PhD thesis project
Quantum simulation of the transition between plateaus in the fractional quantum Hall effect

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General Scope:
Discovered in 1981 in quantum wells of AlGaAs under a strong magnetic field, the quantum Hall effect manifests itself through quantized plateaus of the transverse electrical conductance, which take integer or fractional values of the quantum of conductance e^2/h. The transition between integer plateaus is understood as a percolation transition resulting from the localization of quantum states due to the inevitable presence of disorder in solids. The mechanism of plateau formation in the fractional quantum Hall effect is speculated to be of similar origin, but a verification of this mechanism is lacking, due to the strongly correlated nature of the fractional quantum Hall effect, which complicates the theoretical approach. The lack of control of disorder in solid state platforms makes an experimental approach challenging as well.

Ultracold atoms are a promising quantum simulation platform, which could bring a new vista on the fractional quantum Hall effect, with the possibility to control the microscopic Hamiltonian, and access local and time-dependent observables. Topological models such as the Harper-Hofstadter model have been realized in optical lattices, and the first few-atom fractional quantum Hall states have been prepared [1, 2]. There, the Hall conductance has been measured through density measurements available through quantum gas microscopes, using the Streda formula. Interestingly, universal features such as a fractionally quantized Hall conductance emerge even in the experimentally accessible few-atom systems, and theory predicts that even more signatures could be accessible in small systems [3, 4].

PhD Subject:

The goal of this theoretical PhD project is to design a cold atom protocol to study the transition between plateaus of the fractional quantum Hall effect. We will use many-body numerical methods (exact diagonalization and DMRG) to simulate realistic optical lattice Hamiltonians, and determine the optimal parameter regimes and observables. Overall, the PhD work will shed some light on the microscopic mechanism of plateau formation, while motivating cold atom experiments to explore this rich physics.

References

1. Realization of a fractional quantum Hall state with ultracold atoms, Léonard, Kim, Kwan, Segura, Grusdt, Repellin, Goldman, Greiner, Nature 2023

2. Realization of a Laughlin State of Two Rapidly Rotating Fermions, Lunt, Hill, Reiter,Preiss, Gałka, Jochim, Phys. Rev. Lett. 2024

3. Fractional Chern insulators of few bosons in a box: Hall plateaus from center-of-mass drifts and density profiles, Repellin, Léonard, Goldman, Phys. Rev. A 2020

4. Spectroscopy of edge and bulk collective modes in fractional Chern insulators, Binanti, Goldman, Repellin, Phys. Rev. Res. 2024

Required Skills:

- **Quantum and condensed matter physics, some computational physics**

Laboratory: LPMMC

PhD Supervisors:

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