PICSL
Particle in Cell and Semi-Lagrangian schemes for two species plasma simulations

CEMRACS project 2016

Abstract

The aim of this project is to implement in the unified framework of the Selalib library, Semi-Lagrangian (SL) and Particle in Cell (PIC) methods for solving Vlasov equations for two species of particles coupled to Poisson/Maxwell equations. These models have multi scale behavior due to different parameters. Thus, in order to handle the computation of the numerical solutions we deal with parallelization issues and with an efficient use of SL and/or PIC methods.

Context

Full kinetic simulations for plasma physics involve the Vlasov equation for the ion (resp. electron) distribution function f_i (resp. f_e)

$$\partial_t f_s + v \cdot \nabla_x f_s + \frac{q_s}{m_s}(E + v \wedge B) \cdot \nabla_v f_s = 0,\ s \in \{e, i\}.$$

These equations are coupled via the electric field E and magnetic field B, through Poisson or Maxwell equations. In addition there are also external fields.
There are several difficulties when simulating such a model:

1. the dimensionality (the equations are posed in $3D$ space and $3D$ velocity in the general case),
2. the geometry: it can be a torus, for example for plasma tokamak simulations
3. the mass ratio m_e/m_i which is very small in realistic cases
4. the strong external magnetic field
5. the coupling between the two Vlasov equations through Maxwell/Poisson equations.

Some of these difficulties lead to multi scale time/space behavior of the solution. Such numerical models are often time-hungry and we then need large amount of computational time that are typically provided by advanced computational facilities. This is thus a challenging multi-disciplinary problem between mathematics, computer science and physics.

Objectives

In this project, we plan to address issues 3,4,5 and partly 1, by considering the $2D \times 2D$ case in cartesian geometry. The final aim of the CEMRACS project is to implement efficient numerical schemes for solving test cases in the spirit of the one proposed in [4], which fits well in this framework. The model has the advantage of being "only" $2D\times 2D$ which is more tractable than $2D\times 3D$ or even $3D\times 3D$ models. In the case of Kelvin Helmholtz instabilities, we will be able to compare fluid and kinetic simulations and possibly distinguish the kinetic effects. Concerning the numerical schemes, we have at hand, Semi-Lagrangian (SL) and Particle in Cell (PIC) solvers in the Selalib library [2]; we plan to use them for this problem and to compare their efficiency. One originality of the approach would be also to be able to use them together, as for instance PIC for electrons and SL for ions. In such a study, we may have to deal with denoising technics, so that the semi-Lagrangian scheme will not be too affected by the noise induced by the PIC scheme.

We design here some intermediate steps in order to achieve this challenging problem.

- In the framework of a Landau damping test case, comparison of SL and PIC methods in terms of accuracy and efficiency, for one species Vlasov-Poisson simulation
- Comparison between guiding center approximation and full Vlasov model with strong magnetic field, for both methods, again in the one species case
- Design of the two species algorithm in the Vlasov-Poisson case
- Identification of the limit model according to [1]
- Implementation and validation of the two species Vlasov-Poisson code, via comparison to the limit model
- Design of the one species algorithm in the Vlasov-Maxwell case
- Implementation and validation of the one species Vlasov-Maxwell code through the results in [3]
- Design of the two species algorithm in the Vlasov-Maxwell case
- Implementation and validation of the two species Vlasov-Maxwell code through the results in [4]

Participants:

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Expected presence

- Yann Barsamian: 6 weeks (almost)
- Joackim Bernier: 6 weeks (almost)
- Sever Hirstoaga: week 2, week 5
- Michel Mehrenberger: week 1 (Su evening-Fr), week 2 (Mo-Fr), week 3 (Su evening-Fr), week 6 (Mo-Th, only lunch)
- Pierre Navaro: week 2

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References

[1] Bostan, Negulescu, *Mathematical models for strongly magnetized plasmas with mass disparate particles*, Discrete and Continuous Dynamical Systems, Series B, Vol. 15. No. 3, pp.513-544 (2011).

[2] Selalib, `http://selalib.gforge.inria.fr/`

[3] Umeda, Miwa, Matsumoto, Nakamura, Togano, Fukazawa, Shinohara, *Full electromagnetic Vlasov code simulation of the Kelvin-Helmholtz instability*, Physics of Plasmas 17, 052311 (2010); doi: 10.1063/1.3422547

[4] Umeda, Ueno, Nakamura, *Ion kinetic effects on nonlinear processes of the Kelvin-Helmholtz instability*, Plasma Phys. Control. Fusion 56 (2014) 075006 (11pp)