Institut de Mathématiques de Marseille
Aix-Marseille Université

INSTITUT de MATHÉMATIQUES de MARSEILLE

Master 2 internship offer: Symplectic flow maps in plasma physics

In this internship, you will simulate ion-electron interactions using Vlasov-Poisson equations:

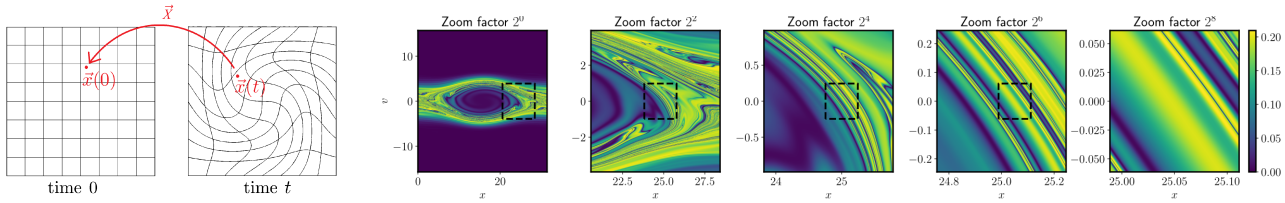
$$\begin{aligned} \partial_t f^{\mathrm{e}} + v\partial_x f^{\mathrm{e}} + \frac{q^{\mathrm{e}}}{m^{\mathrm{e}}} E \partial_v f^{\mathrm{e}} &= 0 \\ \partial_t f^{\mathrm{i}} + v\partial_x f^{\mathrm{i}} + \frac{q^{\mathrm{i}}}{m^{\mathrm{i}}} E \partial_v f^{\mathrm{i}} &= 0\,, \end{aligned} \tag{1}$$

where the ion and electron distribution functions $f^{\mathrm{i}}, f^{\mathrm{e}}$ are connected via the electric field:

$$\partial_x E = \rho^{\mathrm{e}} + \rho^{\mathrm{i}} \quad \rho^{\mathrm{e/i}} = \int f^{\mathrm{e/i}}\,\mathrm{d}v\,. \tag{2}$$

Proposal-link

To simulate this we use a so-called characteristic mapping method [1] that is a semi-Lagrangian method that evolves an underlying grid (shown in fig. 1a) in time. This newly developed method allows studying fine-scale structures of turbulence shown in fig. 1b. However, so far it only addresses single electron dynamics. The task is to extend [1] to solve eqs. (1) and (2) coupling electrons with ions.



(a) Characteristic Map

(b) Zoom into two-stream instability

Figure 1: Visualizing the idea of CMM for the two-stream instability in plasma.

Who? This internship targets physicists in their M2 master's with an understanding of numerical mathematics and who are comfortable with programming in Python/Matlab or C++.

Workplan:

The tasks for this project can be divided into the following points:

- Implementation of numerical flow iteration [2] for eqs. (1) and (2).
- Combination with existing framework [1].
- Simulation of non-linear Landau damping and validation.

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References

[1] Philipp Krah, Xi-Yuan Yin, Julius Bergmann, Jean-Christophe Nave, and Kai Schneider. A characteristic mapping method for vlasov–poisson with extreme resolution properties. *Communications in Computational Physics*, 35(4):905–937, June 2024.

[2] Rostislav-Paul Wilhelm, Jan Eifert, and Manuel Torrilhon. High fidelity simulations of the multi-species vlasov equation in the electro-static, collisional-less limit. *arXiv preprint arXiv:2404.18549*, 2024.