Quantum simulation with ultracold atoms – from Hubbard models to gauge theories

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Well-controlled synthetic quantum systems, such as ultracold atoms in optical lattices, offer intriguing possibilities to study complex many-body problems in regimes that are beyond reach using state-of-the-art classical computations. The basic idea is to construct and use a well-controlled quantum many-body system in order to study its in- and out-of-equilibrium properties and potentially use it to develop more efficient tailored numerical methods that can then be applied to other systems that are not directly accessible with the simulator.

An important future quest concerns the development of novel experimental techniques that allow us to expand the range of models that can be accessed. I will demonstrate this using the example of topological lattice models, which in general do not naturally appear in cold-atom experiments. I will show how the technique of periodic driving, also known as Floquet engineering, facilitates their realization and show how charge-neutral atoms in lattices can mimic the behavior of charged particles in the presence of an external magnetic field.

A key ingredient for quantum simulation is the degree of control one has over the individual particles and the microscopic parameters of the model. We have recently succeeded to not only use the technique of periodic driving to emulate physical systems that we know exist in nature, but to take this idea one step further and realize completely new topological regimes that do not have any static analog. Moreover, we are currently developing a novel hybrid optical lattice platform, where tightly focused optical tweezers are used to locally control the motion of the atoms in the lattice, paving the way towards quantum simulation of simplified lattice gauge theories, which play a fundamental role in a variety of research areas including high-energy physics and topological quantum computation