PhD project

Quantum simulation with an atom-tweezer array in an optical microcavity

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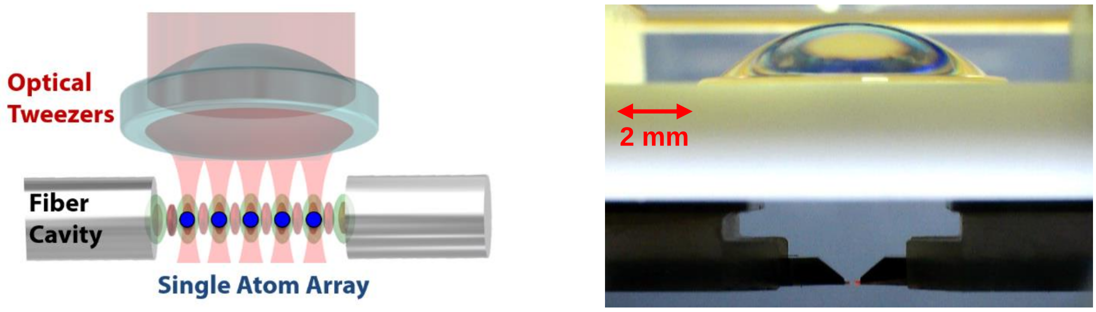
Understanding the dynamics of entanglement and quantum information within a many-body system represents a central challenge in quantum physics, with far-reaching implications for the advancement of quantum technologies. The dynamic properties of the system depend strongly on the range of the interaction between the qubits. In this context, the coupling of cold atoms with the optical mode of a cavity offers a unique platform for engineering infinite and long-range interactions between atoms, mediated by the cavity.

Cavity quantum electrodynamics (CQED) systems have proven to be one of the most powerful tools for generating many-particle entangled states. So far, however, they are constrained in terms of single particle control and spatially resolved detection. At LKB, we have recently accomplished a significant milestone with the development of an experimental setup that combines a high-finesse optical microcavity, allowing us to work in the strong regime of cavity QED, with a high-numerical aperture optical system that enables single-atom control and detection in an array of individually controllable tweezers (see figure).



Left: Principle of the experimental setup: An array of optical trap and control a register of single atoms inside an optical micro-cavity. Right: an image of the actual experiment.

This new system combines the known advantages of optical tweezers arrays with the powerful nonlocal interaction mechanisms characteristic of strong-coupling cavities, opening up new avenues for engineering spatial correlations of entangled states and monitoring their propagation with single-particle resolution.

The goal of this PhD project is to perform first quantum simulations in this new regime. We will investigate transport phenomena in long-range interacting spin systems with a controllable level of disorder, which are highly relevant in condensed matter and quantum optics. The recent experimental discovery of cavity-enhanced transport of excitons and charge in specific disordered polaritonic materials has sparked a substantial body of mostly theoretical results. By leveraging the high level of control offered by the cold atom cavity simulator, we will implement for the first time, spin transport measurements in a single-atom chain coupled to the cavity.

Specifically, the qubit state is encoded in two hyperfine ground states of a ^{87}Rb atom. Operating deep inside the strong coupling regime, the cavity allows the creation of infinite-range and different forms of long-range interactions, while also enabling efficient qubit-by-qubit readout. Additionally, the tweezers allow the introduction of adjustable disorder, thereby realizing a true quantum simulation platform. This will enable us to investigate the fundamental physical mechanisms underlying these transport phenomena, thus significantly advancing the state of the art in this field.

If time permits, we intend to extend our investigation by exploring the transport of quantum information, as well as the build-up and spreading of entanglement along the qubit register.

The student will become an integral part of our highly motivated team, operating within an inspiring research environment and will have the opportunity to gain hands-on experience in optics, lasers, cold atoms and cavity QED physics. Moreover, they will have the opportunity to develop both experimental and theoretical expertise in quantum technologies and entanglement.

We believe that this quantum simulation project is in line with the objectives of the Quantum Information Center Sorbonne (QICS) on quantum information.