Asymmetric Magnetic Reconnection in Partially Ionized Chromospheric Plasmas

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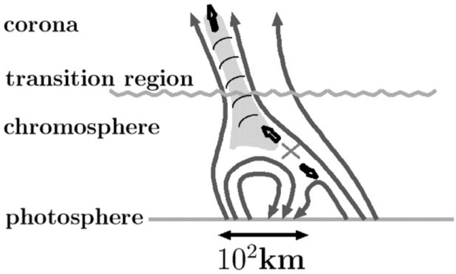
`http://www.cfa.harvard.edu/∼namurphy/Presentations/Murphy_AAS_2014.pdf`

Note: This talk replaces 409.03 which was withdrawn

Magnetic reconnection is ubiquitous in the chromosphere

- Plasma in the solar corona is typically $\sim$fully ionized
- The chromospheric ionization fraction ranges from $\lesssim$0.01–0.5
- Reconnection time scales $\sim$ ionization/recombination time scales $\Rightarrow$ plasma often not in ionization equilibrium
- We perform simulations of asymmetric magnetic reconnection in partially ionized chromospheric plasmas
- Comparisons with the Magnetic Reconnection Experiment (MRX) allow code validation (see Lawrence et al. 2013)
- Motivating questions:
  - How does asymmetry impact chromospheric reconnection?
  - What are the dynamics of the plasmoid instability?

Asymmetric reconnection in chromospheric jets



Shibata et al. (2007)

- Asymmetric inflow reconnection often occurs at the boundaries between different domains of plasma
  - Example: Earth's dayside magnetopause
- Chromospheric jets occur when newly emerged flux reconnects with pre-existing overlying flux
  - Naturally asymmetric!
- The chromosphere is a dynamic magnetized environment
  - Asymmetric reconnection should be the norm

HiFi is an implicit, modular spectral element code with significant flexibility in the equations it solves

- Module for partially ionized plasmas
  - For details, see Meier & Shumlak 2012; Leake et al. 2012, 2013
- Separate continuity, momentum, and energy equations for ions and neutrals
- Continuity equations include ionization and recombination
  - Allows departures from ionization equilibrium
- Includes momentum/energy transfer between ions and neutrals, charge exchange, resistivity, and the Hall effect
- Thermal conduction is
  - Isotropic for neutrals
  - Anisotropic for ions
- Leake et al. (2012, 2013) present HiFi simulations of symmetric partially ionized reconnection

We perform simulations with symmetric and asymmetric upstream temperatures and magnetic field strengths

- Specify **B** and T on each side, and calculate n_i and n_n so there is approximate total pressure balance (with $\beta \gtrsim 3$)
- Initial conditions require ion-neutral drift so forces acting on ions can balance forces acting on neutrals
- Applied electric field applied for $t < 5$ initiates reconnection
- Parameters chosen so that the total pressure and average upstream magnetic energy density are constant between cases
- We present three simulations with:[1]

Case A	$B_1 = B_2 = 7.9$ G	$T_1 = T_2 = 9000$ K
Case B	$B_1 = B_2 = 7.9$ G	$\mathbf{T_1 = 9250}$ **K**, $\mathbf{T_2 = 8750}$ **K**
Case C	$\mathbf{B_1 = 10}$ **G**, $\mathbf{B_2 = 5}$ **G**	$T_1 = T_2 = 9000$ K

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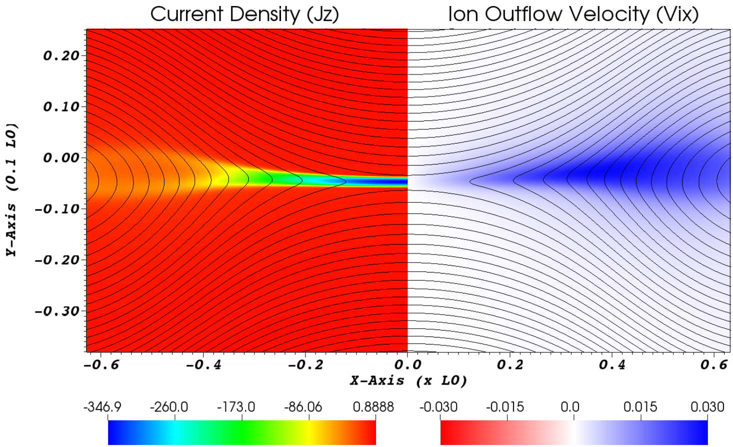
[1] The normalizations are $B_0 = 10$ G, $L_0 = 10$ km, $V_0 = 12$ km s^{-1}, and $n_0 = 3 \times 10^{16}$ m^{-3}

Case B: Asymmetric T, Symmetric **B**

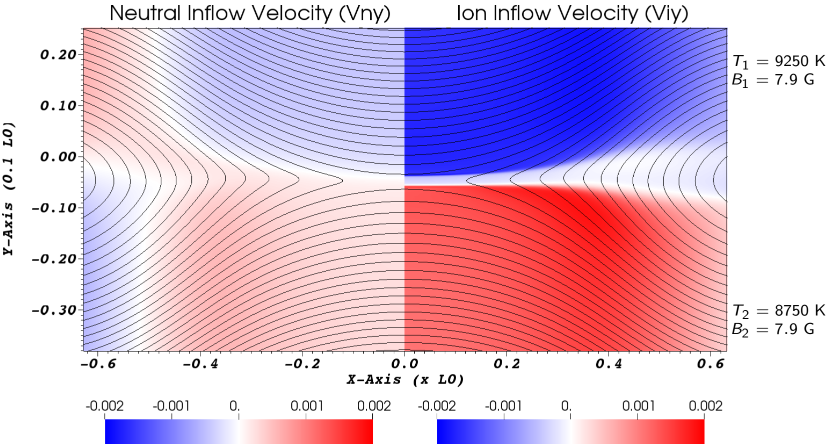


$T_1 = 9250$ K
$B_1 = 7.9$ G

$T_2 = 8750$ K
$B_2 = 7.9$ G

- The ion and neutral outflows are tightly coupled

Case B: Asymmetric T, Symmetric **B**

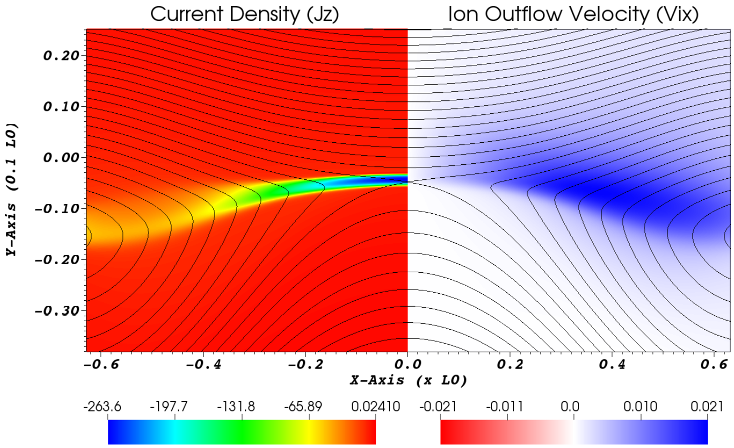


T_1 = 9250 K
B_1 = 7.9 G

T_2 = 8750 K
B_2 = 7.9 G

- Asymmetric decoupling between ions and neutrals in inflow

Case C: Symmetric T, Asymmetric **B**

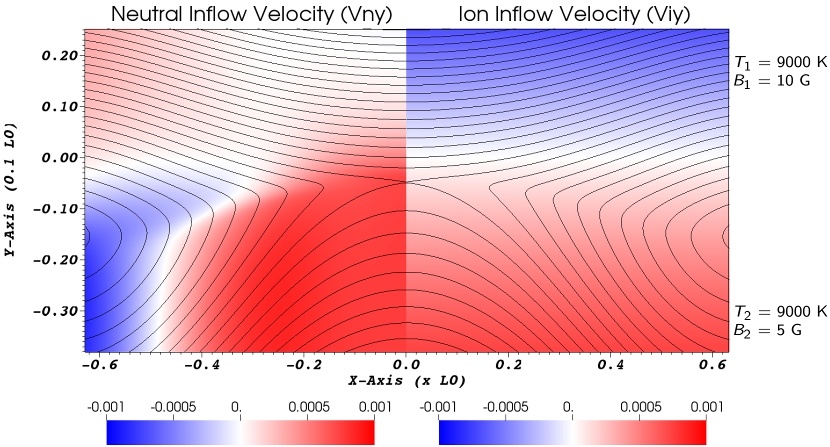


$T_1 = 9000$ K
$B_1 = 10$ G

$T_2 = 9000$ K
$B_2 = 5$ G

- Slightly arched current sheet; X-point on weak **B** side

Case C: Symmetric T, Asymmetric **B**



Neutral Inflow Velocity (Vny)

Ion Inflow Velocity (Viy)

$T_1 = 9000$ K
$B_1 = 10$ G

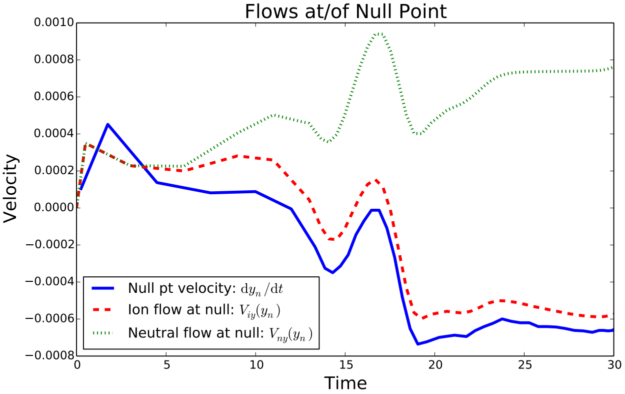
$T_2 = 9000$ K
$B_2 = 5$ G

- Higher neutral pressure on bottom → neutrals flow upward

How do the ion and neutral velocities at the X-point differ from the velocity of the X-point?

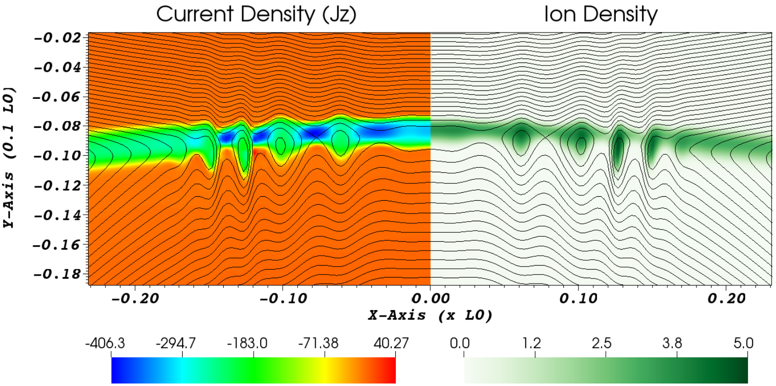
- The null point/X-point is at $y_n(t)$ along $x = 0$
- We compare three different quantities:
  - $\frac{\mathrm{d}y_n}{\mathrm{d}t}$: the velocity *of* the null point
  - $V_{iy}(y_n)$: the ion flow *at* the null point
  - $V_{ny}(y_n)$: the neutral flow *at* the null point
- Differences between $\frac{\mathrm{d}y_n}{\mathrm{d}t}$ and $V_{iy}(y_n)$ result from:
  - Resistive diffusion
  - The Hall effect
- Differences between V_{iy} and V_{ny} indicate momentum transfer between ions and neutrals

How do the ion and neutral velocities at the X-point differ from the velocity of the X-point?



- The null point drifts into the weak **B** upstream region
- Ion and neutral flows are in opposite directions
- Small difference between ion flow and null point velocity

Plasmoid formation late in time



- Mode structure concentrated around principal X-point
- Islands bulge into weak field upstream region
- See Leake et al. (2012, 2013) for symmetric case
- See Murphy et al. (2013) for asymmetric plasmoid instability in resistive MHD

Connecting to solar observations and experiment

- Connecting to solar observations (e.g., *IRIS*)
  - Challenges
    - Non-equilibrium ionization
    - Radiative transfer
    - Very short length scales
    - Confusion along line-of-sight
  - Opportunities
    - Predicting spectral signatures
    - Statistical properties of reconnection events (e.g., jets)
- Connecting to experiment (e.g., MRX; Lawrence et al. 2013)
  - Challenges
    - Limited separation of scales
    - Relatively modest plasma parameters
  - Opportunities
    - *In situ* diagnostic capabilities
    - Improved understanding of basic physics
    - Validation of simulation results

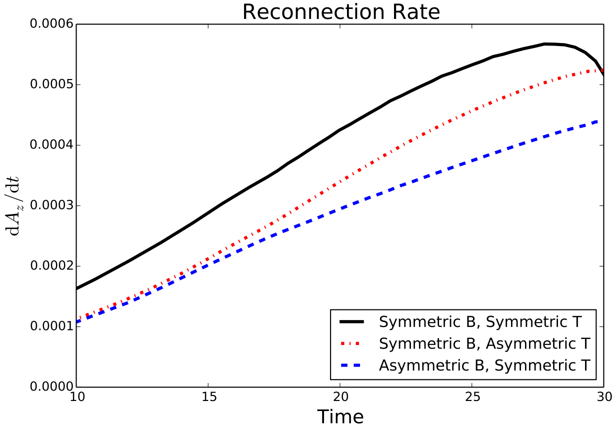
Summary & Conclusions

- We perform simulations of partially ionized reconnection with asymmetric upstream magnetic field strengths and temperatures
    - Tight coupling of ions and neutrals in outflow
    - Asymmetric decoupling of ions and neutrals in inflow
    - Ion and neutral flows across X-point
    - Plasmoid development late in time
- Future work includes
    - Influence of a guide field
    - Dynamics of plasmoid instability (symmetric vs. asymmetric)
    - Use non-equilibrium ionization modeling to track elemental fractionation (with C. Shen, J. Raymond)
    - Connecting to solar observations and MRX

Advertisment: Two SHINE sessions on reconnection

- Magnetic Reconnection in Partially Ionized Chromospheric Plasmas
  - Connecting observations of chromospheric reconnection with simulations, theory, and laboratory experiments on partially ionized reconnection
- Magnetic Reconnection and Flux Redistribution: Multi-scale and 3D dynamics
  - Connecting small-scale physics with global dynamics, understanding reconnection physics from solar observations, and building bridges to laboratory studies
- The SHINE meeting will be from June 23–27, 2014 in Telluride, Colorado. For more information, see: `http://www.shinecon.org/`

Asymmetry reduces the reconnection rate



- Convention: keep average upstream magnetic energy density and total pressure constant between simulations