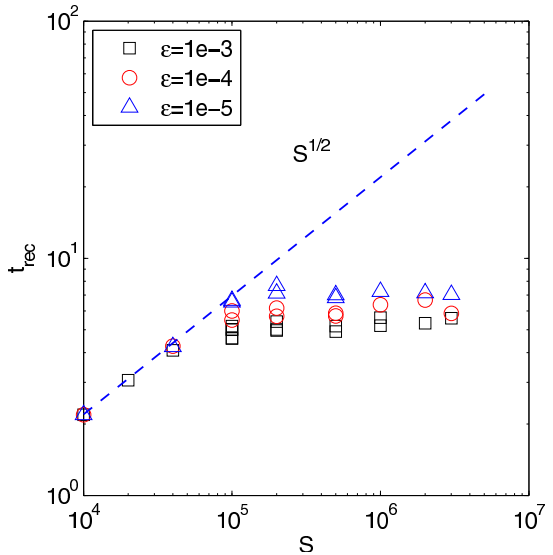
Discussion questions from simulations

- What insights could this give us into the 3-D plasmoid instability?
- Consequences on statistical models of islands
  - What happens when flux ropes are able to pass each other with only partial merging as in 3-D?
  - What is the 'equation of motion' for these plasmoids? What forces are most important?
    - Deposition of momentum by outflow jets?
- What are the consequences of net vorticity in plasmoids?
- What are the linear stability properties of the asymmetric plasmoid instability?
- How is the onset of collisionless reconnection affected by asymmetry?

Are theorists going astray?

- Savage et al. (2012): supra-arcade downflows are the wakes behind shrinking loops, not the loops themselves
  - Is this resolved? Are there other possible interpretations?
  - What can we learn about reconnection by studying the wakes behind these loops? (cross sections, etc.)
  - How and why do these wakes form?
- SADs are not plasmoids!
- Are the blobs seen in LASCO and AIA actually plasmoids? Could they be something else?
  - Condensations? Swept along plasma?
- 2-D high-S simulations show chains of plasmoids, but the moderate-S simulations look more like observations
  - LASCO blobs are barely brighter than rest of CS
  - Is this because there are complicated 3-D structures that average out, or are we missing something important?

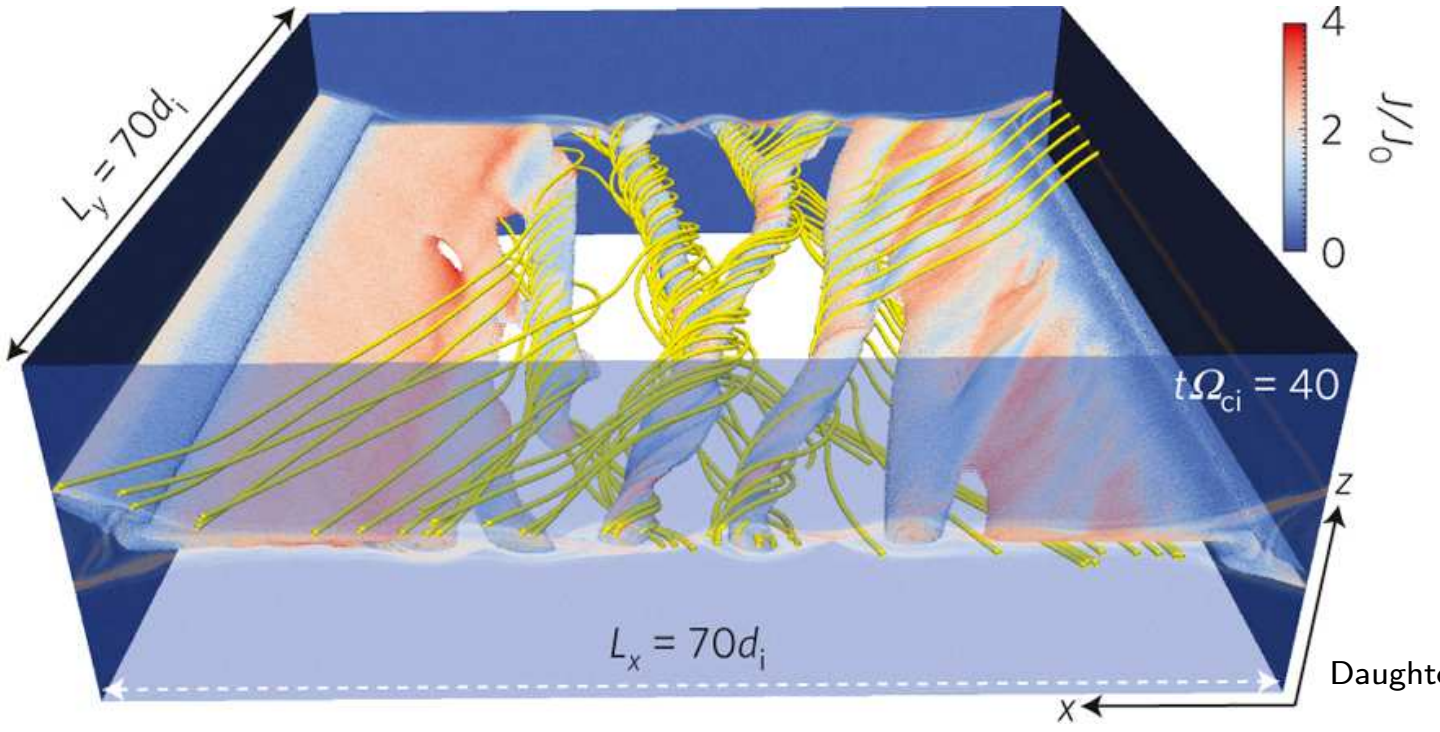
What is the reconnection rate during the 3-D plasmoid instability?



Huang & Bhattacharjee (2010)

- 2-D simulations show that the reconnection rate levels off at 0.01 for S from $\sim 4 \times 10^4$ to $\sim 10^6$
- Shepherd & Cassak argue that this is not fast enough, and that collisionless effects are necessary
- Will the 3-D plasmoid instability give reconnection rates closer to 0.01 or 0.1?
  - Can we answer this without 3-D simulations?
  - Can resistive MHD explain fast magnetic reconnection in the solar atmosphere?

When is 2-D too 2-D?



Daughton et al. (2011)

- Most plasmoid instability simulations are 2-D
- Plasmoids in 3-D will be complicated flux rope structures
- What can we learn from 2-D simulations?
- What mistakes are we making by using 2-D simulations to interpret 3-D systems?