Doctorate School n° 352: PHYSIQUE ET SCIENCES DE LA MATIERE

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Title of the thesis: **Chaotic motion of charged particles in magnetic fields, applications to fusion plasmas.**

General Context:
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 gyrokinetics reduction appeared to be questionnable in these regions, or when it exists, this was shown not to imply the integrability of the dynamics, even in axisymmetric magnetic fields [1, 2]. This local invariant breaking could be a major concern, most notably when considering transport predictions coming out of gyrokinetic codes, which are often considered as "first principles" results by the community. Indeed the existence of regions where μ displays large fluctuations, does not allow a global change of variables in the Vlasov density functions of particles, so that the gyrokinetic reduction of the Vlasov equation can be impaired. An objective of the PhD is to estimate how the existence of these regions impact the results in regards to other physical/numerical approximations made in current implementations of gyrokinetics. Besides plasma confinement has been greatly improved when operating in the so-called H-mode. This high-confinement mode is triggered by the emergence of internal transport barriers in the plasma. In this regime, the impact of the chaotic motion of the particles can be quite tricky: although chaos usually implies larger diffusivity and as such less confinement, the destruction of the nested set of magnetic surfaces by the presence of some magnetic perturbation inducing chaotic magnetic field lines, does not necessarily means less confinement, as particle chaos and field line chaos are not simply linked [2, 3]. These phenomenon need as well to be further investigated and understood. A first step for the phD will be to set up an algorithm to compute charged particle trajectories using high order Taylor expansions. If successful, and validated against the current 6th-order symplectic implementation, this technique should allow us to speed up the computation of very large time trajectories and ease the investigation of the realm of adiabatic chaos that can also occur on large time scale.

Required knowledge: This PhD work will be in the framework of theoretical/numerical physics. Some knowledge in nonlinear physics, Hamiltonian chaos and dynamics, and plasma physics would be very much appreciated. The mastering of the numerical tools in order to perform numerical simulations (programming language of the type fortran90 or C and C++) and some tools to do post-processing (matlab, octave, python) is necessary. The knowledge of formal calculus software like maxima or mathematica is a plus. Mastering of the English language knowledge is a must.

Scientific Environment: This phD 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).

[1] B. Cambon, X. Leoncini, M. Vittot, R. Dumont, and X. X. Garbet. Chaotic motion of charged particles in toroidal magnetic configurations. *Chaos*, 24:033101, 2014.
[2] 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.
[3] S. Ogawa, X. Leoncini, G. Dif-Pradalier, and X. Garbet. Study on creation and destruction of transport barriers via effective safety factors for energetic particles. *Phys. Plasmas*, 23:122510, 2016.