PhD THESIS DEFENSE: Exploring Quantum Many-Body Systems from an Entanglement and Nonlocality Perspective

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ICFO Auditorium and Online (Teams)

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Quantum Optics Theory

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Entanglement and non-local correlations give rise to unprecedented phenomena with no classical analogue. As a result, they have settled themselves as fundamental properties in the study of quantum many-body systems, as well as key resources for emerging quantum technologies. However, the lack for general and efficient criteria to characterize them in many-body systems poses many challenges, often intractable. Consequently, despite the growing interest in their properties, the role of entanglement and non-local correlations in many-body systems remains largely unexplored.

The subject of the present Thesis is to explore quantum many-body systems from an entanglement and non-local correlations perspective, aiming at expanding the interplay between quantum information processing and quantum many-body physics. We examine adequate properties, like symmetries, that allow us to delve into entanglement and non-local correlations in many-body systems of physical relevance. The original results that we present are achieved at the fundamental level, even though many practical methods that can be experimentally implemented stem from them.

First, we explore the complexity to characterize entanglement in simplified cases. In particular, we consider the separability problem for diagonal symmetric states. We establish a connection with the field of quadratic conic optimization that allows us to provide significant sufficient criteria. Furthermore, it allows us to prove that obtaining necessary and sufficient criteria remains an NP-hard problem, even for a case with such a simplified structure.

Second, the elusiveness of the characterization of entanglement motivates certification criteria for its detection, specially in the multipartite scenario. By means of non-local correlations, we provide device-independent certification criteria that characterizes the amount of entanglement present on a quantum many-body system. This type of certification does not rely on assumptions about the internal workings of the measuring device nor about the system itself. Moreover, by relying solely on non-local correlations, the criteria dismisses all the correlations that have a classical analogue, thus being a natural candidate as a certifier for emerging quantum technologies.

Third, we explore non-local correlations in the vicinity of quantum critical points, which are known to stabilize large-scale entanglement. We show the presence of non-local correlations across the phase diagram via a certain Bell inequality. Furthermore, we show that the Bell inequality is maximally violated at the quantum critical point, hinting at a possible connection between many-body Bell correlators and quantum phase transitions.

Fourth, we present a solution to the quantum marginal problem restricted to symmetric states. This allows to partially circumvent the inefficient representability inherent to the multipartite Hilbert space in cases of interest. In addition, we illustrate some of the applications that our solution brings on central quantum information problems. Namely, (i) as an undemanding and efficient variational method to optimize local Hamiltonians over symmetric states, (ii) to optimize few-body symmetric Bell inequalities over symmetric states and (iii) to explore which symmetric states cannot be self-tested solely from their marginals.

Finally, we conclude by presenting a methodology to derive two-body symmetric Bell inequalities for three-outcomes. These novel Bell inequalities are natural candidates to explore the role of non-local correlations on quantum phenomena tailored to qutrit or spin-1 many-body systems. We select a particular Bell inequality to characterize and show that it reveals non-local correlations in the ground state of many-body Hamiltonians physically relevant to, e.g., nuclear physics.

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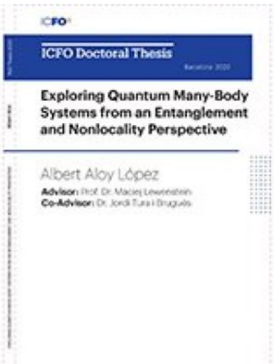
Thesis Advisor: Prof Dr Maciej Lewenstein

Hosted by: Maciej Lewenstein



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