# THESIS DEFENSE: Classical and Quantum simulation of quantum matter beyond symmetry breaking

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14:00

ICFO Auditorium

When matter is cooled to temperatures near absolute zero, its quantum nature begins to emerge. The interactions between its microscopic constituents can then lead to the emergence of fascinating physical properties. While the framework of spontaneous symmetry breaking has been incredibly successful in describing how a macroscopic number of particles cooperate to give a system its properties, there are many situations where this is not sufficient to describe quantum systems. This is especially true for strongly interacting many-body systems.

In recent years, multiple techniques have been developed to address this problem. On the one hand, the incredible advances in classical computing hardware and algorithms, have made it possible to study systems with a number of elementary components that were unimaginable just a few decades ago. In particular, the development of techniques such as tensor networks has unified the framework of quantum information with condensed matter physics, making it possible to optimize the computational complexity of simulating a system, based on its entanglement content.

On the other hand, the development of platforms to directly perform simulations on quantum systems is a highly sought objective. While a hypothetical universal quantum computer could dramatically increase our understanding of the quantum nature of matter, its difficult development makes it essential to study analog platforms where specific many-body models can be studied directly in a controlled environment. In these quantum simulators, novel quantum phenomena can be studied in an environment free of disorder, with excellent control over parameters and measurement capabilities.

In this thesis, we aim to explore these two paths to study some of the most relevantactive topics in physics beyond the symmetry breaking paradigm. In the first part, devoted to topology, we propose and analyze new techniques for the detection of topological excitations. We start by proposing a protocol to detect anyons, quasiparticles that do not behave either as bosons or fermions, in Fractional Quantum

Hall Effect systems through measuring the angular momentum of impurities binding to the anyons. We then show how similar excitations can be identified in topological superconductors through an interaction between the electromagnetic field of a strong laser pulse and the system in a process called High Harmonic Generation.

In the second part, we move to the study of quantum frustration. This phenomenon, which describes a situation in which various constraints of the system cannot be satisfied simultaneously, can lead to the emergence of unexpected phases of matter. In particular, we study how frustrated phases and a particular class of quantum critical points, called deconfined can emerge in one-dimensional frustrated systems, potentially realizable in quantum simulators. We then study how frustration could explain the onset of superconductivity mixed with charge density modulations in two-dimensional strongly-correlated systems.

**Friday July 05, 14:00 h. ICFO Auditorium**
**Thesis Director: Prof. Dr. Maciej Lewenstein and Dr. Luca Barbiero**
**Hosted by:** Prof. Dr. Maciej Lewenstein