INTERNSHIP PROPOSAL

(One page maximum)

Laboratory name: Laboratoire Collisions Agrégats Réactivité (LCAR)
CNRS identification code: UMR 5589
Internship director'surname: Guéry-Odelin (David), co-supervisor: Billy (Juliette)
e-mail: dgo@irsamc.ups-tlse.fr Phone number: +33 5 61 55 83 21
Web page: https://www.quantumengineering-tlse.org
Internship location: LCAR, Université de Toulouse, Bât. 3R4, 118 route de Narbonne, 31062 Toulouse
Thesis possibility after internship: YES
Funding: NO (ANR application in progress)

Finite-time optimal quantum sensors: engineering the Fisher information with cold atoms in modulated optical lattices

Summary:
Atom interferometers rely on prescribed sequences (splitting, reflection, recombination), optimized step by step, whose precision improves through the repetition of measurements. This project addresses a complementary question, which becomes essential whenever the interrogation time or the number of experimental runs is limited: how much information can a single experimental cycle deliver? The idea is to design state preparation, dynamics and readout globally so as to maximize this information.
With a rubidium-87 Bose–Einstein condensate in an optical lattice whose phase is modulated in real time, we have recently demonstrated this strategy for the measurement of a force. The modulation, optimized from the Fisher information, spontaneously gives rise to an interferometer (splitting, velocity reversal, recombination) that reaches the quantum bound in a fraction of a millisecond.
The goal is now to determine what replaces the standard interferometric scheme when several parameters are measured simultaneously, for instance the components of an acceleration, or an acceleration and a rotation. The quantity to optimize then becomes a Fisher matrix, which describes both the attainable precisions and the correlations between the estimates. Are there fundamental incompatibilities between parameters? Can the quantum bound be reached with realistic measurements? What is the nature of the optimal dynamics?
The project will first extend our one-dimensional demonstration to the optimal measurement of a force gradient, compared with a conventional gradiometer, and then to the joint estimation of an acceleration and its gradient, using the combined control of the phase and the depth of the lattice. It will then address two-dimensional vectorial sensing: the same set of laser beams produces either a square lattice, in which the dynamics decomposes into two independent chains, or a triangular lattice, which is genuinely non-separable. We will investigate whether this non-separability is a geometric resource offering more informative Fisher matrices, and compare rotation-sensing protocols with the Sagnac scheme. Finally, robustness against poorly known parameters (lattice depth, velocity spread) and the role of atomic interactions will be studied.
The internship combines experiment (reconfigurable optical lattices, electro-optic modulation) and computation (simulation, control optimization, Fisher matrices). It offers a complete training at the interface between cold atoms, quantum control and quantum metrology.

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