Master 2: ***International Centre for Fundamental Physics***

INTERNSHIP PROPOSAL

Laboratory name: Matériaux et Phénomènes Quantiques (MPQ), Université Paris Cité
CNRS identification code: UMR 7162
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Thesis possibility after internship: YES

Emergent long-range interactions and phase transitions in dissipative atom-cavity systems

Ultra-cold atoms in optical lattices provide a natural platform to engineer the fundamental models of condensed matter theory in a highly controlled way and to explore the associated quantum phenomena. A paradigmatic example is the Bose-Hubbard model and the related superfluid to Mott insulator phase transition at integer fillings. When the bosons are coupled to a dissipative mode of an optical cavity, they experience effective nonlocal interactions, which in turn drive the system towards new additional phases, like the supersolid state and the charge density wave insulator, which have been observed experimentally [Landig2016]. The theoretical understanding of these hybrid systems has so far been based on approximate schemes, where the cavity mode is integrated out, leading to an extended Hubbard model for the bosons.

In this Internship we will use phase space methods to simulate numerically the quantum dynamics of the full system, including the dissipative cavity mode. In these methods local quantum field operators are replaced by classical variables, obeying stochastic differential (Ito) equations. Their solution determines multiple trajectories in phase space, from which one extract all physical observables by averaging [Deuar2021]. We will characterize the properties of the steady state and study the different phase transitions that appear by varying the strength of the atom-cavity (Rabi) coupling and the system size.

During the internship the student will develop a basic python code to solve numerically the stochastic equations for one-dimensional hybrid systems and will use it to uncover their properties in the steady state regime.

[Landig2016] R. Landig et al, Nature 532, 476 (2016).
[Deuar2021] P. Deuar, A. Ferrier, M. Matuszewski, G. Orso, and M.H. Szymanska, PRX Quantum 2, 010319 (2021).

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics: YES
Soft Matter and Biological Physics: NO
Quantum Physics: YES
Theoretical Physics: YES