Realization of a Topological Model in a Dynamical Quantum System with a Bose–Einstein Condensate

Topology describes global properties of quantum states that are robust against defects or imperfections, and which often manifest through the emergence of protected states or invariant physical quantities. In recent years, such effects have been observed in exotic materials such as topological insulators, but they can also be realized in periodically driven systems (Floquet systems), which provide a privileged framework for exploring the emergence of nonequilibrium topological phases. A simple model, experimentally realizable with a Bose–Einstein condensate (BEC) and known as the quantum kicked rotor [1,2], constitutes an ideal paradigm for studying these phenomena [3,4,5].

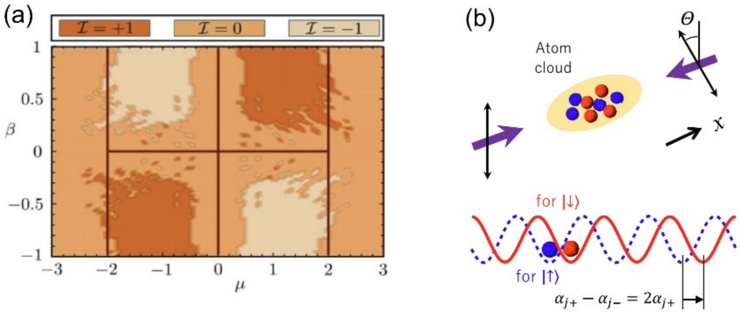

Figure 1 (a) Phase diagram of a topological driven system (from [3]). (b) Implementation of a topological system with a spin-dependent optical lattice [5]

The aim of this project is to explore these phenomena both experimentally and numerically using a potassium Bose–Einstein condensate subjected to periodic light pulses. The team has recently demonstrated an original scheme for effective spin–orbit coupling, involving both spin-dependent optical potentials and a periodically modulated Raman coupling between internal states. This scheme will form the basis for a future experimental realization of topological states.

The internship will focus on studying the atomic dynamics and identifying characteristic signatures of topological phases, such as the transition between localized and delocalized states or the emergence of topological invariants in the quasi-energy spectrum. During the internship, the student will participate in ongoing experiments within the group, involving the production and manipulation of potassium BECs, contributing to the implementation of experimental sequences and the analysis of collected data. The student will also develop numerical simulation to model these phenomena and test different experimental protocols, benefiting from an ongoing collaboration with theorists in the team.

In the longer term, the internship will lead to a PhD project, funded by an ongoing ANR project, where the internship developments will be extended to many-body topological quantum systems, leveraging the controllable interactions of the potassium condensate.

Candidate profile: The ideal candidate should have a strong interest in both experiment and theory, and a good academic record in atomic and quantum physics. Previous lab experience (internships, projects) will be highly valued.

Integration: The internship will take place in the PhLAM laboratory – University of Lille, CNRS. The chosen candidate will join the “Quantum Systems” team (7 permanent members and 5 PhD students and 1 post-doc). Experiments will utilize an existing potassium BEC experiment (resp. Radu Chicireanu), and will benefit from local theoretical support (resp. Adam Rançon).

Keywords: Ultracold quantum gas experiments, Topology, Quantum simulations.

[1] Nat. Commun. **9** 1382 (2018), Controlling symmetry and localization with an artificial gauge field in a disordered quantum system
[2] Nat. Commun. **16** 2519 (2025), Observation of quantum criticality of a four-dimensional phase transition
[3] Phys. Rev. B 84, 115133 (2011) Quantum Hall effect in a one-dimensional dynamical system
[4] PRL 113, 216802 (2014), Planck's Quantum-Driven Integer Quantum Hall Effect in Chaos
[5] PRR 5, 043167 (2023), Designing nontrivial one-dimensional Floquet topological phases using a spin-1/2 double-kicked rotor