Classical Analogs of Quantum Systems

DIRECTEURS DE THESE : GIOVANNI MANFREDI
INSTITUT DE PHYSIQUE ET CHIMIE DES MATERIAUX DE STRASBOURG (IPCMS)
TEL: 03 88 10 72 14 ; E-MAIL: GIOVANNI.MANFREDI@IPCMS.UNISTRA.FR

Analogies in physics constitute a powerful tool for the understanding of complex phenomena. They enable us to transfer knowledge and intuition between some *a priori* unrelated domains, and sometimes motivate the development of new theoretical or experimental tools by exporting them to a different field. Analogies are particularly useful when one of the two systems (A) is beyond reach from an experimental point of view – then, the experiments can be carried out on the analog system (B), and the results transposed back to system (A). Of course, this is only valid as far as the mathematical analogy holds. For instance, in recent years, table-top experiments have been used to get insight into complex, and experimentally unreachable, domains such as quantum gravity and black holes, using acoustic [Bar11] or optical [Rog16] analogs.

Classical analogs of quantum systems have been developed in the past, based on optical [Bou95] or hydrodynamic [Cou05] experiments. In particular, Couder's experiments [Cou05] using small oil droplets bouncing on a fluid have triggered a lot of interest, as they are close to reproducing Louis de Broglie's original idea of deterministic motion guided by a pilot wave.

The present proposal is devoted to the exploration of quantum systems using classical stochastic analogs, implemented experimentally by means of micron-sized Brownian particles optically trapped by a laser beam. The particles are usually dielectric beads immersed in a fluid (water, air) acting as a thermal bath. The shape and stiffness of the trapping is proportional to the intensity of the laser and can thus be precisely controlled and tailored in real time. The corresponding instantaneous diffusive motion of the bead inside the modulated trap can be recorded with very high resolution.

The PhD work will be structured around two main themes:

1. Classical analogs of unitary quantum evolutions, described by the time-dependent Schrödinger equation, based on Nelson's stochastic representation of quantum mechanics [Nel66];
2. Classical analogs of open quantum systems (in contact with an environment) described by quantum hydrodynamic models [Man05, Goe20].

The PhD candidate will develop and analyze the relevant stochastic models that underpin the classical/quantum analogy. He/she will also implement the numerical codes needed to simulate the stochastic dynamics, which will be used to benchmark the experimental results.

This theoretical work will be accompanied by experiments carried out at the Institut de Science et d'Ingénierie Supramoléculaires, in the framework of an ongoing collaboration with Dr. Cyriaque Genet [Goe20, Ros20].

[Bar11] C. Barcelo et al., Living Rev. Relativity **14**, 3 (2011)
[Bou95] D. Bouwmeester et al. Physical Review A **51**, 646 (1995)
[Cou05] Y. Couder, S. Protiere, E. Fort, and A. Boudaoud, Nature **437**, 208 (2005)
[Goe20] R. Goerlich et al., arXiv:2007.12246 (2020)
[Man05] G. Manfredi, Fields Inst. Commun. Series **46**, 263 (2005)
[Nel66] E. Nelson, Phys. Rev. **150**, 1069 (1966)
[Rog16] T. Roger et al., Nature Commun. **7**, 13492 (2016)
[Ros20] Y. Rosales-Cabara et al., Phys. Rev. Res. **2**, 012012(R) (2020)