Electron dynamics in Magnetic Reconnection: a hybrid model with Landau Fluid closure

F. Finelli[(a)], *D. Laveder*[(b)], *S. S. Cerri*[(c)], & *F. Califano*[(a)]

(a) Physics Department "E. Fermi", University of Pisa, Largo Bruno Pontecorvo 3, 56127 Pisa, Italy
(b) UNS, CNRS, Observatoire de la Côte d'Azur, Bd. de l'Observatoire, C.S. 34229, 06304 Nice, France
(c) Department of Astrophysical Sciences, Princeton University, Princeton, 08544 USA

Introduction

One of the main challenges in (space) plasma physics is to provide a clear analysis of **the electron dynamics** and the electromagnetic fields **in the reconnection layer**, in particular in the so-called electron diffusion. Here we present new results using a **hybrid model with kinetic ions and fluid electrons**. The electron model **adopts the 3+1 moments Landau Fluid closure**, a nonadiabatic closure recently developed aimed at reproducing the Landau damping effect and gyrotropic anisotropy. The model is integrated numerically using a Eulerian Vlasov code and an isothermal closure for the electrons has been also adopted for comparison.

Model: the Landau Fluid

Several **closures** have been **formulated to capture** certain aspects of **kinetic physics**. The Hammett-Perkins closure [2] was derived by matching the **linear Landau damping** rate and then various **gyrokinetic effects** had been added, both gyrotropic [7] and non-gyrotropic [5, 6, 8]. These descriptions involve **dynamical equations for the parallel and perpendicular temperatures** (or pressures), and thus permits the development of **temperature anisotropies**. In this study, **we adopted the 3+1 moments gyrotropic Landau Fluid closure for the electrons**, as presented in [8], i. e., the electrons' heat fluxes are:

$$q_{e\parallel} = -2\sqrt{\frac{2\,m_i}{\pi\, m_e}\langle T_{e\parallel}\rangle}\,\mathcal{H}\left[T_{e\parallel}\right]$$

$$q_{e\perp} = -2\sqrt{\frac{2\,m_i}{\pi\, m_e}\langle T_{e\parallel}\rangle}\,\mathcal{H}\left[\frac{\langle T_{e\perp}\rangle}{\langle T_{e\parallel}\rangle}\left(\langle T_{e\perp}\rangle - \langle T_{e\parallel}\rangle\right)|\vec{B}| + T_{e\perp}\right] + \langle T_{e\perp}\rangle\left(\langle T_{e\perp}\rangle - \langle T_{e\parallel}\rangle\right)\vec{b}\cdot\vec{j}$$

where $\vec{b} = \vec{B}/|\vec{B}|$, $\vec{j} = \vec{\nabla}\times\vec{b}$ and $\mathcal{H}$ is the Hilbert transform $(\mathcal{H}f)(\vec{k}) = (\vec{b}\cdot\vec{\nabla}f)(\vec{k})/\sqrt{k_i\langle b_i b_j\rangle k_j}$. It has been shown [7] that, unlike previous models such as the CGL closure [1], these Hammett-Perkins-like models correctly predict the threshold for the mirror instability.

Numerical approach: HVM

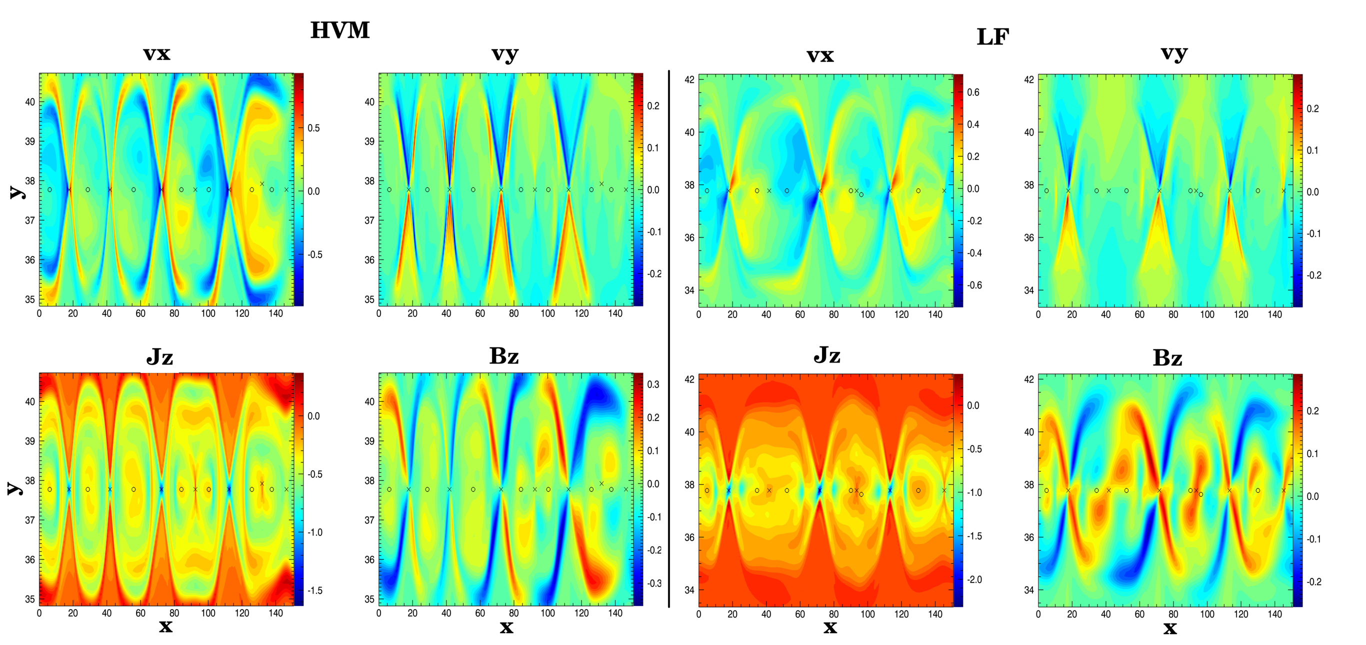
The numerical models **integrate the Vlasov equation for the ions in the 2D-3V phase space**, self-consistently coupled with the Faraday's equation, the generalized Ohm's law, and an **electron fluid**. To advance in time the distribution function, we solve the Vlasov equation by using a **Eulerian approach**, allowing an accurate and **almost noise-free** investigation of the distribution function. The algorithm treats the Vlasov equation as a **multi-advection system** advanced by using a **third-order Van Leer scheme** [3]. The integration of the equations for the **electromagnetic fields** is based on the **Current Advance Method** [10]. In this project, the same **randomly perturbed magnetic shear** was evolved with the **LF closure and an isothermal one** (for comparison).

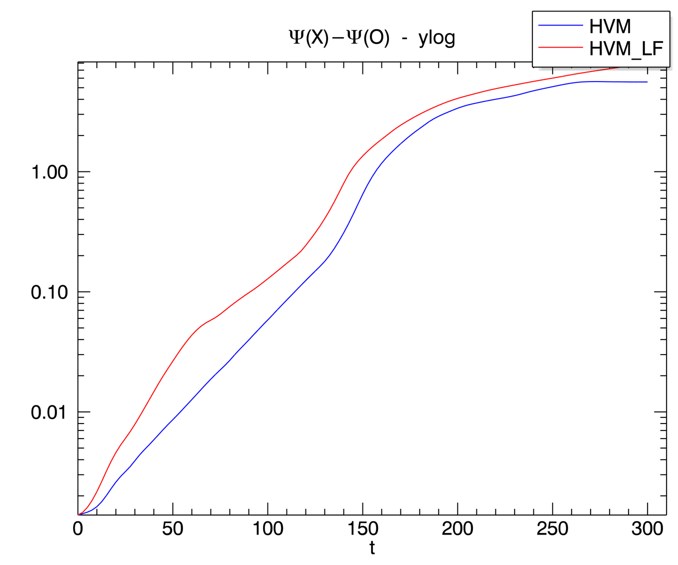
Acknowledgments

The simulations were performed on the Marconi supercomputer hosted by CINECA, as part of the ISCRA B project HP10BEQM02.

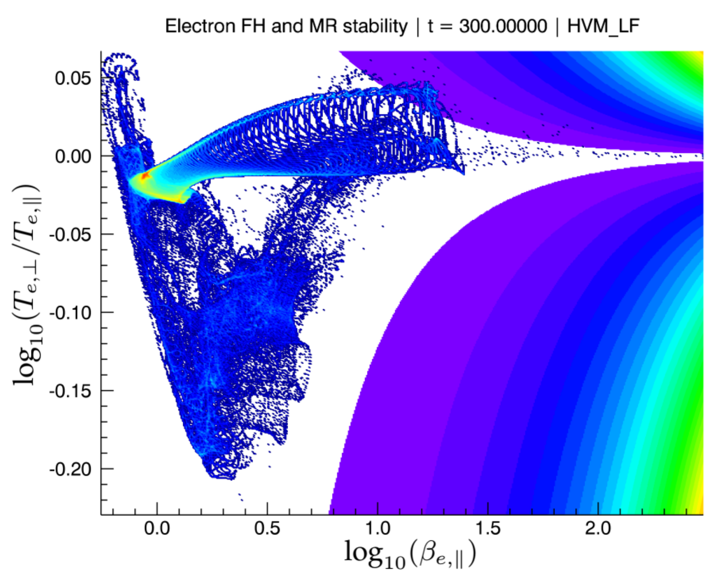
Results: LF vs. isothermal closure

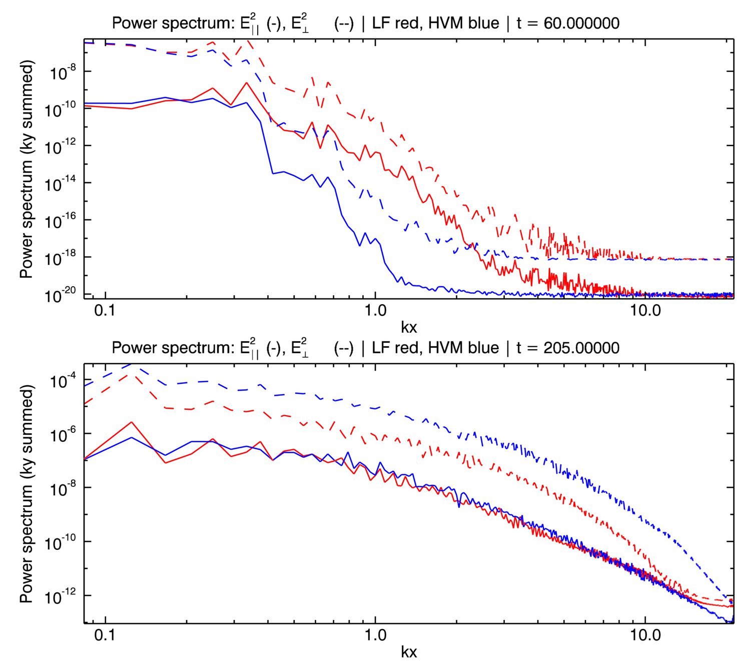
Inflow streams are symmetric in both models, **outflow jets and current sheets** are **asymmetric in the LF** one. The fact that they are oblique (not normal to the shear gradient) is something **expected** during magnetic reconnection in the presence of a guide field, **and** it is **observed *in situ* and from full-kinetic simulations**, but not in hybrid models with isotropic closures.





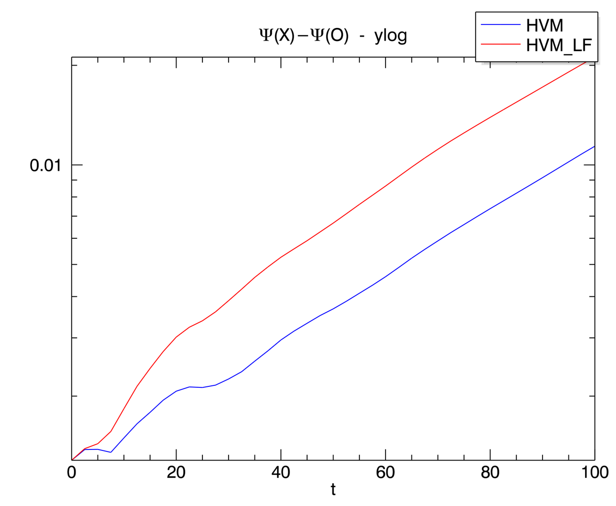
In [9] is argued that the **LF model should drive the system toward an isothermal behavior**. Studying the reconnected flux over time, we see that in late times that seems the case, **but in the linear phase, reconnection starts faster in the LF model**. After investigations, we find that the **initial condition results mirror unstable with the LF closure**: it is sensitive to some kinetic effects. Indeed, we can see how **electrons take part in pushing the system near the mirror stability threshold**.

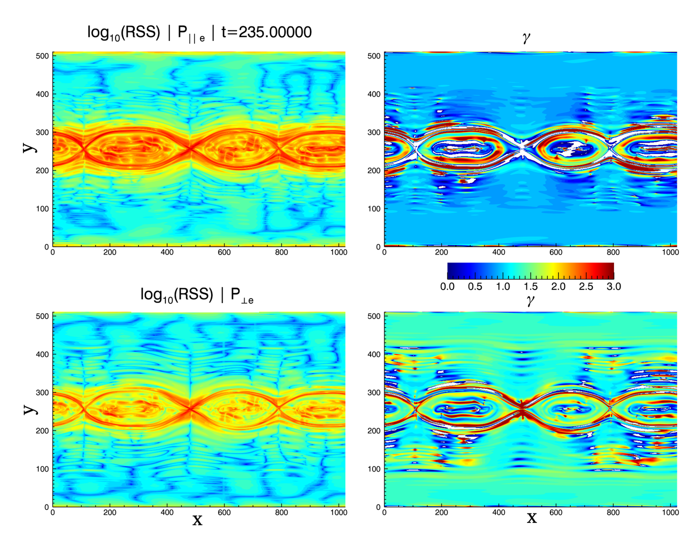




We studied $E_\parallel$ and $E_\perp$ as a measure for **parallel vs. perpendicular heating**. Assumed a polytropic closure, $E_\parallel$ **linearly depends on the polytropic factor** as $E_\parallel = -\gamma(P_e/n_e^2)\vec{\nabla}n_e\cdot\vec{B}$ (see [4]). Indeed, in later times, power spectra show clearly the **isothermal tendency of the LF model** and, at the same time, suggest **differences in the generated anisotropy**.

Future work





We started **new simulations with a kinetic stable initial condition** and already found no break in the reconnected flux. Also, we start a new kind of analysis based on the study of **local polytropic parameters**, which can be used to define **barotropic barriers**.

References

[1] G. F. Chew, M. L. Goldberger and F. E. Low, Proc. of the Royal Society 236 (1204), 112-118, 1956
[2] G. W. Hammett and F. W. Perkins, PRL 64 (25), 3019-3022, 1990
[3] A. Mangeney, F. Califano, C.Cavazzoni, J. Comp. Phys 179, 475, 2002
[4] Parashar et al., Physics of Plasmas 22, 4, 2014
[5] T. Passot and P. L. Sulem, Phys. of Plasmas 14, 082502, 2007
[6] T. Passot, P. L. Sulem, and P. Hunana, Phys. of Plasmas 19, 082113, 2012
[7] P. B. Snyder and G. W. Hammett, Phys. of Plasmas 4, 3974, 1997
[8] P. L. Sulem and T. Passot, J. Plasma Phys. 81, 325810103, 2015
[9] E. Tassi, D. Grasso et al., J. Plasma Phys. 84, 725840401, 2018
[10] F. Valentini, F. Califano et al., J. Comp. Phys. 225, 753, 2007

LaTeX TikZposter