

Séminaire AXE 1 - Sciences et Matériaux Quantiques



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Towards optimal control of quantum many-body systems

Quantum many-body systems of strongly correlated fermions on a lattice are a central topic in condensed-matter physics. They remain notoriously difficult to solve, even with state-of-the-art numerical techniques, particularly in regimes where multiple degrees of freedom compete or cooperate at comparable energy and length scales. Richard Feynman famously argued that such systems are best simulated using synthetic quantum devices, which are inherently quantum mechanical.

However, two key challenges persist. First, quantum devices suffer from intrinsic limitations in experimental control, for instance due to the finite precision of optical tweezers. Second, some platforms are naturally restricted to simulating quantum spin models.

To address the first challenge, one can turn to Hamiltonian learning, whose goal is to infer the experimentally realized Hamiltonian in a scalable way from measurements. I will introduce a physics-inspired model based on Graph Neural Networks (GNNs), which incorporates local magnetization and spin-spin correlation functions to predict the underlying microscopic Hamiltonian parameters across system sizes. This approach enables a posteriori calibration of the experimental setup.

To address the second challenge, slave-particle approaches provide an approximate yet powerful framework to treat interacting fermionic systems. I will present a spin-1 slave-spin formalism that allows fermionic models to be simulated on spin-based quantum platforms at arbitrary electron doping, in an efficient and economical way. Within this framework, the phase diagram is explored under various conditions, revealing the emergence of charge and spin stripe phases in qualitative agreement with more established numerical methods.

Taken together, Hamiltonian learning and slave-particle approaches demonstrate that complex fermionic many-body states can be realistically implemented and investigated using spin-based quantum simulators, such as Rydberg-atom platforms.

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