Ionisation and Recombination Effects on Current Sheet Dynamics in Chromospheric Partially Ionised Plasmas

*Giulia Murtas[1], Andrew Hillier[1] and Ben Snow[1]

[1]College of Engineering, Mathematics and Physical Sciences, University of Exeter

*Email: gm442@exeter.ac.uk

UNIVERSITY OF EXETER

Chromospheric reconnection and coalescence instability

Bursty events in the chromosphere can be driven by fast magnetic reconnection, that takes place at high Lundquist numbers S (> 10^4).

Plasmoids are commonly present in reconnecting systems and found in observations of solar chromosphere (see **Fig. 1**).

Plasmoids are subject to the coalescence instability and merge when resistivity (η) is present. Coalescence is efficient in shortening the reconnection time scale – which might explain fast reconnection in the solar chromosphere.

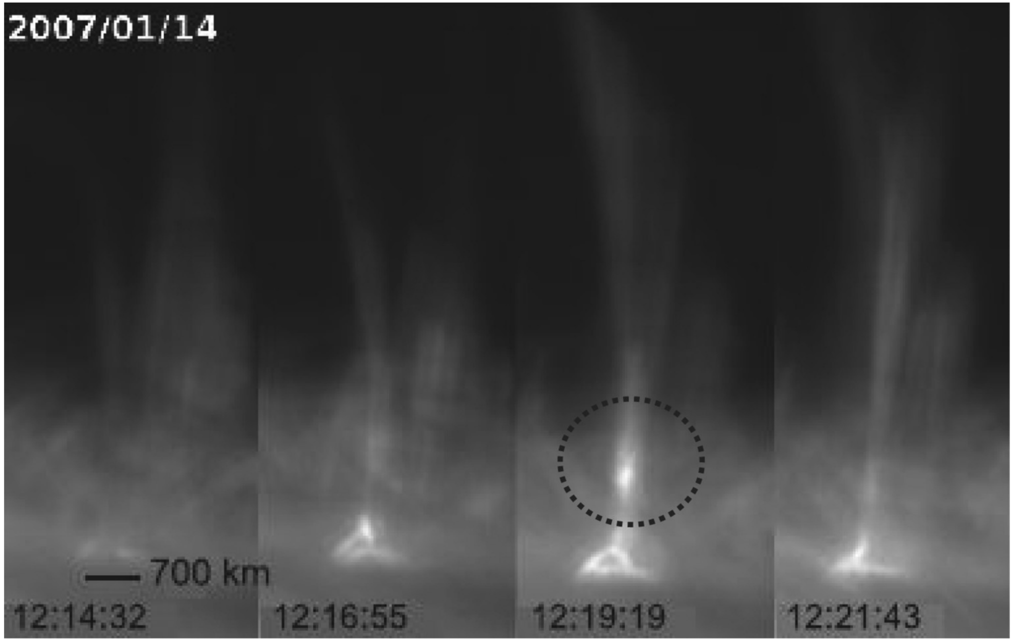


Fig. 1: Chromospheric jet and plasmoid expulsion (Singh et al., 2011)

Numerical model

Two-fluid simulations of a partially ionised plasma performed with (PIP) code (Hillier et al. 2016):

1D cases: current sheet collapse (top **Fig. 2**)

- **Resolution: 16014 grid points**. Initial imbalance between magnetic and gas pressure. Free boundaries
- **Initial collision frequency** $(\alpha_0\rho_0)$ = 100 collisions t^{-1}

2.5D cases: plasmoids coalescence (bottom **Fig. 2**)

- **Resolution: 4110 x 3086 cells**. Initial setting provided by force-free modified Fadeev equilibrium. Top & Bottom: symmetric boundaries. Sides: periodic boundaries
- **Initial collision frequency** $(\alpha_0\rho_0)$ = 5, 100 collisions t^{-1}

Other initial conditions: plasma β = 0.1, ion fraction ξ = 0.01, resistivity η = 0.0015

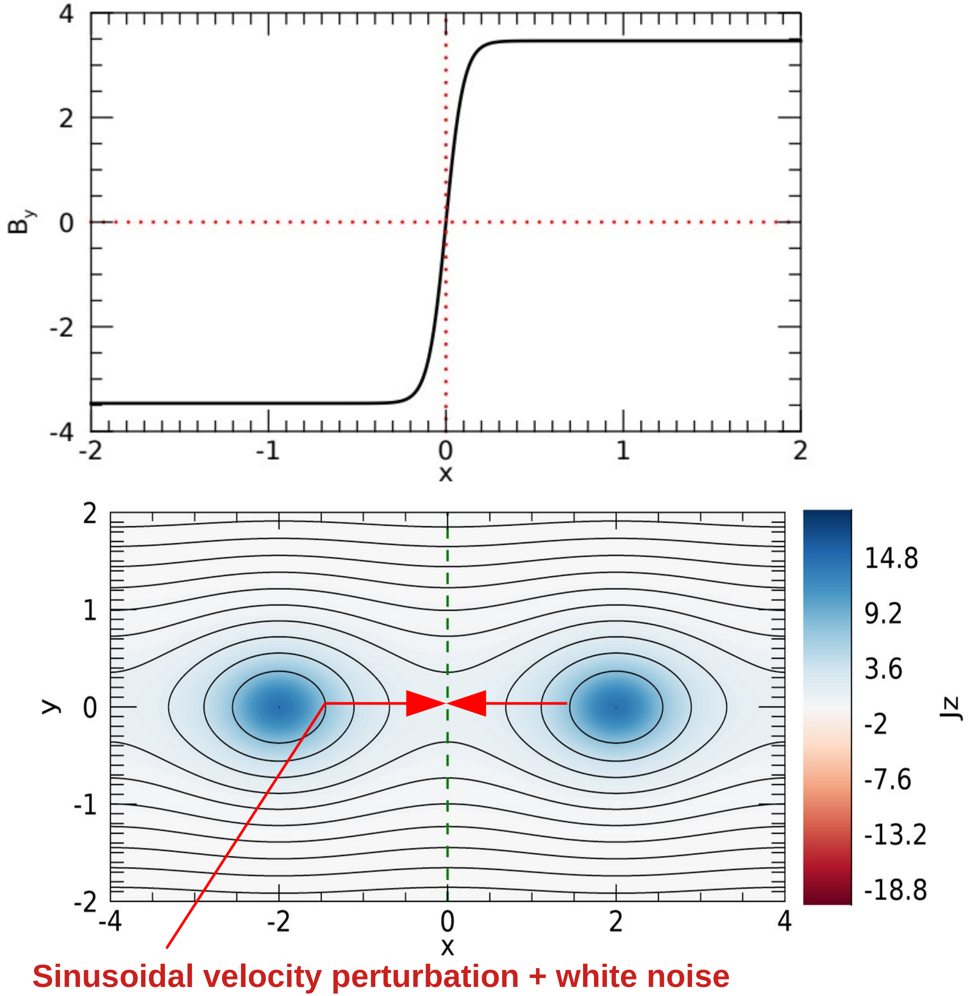


Fig. 2: Initial conditions for 1D and 2.5D simulations

1D current sheet collapse

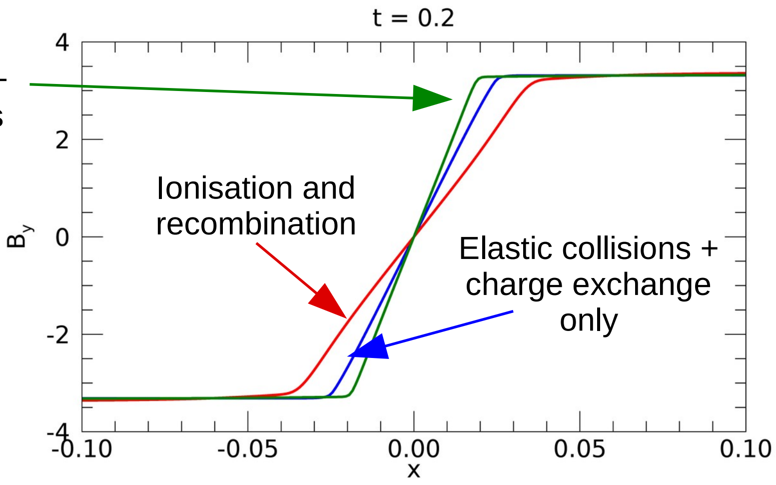


Fig. 3: B_y structure of three current sheets with different two-fluid coupling

- Burst in ionisation increases ion fraction (ξ) making thicker current sheets (see **Fig. 3**).
- Double peak is observed in the current density: collisionless collapse + two-fluid evolution at later time (see **Fig. 4**).
- Radiative losses increase the recombination rate (lower ξ) and leads to bigger current densities (thinner current sheet).

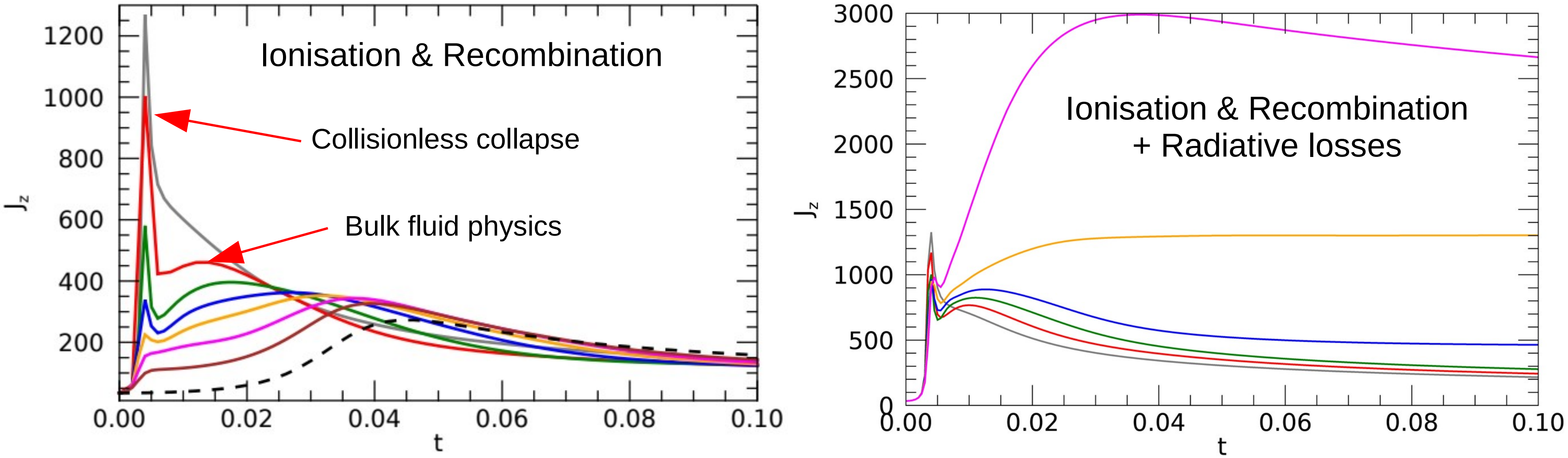
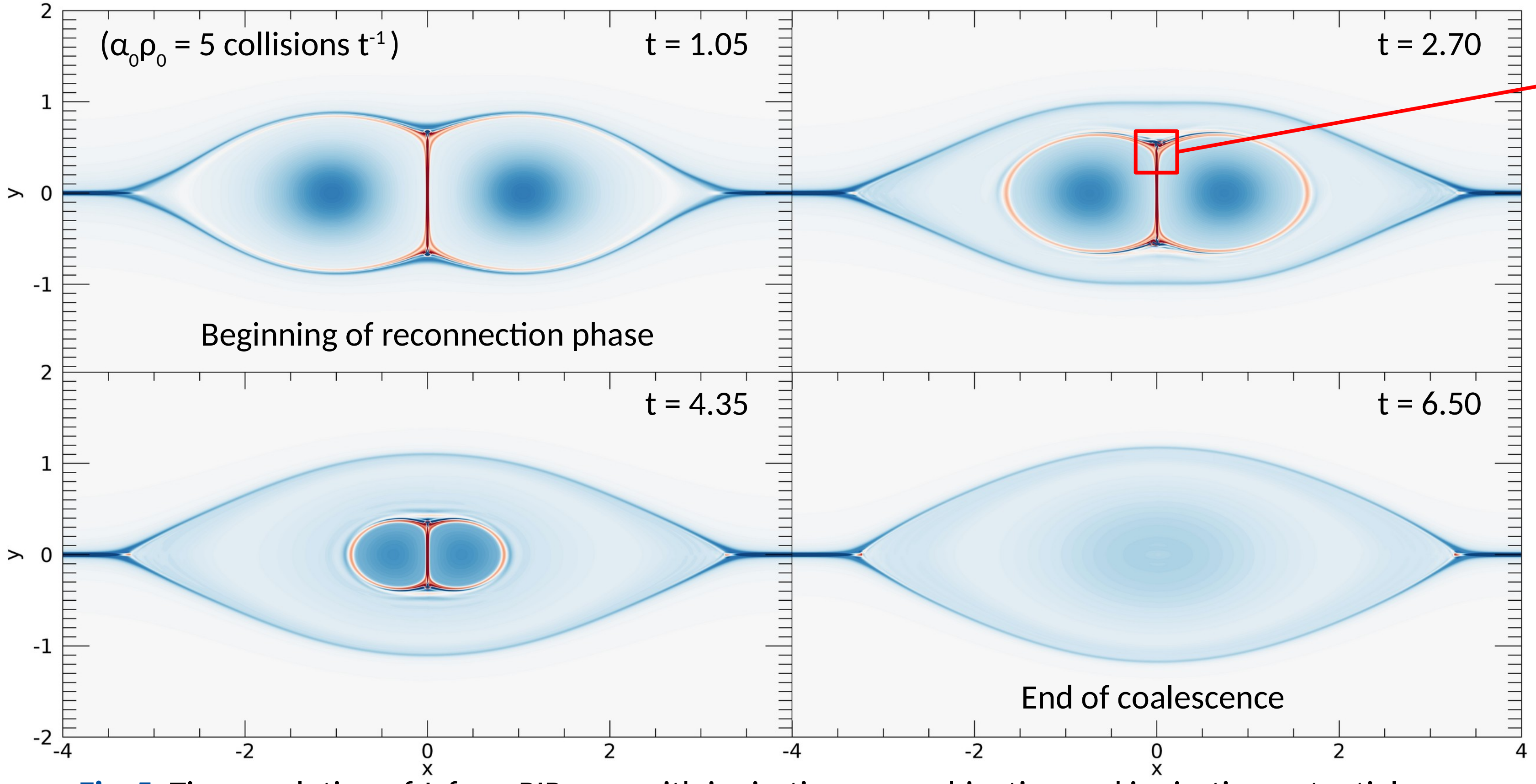


Fig. 4: Current density at the current sheet centre for τ_{IR} = 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}, 1, 10 and 10^{2}. Comparative MHD case is the black dashed line.

2.5D plasmoid coalescence instability



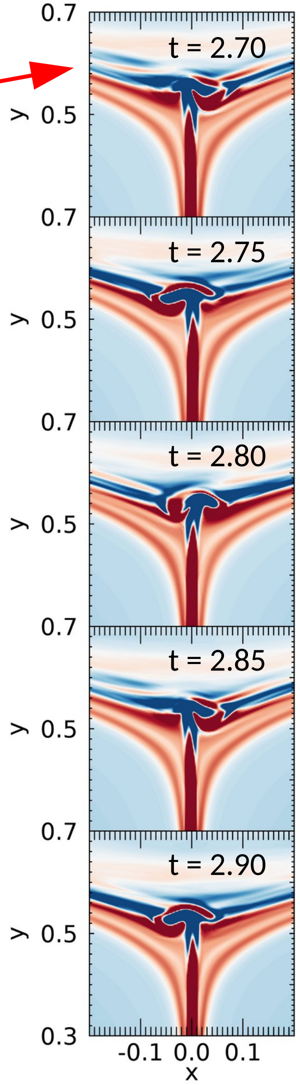


Fig. 5: Time evolution of J_z for a PIP case with ionisation, recombination and ionisation potential

Coalescence in a partially ionised plasma is laminar when ionisation and recombination are included (see **Fig. 5**). No turbulent reconnection is seen, even with ionisation potential. Oscillatory behaviour occurs around the reconnection jet termination shock. Results are dependent on η.

2.5D simulations: two-fluid coupling and τ_{IR} survey

- Ionisation and recombination slow down the coalescence by acting on the current sheet size, and stabilising it (see **Fig. 6**). Similar coalescence time scale for all PIP cases, shorter than the fully ionised plasma case.
- Survey on τ_{IR}: turbulent reconnection observed only in the case with lowest τ_{IR} (= $5 \cdot 10^{-6}$), where fluids are almost decoupled (see **Fig. 7**). All other cases show laminar reconnection or oscillatory behaviour.

Fig. 6: Time evolution of J_z at current sheet centre

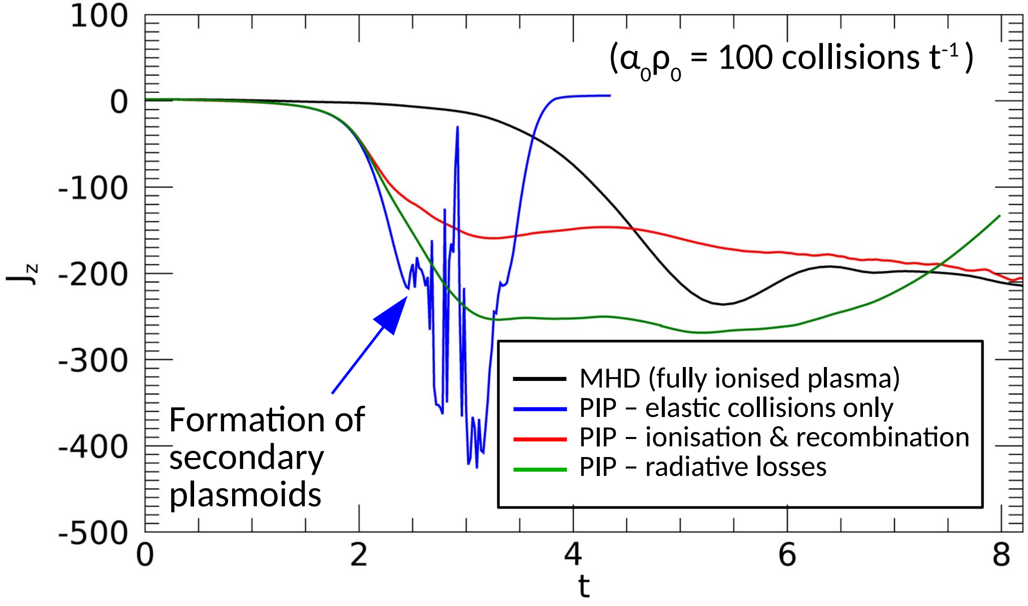
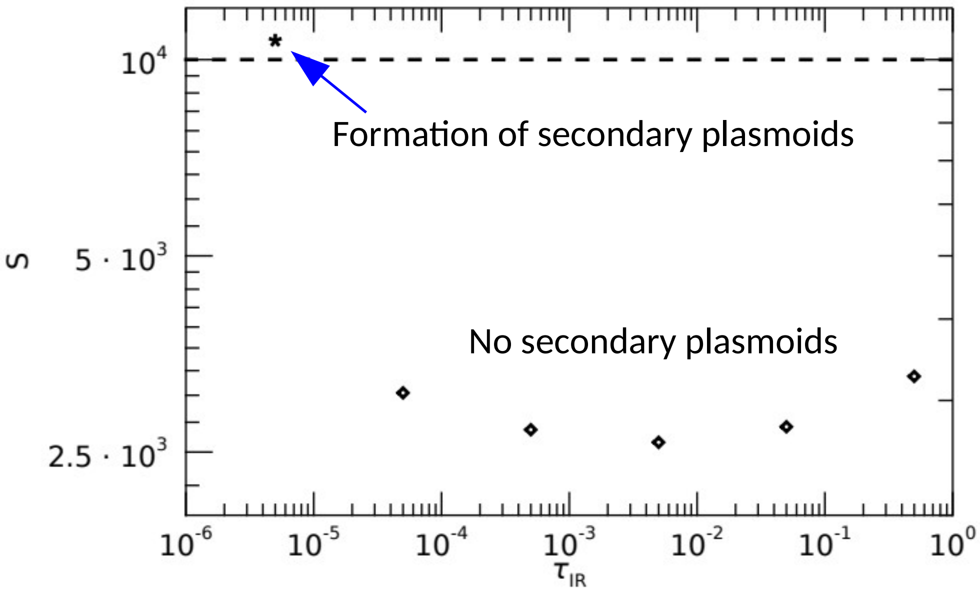


Fig. 7: Lundquist number with respect to τ_{IR} ($\alpha_0\rho_0$ = 5 collisions t^{-1})



Summary

- Chromospheric bursty events are associated to fast magnetic reconnection and plasmoid formation, which is subject to the coalescence instability.
- We investigate current sheets and plasmoid coalescence dynamics in partially ionised plasmas, focusing on different physical processes coupling plasma and neutrals: **elastic collisions and charge exchange**, **ionisation and recombination** and **radiative losses**.
- **1D simulations**: the inclusion of ionisation and recombination increases the current sheets thickness. Radiative losses thin the current sheet, resulting in bigger currents.
- **2.5D simulations**: coalescence speed decreases when more physics is included. At high collisional couplings (α_0 = 100) secondary plasmoids form only without ionisation/recombination. At low collisional couplings (α_0 = 5) secondary plasmoids form only at very low ionisation/recombination rates. Oscillations are seen at the termination of the reconnection jet.

For more details, please contact: gm442@exeter.ac.uk