Quantum Information and Entanglement in Correlated Quantum Matter

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The spectacular development of quantum over the past few years has sparked renewed interest in quantum information. In addition to quantum computation, recent advances permit to envision revolutionary technological developments in quantum simulation, quantum metrology, and quantum communications. Still, many fundamental questions remain unanswered regarding the very foundations of quantum information, first and foremost quantum correlations and entanglement.

We are only at the beginning of understanding the close relationship between quantum information and correlated quantum matter, for instance on emerging phenomena such as phase transitions. Another equally fundamental question is to understand how information propagates in correlated quantum systems, with applications of prime importance not only for quantum communications, but also for the foundations of statistical physics and the ergodicity of isolated systems. The study of these questions is particularly suited to close collaboration between theory and experiments realized out on new quantum control devices.

This project aims to explore two aspects of these questions:

(i) The role of entanglement in quantum phase transitions;

(ii) The propagation of information in correlated quantum systems.

In our group, we have recently obtained several original results on both questions. For instance, we have shown that entanglement properties offer a new signature of quantum phase transitions, including those of a topological nature, in a long-range spin system [1]. We have also developed a universal theory of the propagation of quantum correlations [2], validated by advanced numerical calculations [3,4], see also [5,6], as well as an original spectroscopy method based on correlation spreading properties [7-10].

The objective of this project is to extend this work towards two fundamental directions: The roles of disorder and coupling to the environment. Both are fundamental challenges for real quantum devices. We will focus on long-range models as realized on state-of-the-art quantum simulation platforms, including Rydberg atoms, eg as realized at Institut d'Optique, and cavity optical tweezers, eg as realized at the Laboratoire Kastler-Brossel. The challenges are to understand the behavior of quantum information in these systems and to determine the relevant observables to unveil its nature. These questions will be addressed from a theoretical point of view, using the most modern N-body approaches, both analytical and numerical, for instance using Matrix Product State approaches [1,3,4,11]. Collaborations with experimental teams will also be systematically stimulated.

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