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Exploring topology in synthetic quantum Hall systems using atomic dysprosium

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Topological quantum states are associated with integer invariants and are thus protected from continuous small deformations of the system. Topological invariants ensure the robustness of various phenomena, e.g. the quantized Hall conductance in two-dimensional electron gases subjected to a magnetic field, and are promising tools in different fields of physics, such as quantum computation. Phases characterized with non-trivial topological invariants have been widely studied in the context of the integer and fractional quantum Hall effects and of topological insulators, both theoretically and experimentally.

Recently, the concept of synthetic dimension has attracted attention as it allows extending current studies to more exotic geometries. It relies on internal degrees of freedom to simulate an extra dimension, with an additional flexibility on its properties compared to a real physical dimension.

In this poster, I will present some recent experimental works on quantum Hall systems using ultracold samples of atomic dysprosium. We benefit from the large total angular momentum J=8 of dysprosium atoms in their electronic ground state to simulate a synthetic dimension, with 2J+1=17 discrete positions. In a previous work, using optical Raman transitions coupling neighboring Zeeman sublevels of the electronic ground state, we showed that a Hall ribbon with sharp edges can be engineered.

We now report the use of this internal degree of freedom as a discretized dimension with periodic boundary conditions, used to prepare the equivalent of a Hall cylinder. In this geometry, the threading of a quantum of magnetic flux through the hole of the cylinder induces a quantized particle transport along the inifinite dimension, associated to the 1st Chern number.
Pushing the versatility of this approach forward, we also encode two synthetic dimensions in the total angular momentum of each atom, that we couple to two real physical dimensions. This effectively simulates a four-dimensional quantum Hall system with one cyclic dimension, one finite dimension with edges and two infinite dimensions. The dimensionality strongly affects the underlying physics: the topology of four-dimensional Hall systems is characterized by the 2nd Chern number which corresponds to a quantized non-linear response.

Presenter name

Fabre, Aurélien

online poster URL

Primary authors: FABRE, Aurélien (Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-PSL University, Sorbonne Université); BOUHIRON, Jean-Baptiste (Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-PSL University, Sorbonne Université); SATOOR, Tanish (Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-PSL University, Sorbonne Université); REDON, Quentin (Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-PSL University, Sorbonne Université); LIU, Qi (Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-PSL

University, Sorbonne Université); LOPES, Raphael (Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-PSL University, Sorbonne Université); NASCIMBENE, Sylvain (Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-PSL University, Sorbonne Université)

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