Master 2: *International Centre for Fundamental Physics*

INTERNSHIP PROPOSAL

(One page maximum)

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Internship location: PhLAM Laboratory, "Quantum Chaos group"

Thesis possibility after internship: YES
Funding: YES If YES, which type of funding: University, HdF Region

Localization phenomena in a Bose-Einstein condensate with tunable interactions

The physics of many-body quantum systems is extremely complex to study, both theoretically and numerically. One way to study experimentally these systems is to carry out "quantum simulations", using model systems that are both very flexible (with a large number of controllable parameters) and which obey the same type of many-body Hamiltonian as the original one. To make a quantum simulator, it is now possible to experimentally use gases of ultra-cold atoms, having temperatures very close to absolute zero. Quantum behavior then becomes dominant, and leads to the emergence of new states of matter, such as the Bose-Einstein condensate.

One of the research fields of the "Quantum Chaos" group in PhLAM laboratory in Lille is to use these tools to study certain condensed matter phenomena - in particular to understand the conduction properties of electrons in a crystal lattice in the presence of disorder [1,2]. Because electrons (and ultra-cold atoms) are quantum particles they can follow several 'trajectories', or 'Feynman paths', as they propagate through the potential, which interfere with each other. Under certain conditions, this can lead to an exponential decrease in the probability of particles ending up far from their original position - akin to insulating behavior. This phenomenon is called Anderson localization.

Our team is currently working at building a new experiment for the Bose-Einstein condensation of potassium atoms. This atomic species is particularly well suited to introduce controllable interactions between the atoms of the condensate, via the application of static or radiofrequency magnetic fields. The internship subject will be oriented towards the implementation of the different stages of evaporative cooling leading to condensation and potentially towards the observation and characterization of Feshbach resonances.

In perspective, the presence of interactions will create quantum correlations between the particles of the Bose-Einstein condensate and modify the nature of the localization - in connection with the phenomenon of 'N-body localization' (or 'Many Body Localization', MBL) [3], which has been observed very recently, and whose study is still at its beginnings. Another exciting perspective consists in controlling the fundamental properties of symmetries of the Hamiltonian [4,5], by introducing a spin-orbit type coupling. This will open perspectives for the quantum simulation of topological phenomena related with the physics of the quantum Hall effect [6].

Collaborations : D. Delande, N. Cherroret (ENS Paris), G. Lemarié (LPT Toulouse), C. Tian (Académie de Pekin)

[1] J-C. Garreau, C. R. Phys. 1, 31 (2017)	[4] C. Hainaut et al. Nat. Commun. 9, 1382 (2018)
[2] C. Muller, D. Delande arXiv:1005.0915 (2016)	[5] C. Hainaut et al. Phys. Rev. Lett. 121, 134101 (2018)
[3] D. Abanin, et al. Rev. Mod. Phys. 91, 021001 (2019)	[6] C. Tian et al. Phys. Rev. Lett. 113, 216802 (2014)

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:
Condensed Matter Physics: NO Soft Matter and Biological Physics: NO
Quantum Physics: YES Theoretical Physics: NO