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Project title: Quasicrystalline phases of interacting bosons
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Motivation

Quasiperiodic potentials are characterized by long-range order, despite their lack of translational invariance; their quantum properties are located somewhere in between those of fully periodic and completely disordered systems. Their states exhibit self-similar and sometimes fractal properties, and have been shown to act as a bridge between low-dimensional and high-dimensional physics. In recent years, interest in quasicrystals has risen - in parallel with that reserved to topological states of matter - spurred by technical advancement in both low-temperature physics and photonics, which promise experimental verification for a large number of theoretical predictions.

Recent experiments have successfully identified the quantum localisation transition of a Bose-Einstein condensate in a two-dimensional quasiperiodic lattice. In the student's master thesis, this same behaviour has been evidenced in a purely two-dimensional fluid of bosons, confined inside a harmonic trap and interacting through a hard-core potential, through use of path integral Monte Carlo (PIMC) simulations .

Research directions

1) Continuing our investigation in the harmonic trap, one goal is to map out the impact of trap frequency and number of particles on the transition. We also aim to give a characterisation of local superfluid effects, which will provide useful information regarding phases of the Bose glass kind. An analysis of correlation functions in the localised phase will look at analogies and differences with respect to the periodic lattice, with a focus on algebraic properties typical of two-dimensional systems.

2) The introduction of more complex interactions is uncharted ground; for example, long-range interactions will enable the investigation of phases where the quasicrystalline structure overlaps with a system which is supersolid in nature.

3) Open questions concern the possibility of techniques extending PIMC techniques to the study of fermionic systems and to explore dynamical observables. These areas are still in development, extending beyond the application to quasicrystalline systems.

Methodology

The main tool in this research project is represented by Path Integral Monte Carlo algorithms in continuous space, which are capable to simulate quantum systems at finite temperature. The methods are virtually exact, as errors can, in principle, be made arbitrarily small. We focus specifically on the application of the Worm algorithm, which provides accurate sampling of bosonic configurations. The algorithm provides us with immediate access to thermodynamic observables - including correlation functions, the one-body density matrix, and the superfluid and condensate fractions.

Given the heavy computational requirements of PIMC simulations, they will be accompanied by other numerical techniques, such as lattice simulations of quasicrystalline Bose-Hubbard models or continuous-space mean-field simulations.