Coalescence instability in Chromospheric Partially Ionised Plasmas

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Overview

- Magnetic reconnection is a recurring process in the solar atmosphere, but still little is known about how it develops in partially ionised plasmas.
- We investigate the role of partial ionisation on reconnection through the coalescence instability in a force-free field.
- We find that partial ionisation effects speed up the coalescence process and change the reconnection dynamics.

Introduction

The steady-state reconnection rate from the Sweet-Parker (SP) model depends on the Lundquist number *S*. For *S* sufficiently high, the SP current sheet becomes unstable and plasmoids forms.

Plasmoids interact through the coalescence instability, and fast reconnection takes place. This phenomenon is well known in fully ionised media but not investigated in partially ionised plasmas (*PIP*) like the chromospheric plasmas.

In this study we investigate the coalescence instability in partially ionised plasmas (*PIP*) at different levels of collisional coupling between neutrals and charges (α = 1 – 3000 collisions t^{-1}), and comparing it with the fully ionised regime (*MHD*).

Numerical Simulations

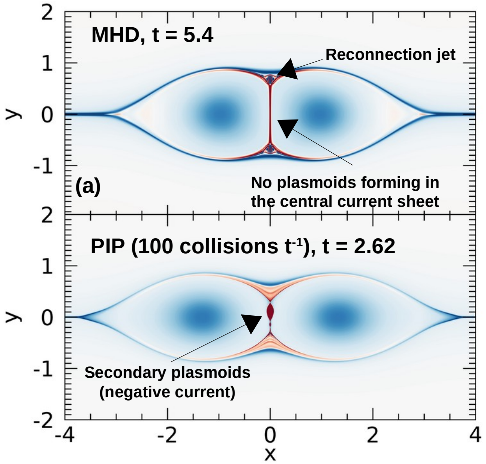
2D simulations of plasmoids coalescence, using (PIP) code (*Hillier et al. 2016*), *2049 x 1535 cells*. Initial setting provided by the 2D Fadeev equilibrium plus B_z component added to obtain a force-free field. Initial sinusoidal velocity perturbation and white noise.

$$B_x = -\frac{B_\infty \epsilon \sin(ky)}{[\cosh(kx) - \epsilon\cos(ky)]} \qquad B_y = -\frac{B_\infty \sinh(kx)}{[\cosh(kx) - \epsilon\cos(ky)]}$$

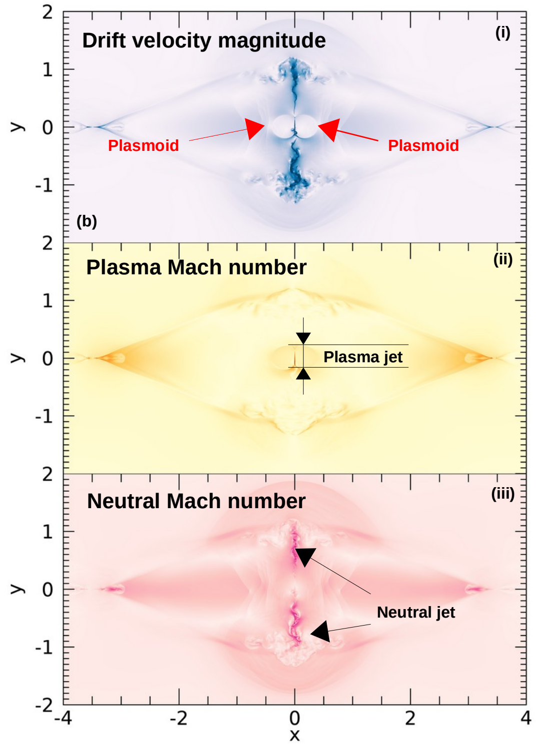
$$B_z = \frac{B_\infty \sqrt{1-\epsilon^2}}{[\cosh(ky) + \epsilon\cos(kx)]} \qquad v = -0.05\sin\left(\frac{kx}{2}\right)e^{-y^2}$$

Initial conditions. Plasma β = 0.1, neutral fraction = 0.99, resistivity (η = 0.0005), $B_\infty = \sqrt{(2\,\gamma^{-1}\,\beta^{-1})}$, k = $\pi/2$, ϵ ~ 0.5 and C = γ^{-1}.

Boundary conditions. *Top & Bottom*: symmetric boundaries. *Sides*: periodic boundaries.



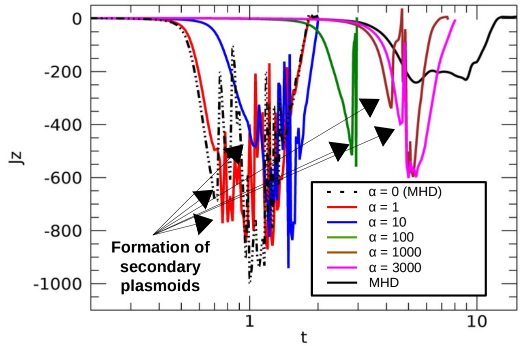
(a): Comparison of J_z (perpendicular to the plane) between MHD case (top) and PIP case (bottom). Positive current shown in blue, negative current in red.



(b): Magnitude of the drift velocity between the two fluids (i) and Mach numbers of the plasma (ii) and of the neutral flow (iii) at t = 3.48 for the PIP case (100 collisions t^{-1}) .

Results

- Formation of secondary plasmoids between the coalescing plasmoids in the PIP cases (*see Fig.* **(a)**). Found in MHD cases by increasing S of one order of magnitude (either by decreasing resistivity or β).
- Faster and more explosive magnetic reconnection observed in the PIP case, *SP*-like reconnection in the MHD case.
- **PIP** – A jet-like structure forms during plasmoid coalescence and is subject to the Kelvin-Helmholtz instability (*see Fig.* **(b)**). The jet is observed in the neutral flow and does not have a counterpart in the plasma.
- Coalescence rate increases at the decrease of collisional frequency ($\alpha \to \infty$ for the MHD case) as the Alfvén speed changes (*see Fig.* **(c)**).



(c): Evolution of central current density J_z (*x = 0, y = 0*) over time. All the PIP cases show formation of secondary plasmoids (fluctiation in the current density).

Conclusion

- The collisional coupling largely affects the timescale of coalescence (faster the lower the collisional frequency is), and the stability of the central current sheet.
- Presence of partial ionisation effects (promoted production of secondary plasmoids, neutral jet) that have no counterparts in the MHD case.

References: Biskamp, *Magnetic Reconnection in Plasmas*, 2000; Fadeev et al., *Nuclear Fusion*, 5(3):202–209, 1965; Hillier & Polito, *ApJ*, 864:L10, 2018; Hillier et al., *A&A*, 591:A112, 2016; Tajima & Shibata, *Plasma astrophysics*, 2002.