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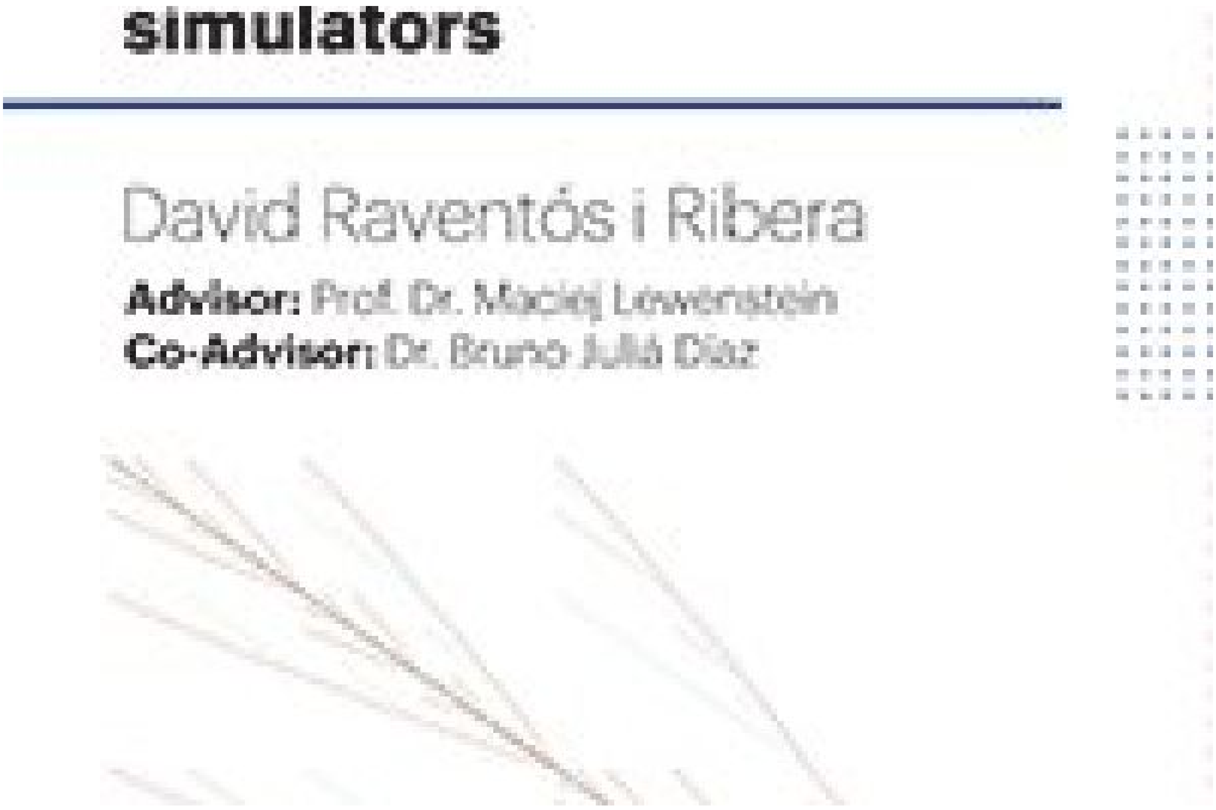

PhD Thesis Defense DAVID RAVENTOS RIBERA 'Exact Diagonalization Studies of Quantum Simulators'

DAVID RAVENTOS RIBERA

April 15, 2019

Monday, April 15, 11:00. ICFO Auditorium

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Quantum Optics Theory

ICFO-The Institute of Photonic Sciences

Understand and tame complex quantum mechanical systems to build quantum technologies is one of the most important scientific endeavour nowadays.
In this effort, Atomic, molecular and Optical systems have clearly played a major role in producing proofs of concept of several important applications.
Notable examples are Quantum Simulators for difficult problems in other branches of physics

i.e. spin systems, disordered systems, etc., and small sized Quantum Computers. In particular, ultracold atomic gases and trapped ion experiments are nowadays at the forefront in the field.

This fantastic experimental effort needs to be accompanied by a matching theoretical and numerical one. The main two reasons are: 1) theoretical work is needed to identify suitable regimes where the AMO systems can be used as efficient quantum simulators of important problems in physics
and mathematics, 2) thorough numerical work is needed to benchmark the results of the experiments in parameter regions where a solution to the problem can be found with classical devices.

In this dissertation, we present several important examples of systems, which can be numerically solved. The technique used, which is common to all the work presented in the dissertation, is exact diagonalization. This technique works solely for systems of a small number of particles and/or a
small number of available quantum states. Despite this limitation, one can study a large variety of quantum systems in relevant parameter regimes.
A notable advantage is that it allows one to compute not only the ground state of the system but also most of the spectrum and, in some cases, to study dynamics.

The dissertation is organized in the following way. First, we provide an introduction, outlining the importance of this technique for quantum simulation and quantum validation and certification. In Chapter 2, we detail the exact diagonalization technique and present an example of use for the phases of the 1D Bose-Hubbard chain. Then in Chapters 3 to 6, we present a number of important uses of exact diagonalization. In Chapter 3, we study the quantum Hall phases, which are found in two-component bosons subjected to artificial gauge fields. In Chapter 4, we turn into dynamical gauge fields, presenting the topological phases which appear in a bosonic system trapped in a small lattice. In Chapter 5, a very different problem is tackled, that of using an ultracold atomic gases to simulate a spin model. Quantum simulation is again the goal of Chapter 6, where we propose a way in which the number-partitioning problem can be solved by means of a quantum simulator made with trapped ions. Finally, in Chapter 7, we collect the main conclusions of the dissertation and provide a brief outlook.

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