Centre de Physique Théorique: Systèmes dynamiques Théories et applications

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Title of the internship: **Hamiltonian chaos and out of equilibrium statistical physics: applications to collisionless plasmas.**

Key-words: *Hamiltonian Chaos, systems with long-range interactions, Vlasov equation*

General Context:
Systems with many degrees of freedom interacting through a long range potential display non trivial collective properties. These can be associated to the fact that in the limit of large size, these systems are collectively well described by a Vlasov equation, and so called quasi-stationary states[1]. One consequence of this phenomenon is that one can attempt to understand the global dynamics from a low dimensional Hamiltonian system describing some "passive" particles moving in a self-consistent field, which can for instance explain phenomena of self-regularization the microscopic dynamics observed for some systems, or the formation of crystal like structures[2–5].

One natural setting where the Vlasov equation emerges is in hot collisionless plasmas, which are at the heart of the physics of magnetic confinement fusion. Moreover in the last few years, the impact of low dimensional chaos in the motion of charged particles in ideal plasma configurations has been shown to be able to destroy quasi-invariants in some regions of the phase space. Most notably the existence of an adiabatic constant, namely the magnetic moment μ, which is at the heart of the gyrokinetic reduction [6] appeared to be questionable in these regions. And when μ does exist, it was shown not to necessarily imply the integrability of the dynamics, even in axisymmetric magnetic fields [7, 8].

Recently some exact stationary self-consistent solutions of the Maxwell-Vlasov equations have been computed [9–11]. The stability of these exact solutions as well as the physical implications of predicted density profiles with respect to the existence of homoclinic orbits (unstable points) have not yet been studied and could provide interesting new perspectives in the understanding of global plasma dynamics, especially for the formation of internal or external transport barriers and how to trigger/control them from an experimental view point. This is a topic of current great interest for fusion as the onset and sustainment of a stable external transport barrier is the baseline operational scenario for ITER. The internship work will focus on studying out-of-equilibrium statistical and dynamical properties of systems with long-range interactions with the goal to transpose the findings in the plasma context.

Scientific Environment: This internship work will be part of a long standing collaboration with the IRFM of the CEA Cadarache within the French national research federation of magnetic confinement fusion (FR-FCM).

This internship is eventually meant to be continued during a PhD.

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[1] Alessandro Campa, Thierry Dauxois, and Stefano Ruffo. Statistical mechanics and dynamics of solvable models with long-range interactions. *Phys. Rep.*, 480:57–159, 2009.

[2] R. Bachelard, C. Chandre, D. Fanelli, X. Leoncini, and S. Ruffo. Abundance of regular orbits and out-of-equilibrium phase transitions in the thermodynamic limit for long-range systems. *Phys. Rev. Lett.*, 101(26):260603, 2008.

[3] X. Leoncini, T. L. Van den Berg, and D. Fanelli. Out of equilibrium solutions in the XY-Hamiltonian mean field model. *EPL*, 86:20002, 2009.

[4] Alessio Turchi, Xavier Leoncini, and Duccio Fanelli. Emergence of a coherent crystal in a classical system with long range interactions . *EPL (Europhys. Lett.)*, 111:30011, 2015.

[5] T. L. Van den Berg, D. Fanelli, and X. Leoncini. Stationary states and fractional dynamics in systems with long range interactions. *EPL*, 89:50010, 2010.

[6] A. J. Brizard and T. S. Hahm. Foundations of nonlinear gyrokinetic theory. *Rev. of Modern Physics*, 79(2):421, 2007.

[7] B. Cambon, X. Leoncini, M. Vittot, R. Dumont, and X. Garbet. Chaotic motion of charged particles in toroidal magnetic configurations. *Chaos*, 24:033101, 2014.

[8] S. Ogawa, B. Cambon, X. Leoncini, M. Vittot, D. Del Castillo-Negrete, G. Dif-Pradalier, and X. Garbet. Full particle orbit effects in regular and stochastic magnetic fields. *Phys. Plasmas*, 23:072506, 2016.

[9] Shun Ogawa, Xavier Leoncini, Alexei Vasiliev, and Xavier Garbet. Tailoring steep density profile with unstable points. *Phys. Lett. A*, 383:35–39, 2019.

[10] Elias Laribi, Shun Ogawa, Guilhem Dif-Pradalier, Alexei Vasiliev, and Xavier Leoncini. Influence of Toroidal Flow on Stationary Density of Collisionless Plasmas. 4(3):172.

[11] Aurelien Cordonnier. Chaotic motion of charged particles in magnetic fields, from single trajectories to collective equilibrium: applications to fusion plasmas. Master's thesis, 2019.