Master Research internship: February-June 2022

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Title : Collisional operators in plasmas: Comparison with an exact N-body simulation

Summary pf the project

Background: One of the main challenges of nuclear fusion is the simulation of a turbulent plasma immersed in a strong magnetic field. This plasma turbulence is studied using kinetic equations, whereby the plasma is described by a phase-space distribution function evolving in time. Such kinetic codes are usually collisionless, but for long simulation times it may be necessary to incorporate a collision operator. This is usually done through relaxation operators (Krook) that include the collision time "by hand".

However, this is a purely phenomenological approach. Some recent works [1, 2] – based on a first-principles calculation – seem to suggest that the relaxation approach is not accurate in many situations. For instance, it was estimated that the correct collisional damping of plasma waves is up to two orders of magnitude smaller than predicted by a Krook relaxation method.

Proposed work: In this work, we plan to assess the theory developed in Refs. [1, 2], by performing accurate numerical simulations based on an electrostatic N-body code in one spatial dimension (1D). The code solves *exactly* (up to computer round-off errors) the dynamics of *N* parallel plane sheets for both ion and electron populations, moving in their perpendicular direction in a box with periodic boundary conditions. Although this is a highly idealized situation, it constitutes an appropriate testbed for rigorously checking the theoretical ideas detailed above.

In a plasma, the charged particles interact via long-range forces and this interaction causes the plasma to exhibit collective effects. If the correlation parameter *g* goes to zero (ideal collisionless plasma), the two-body collisions can be neglected and collective effects are dominant. But as *g* increases, the effects governed by the two-body collisions are longer negligible. Therefore, the transition between a collisionless and a collisional regime can be studied by progressively increasing the value of the parameter *g* [3].

In the present work, we will study the evolution of both electron plasma waves and ion acoustic waves for different values of *g*. The principal aim will be to compare the collisional relaxation process given by the exact code with the one provided by the heuristic Spitzer formula. It will also be possible to compare the results of the exact N-body code with simulations performed using a Vlasov code augmented by a Krook collision operator. The Vlasov code, developed by G. Manfredi, is already operational. The exact N-body numerical code is being developed at IJL Nancy by E. Gravier and T. Drouot.

This is a collaborative project between IPCMS (Strasbourg) and Institut Jean-lamour (IJL, Nancy). The M2 Master student will be based at IPCMS, with frequent visits to IJL in order to learn to use and upgrade the numerical code.

[1] S. F. Tigik, L. F. Ziebell, and P. H. Yoon, Physics of Plasmas **23**, 064504 (2016).
[2] P. H. Yoon, L. F. Ziebell, E. P. Kontar, and R. Schlickeiser, Phys. Rev. E **93**, 033203 (2016).
[3] D. F. Escande, D. Bénisti, Y. Elskens, D. Zarzoso, F. Doveil, Rev. Mod. Plasma Phys. **2**, 9 (2018).