Program of the workshop "Topological Quantum Matter with Atoms and Photons"

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Probing supersolidity through excitations in a spin-orbit-coupled Bose-Einstein condensate

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Spin-orbit-coupled Bose-Einstein condensates are a flexible experimental platform to engineer synthetic quantum many-body systems. In particular, they host the so-called stripe phase, an instance of a supersolid state of matter. The peculiar excitation spectrum of the stripe phase, a definite footprint of its supersolidity, had so far remained out of experimental reach. In my talk, I will present our recent experiments on spin-orbit coupled Bose-Einstein condensates, where by leveraging the tunable interaction properties of potassium atoms and a matter-wave optics magnification scheme, we achieve for the first time in situ imaging of the stripes. This allows us to directly observe both superfluid and crystal excitations, investigate superfluid hydrodynamics, and reveal a stripe compression mode. The latter shows that the system possesses a compressible crystalline structure and, through its frequency softening, enables the location of the supersolid transition point. Our results establish spin-orbit-coupled supersolids as a platform of choice to investigate supersolidity and its rich dynamics.

One-dimensional topological crystalline insulators

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The Su-Schrieffer-Heeger (SSH) model, that describes a poly-acetylene chain, is usually taken as the simplest example of a topological insulator. It has been realized recently in artificial crystals made with atoms, photons or polaritons. Actually, although it does trap zero-energy states on topological defects of the dimerization, it is not a good example of a topological insulator. A slight modification of the model, known as the Shockley or s-p orbitals model, is a much better example. In order to understand the difference between SSH and Shockley, we will revisit notions such as: Zak phase, Wannier center, orbital embedding, electric polarization and canonical versus periodic Bloch Hamiltonian.

Observation of a topological edge state induced by dissipation

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Robust states emerging at the boundary of a system constitute a hallmark for topologically nontrivial band structures, usually realised by controlling the tunnelling and on-site potentials in Hermitian lattice systems. Recent theory work proposed that topological edge states can occur even in systems with an a priori trivial band structure, if exposed to spatially modulated gain and loss. In this talk, I will discuss experiments studying the dissipation-induced emergence of such a topological band structure in a non-Hermitian one-dimensional lattice system, realised by arrays of dielectric loaded surface plasmon polariton waveguides (DLSPPWs) with tailored loss. We obtain direct evidence for a topological edge state that resides in the centre of the band gap. By tuning dissipation and hopping, the formation and breakdown of an interface state between topologically distinct regions is demonstrated. Further, I will discuss other recent work on Bose-Einstein condensation of light in a ring-like plaquette of coupled material-filled optical cavities, a promising platform for exploring the topological physics of open systems in the future.

H. Wetter et al., *Phys. Rev. Lett.* 131, 083801 (2023)
A. Redmann et al., *Phys. Rev. Lett.* 133, 093602 (2024)

Exploring quantum Hall physics with ultracold dysprosium atoms

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Ultracold atomic gases can be used to study a wide range of phenomena relevant to quantum matter, including topological states related to the quantum Hall effect. Because of the charge neutrality of atoms, the simulation of the quantum Hall effect relies on the application of an artificial magnetic field, whose generation can be greatly facilitated in systems with synthetic dimensions.

In this talk, I will present an experimental realization of a quantum Hall system using ultracold gases of dysprosium atoms. We use the large spin J = 8 of this atom to encode a synthetic dimension in the magnetic projection states m. We couple the spin to the atomic motion using two-photon optical transitions, which leads to an effective magnetic field. We measure characteristic features of the quantum Hall effect, namely a quantized Hall response and gapless chiral edge modes.

I will then discuss a more complex experiment probing spatial entanglement properties, by simulating the so-called entanglement Hamiltonian. This experiment relies on the Bisognano-Wichmann theorem, which states that the entanglement Hamiltonian is given by a spatial deformation of the system, which we implement along the synthetic dimension.

Probing the Hall response in strongly interacting ultracold fermions

Leonardo Fallani, U. Florence, Italy