Master 2 internship Position

Topological states of matter with atomic Dysprosium

Laboratory

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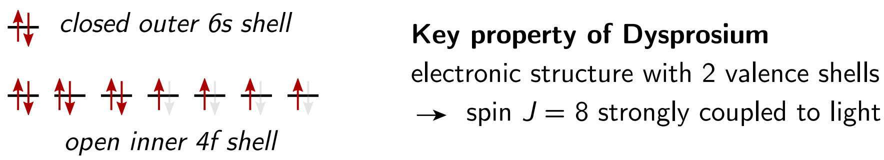
Scientific context

Since the observation of Bose-Einstein condensation in 1995, the research field of ultracold atomic gases expanded towards the study of various types of complex quantum systems. Among them, the so-called topological states of matter – for which the 2016 Nobel prize in physics was awarded to J. M. Kosterlitz, D. Haldane and D. J. Thouless – recently attracted a lot of efforts, due to the very exciting and peculiar physical behaviors expected in such systems, such as the possible occurrence of anyons, which are quasi-particles that exhibit neither bosonic nor fermionic quantum statistics.

Topology arising from light-spin coupling

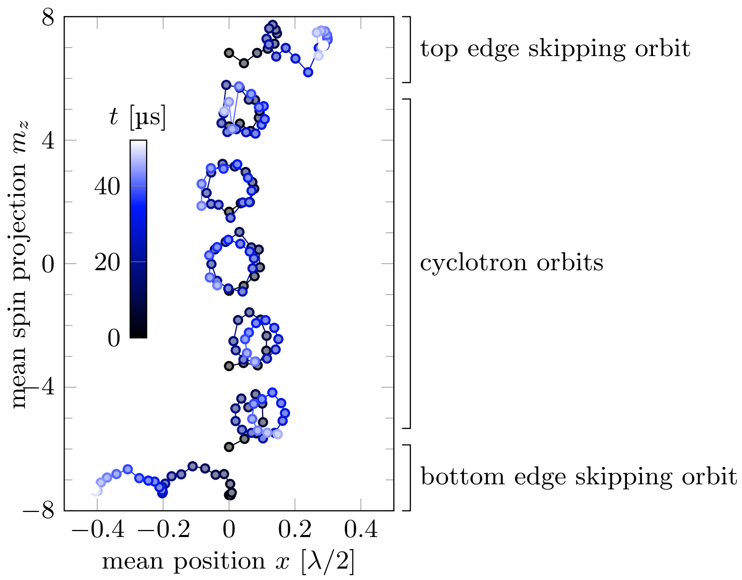
Our experiment, which produces ultracold samples of atomic Dysprosium (both bosonic and fermionic isotopes), aims at realizing atomic instances of topological phases of matter. A non trivial topology can be induced by coupling the internal spin of the atoms with their motion, resulting in an artificial gauge field. The specific electronic structure of Dysprosium provides efficient light/spin coupling for the gauge field generation.



Status of the experiment

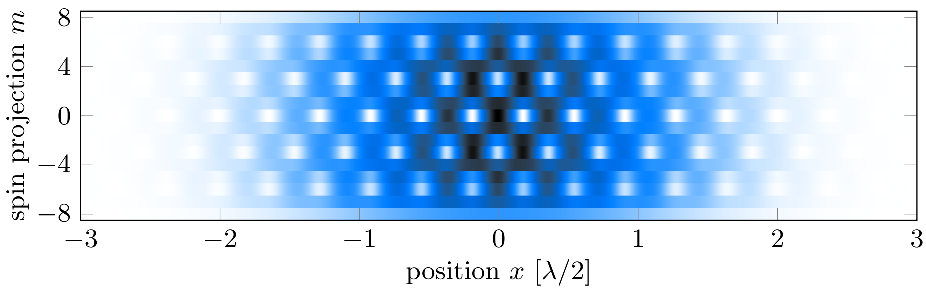
The experimental setup was built over the last years, and we now routinely produce ultracold samples of Dysprosium [1, 2]. In the last two years we have performed several projects based on the manipulation of the spin degree of freedom via coherent light field close to a narrow optical transition, leading to the production of highly non-classical spin states [3, 4, 5, 6].

We have extended these techniques to induce a coupling between the atom motion and its spin. Such a coupling leads to an effective magnetic field at low energy, such that one recovers the physics of the quantum Hall effect. In particular we have been able to probe the underlying topological structure of quantum states, via the quantization of the Hall response [7]. We show below measurements of elementary excitations in this structure, in the form of cyclotron/skipping orbits typical of quantum Hall physics. Our protocol is also suited to engineer quantum Hall physics in more complex geometries, namely cylindrical [8] and four-dimensional geometries [9].



PhD project

In the first part of the PhD, we will investigate the physics of weakly interacting gases of bosonic atoms in synthetic quantum Hall systems. We expect the atoms to organize into a Bose-Einstein condensate, pierced with a regular lattice of quantized vortices (see figure below). The expected phenomenology of this system corresponds to the behavior of superfluid liquid Helium or superconductors in a magnetic field.



The second part of the PhD will be devoted to the study of the strongly interacting regime. This regime will be reached with dilute gases, such that the quantum orbitals are not macroscopically filled. We expect to produce analogs of fractional quantum Hall states encountered in 2D electron gases under strong magnetic fields. These phases of matter have a very rich and exhibit a peculiar physical behavior, e.g. elementary excitations with anyonic quantum statistics. We also plan to use fermionic atoms, also subjected to a light-induced gauge field, to generate a different class of strongly-interacting topological phases, namely topological superconductors [10, 11].

Master 2 project: laser at 565 nm

The study of interacting systems in quantum Hall structures requires modifying the protocol used to simulate the magnetic field. We plan to realize a new laser at 565 nm, a wavelength for which the light-spin coupling has a simple structure which facilitates the realization of quantum Hall systems and makes it more suited for interacting systems. This laser light will be generated by sum frequency generation, by combining lasers at 1550 nm and 888 nm in a non-linear crystal.

Profile of the candidate

We are interested in Master students aiming to realize both their Master internship and PhD thesis in our group. We expect a solid background in quantum physics and a prior experience in lab work. The selected student will be involved in the different aspects of experimental physics involved in our project: daily running of a complex cold atom experiment, preparation of new optical setups for future projects, data taking and analysis, numerical simulations for the interpretation of measurements. He will join a group typically involving 3 PhD students, one postdoc and two permanent researchers.

References

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