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Subject: Review of the PhD dissertation:

Ergodicity breaking in quantum systems: from exact time evolution to machine learning

by Tomasz Szółdra

Tomasz Szółdra has completed the PhD dissertation “Ergodicity breaking in quantum systems: from exact time evolution to machine learning“, carried out under the supervision of Prof. Jakub Zakrzewski. I have read the dissertation, and I am hereby providing the following review.

The topic of the thesis are non-equilibrium quantum many-body systems, subject to disorder or other types of interactions that may give rise to non-ergodic behavior. The goal of the thesis is to provide new insights into this rapidly evolving field of physics, in which one of the main questions is the existence of a robust non-ergodic phase of matter. To this end, the author pursues two main approaches: he studies stability of many-body localization, expected to occur in spin chain models subject to strong disorder, and quantum many-body scars and Hilbert space fragmentation, which may occur in certain constrained systems.

Within the studies of many-body localization, the author focuses on the physics of quantum avalanches, which are believed to provide a relevant mechanism for the (de)stabilization of many-body localized systems. First, the author uses neural networks as a tool to detect thermal bubbles that may give rise to avalanches, and second, the author pursues an approach in which he implants low disorder regions to stimulate the creation of avalanches, which are then studied via the spreading into the strongly disordered portion of the lattice. These studies are complemented by a study in which locality of quantum time evolution is explored via site resolved autocorrelation functions. Within the studies of quantum many-body scars and Hilbert space fragmentation, the author again resorts to machine learning tools to propose a method to detect scarred Hamiltonian eigenstates.

In the opening part of the dissertation, the author provides a comprehensive introduction to the subject of quantum chaos, random matrix theory, thermalization and the relevance of the underlying mechanism of thermalization, i.e., the eigenstate thermalization hypothesis (ETH). One of the main outcomes of research in the last two decades in the context of many-body quantum systems is that isolated systems, which time-evolve unitarily, can thermalize despite the absence of coupling to a thermal bath. It is then natural to ask whether it is possible to find counterexamples to thermalization. The author addresses this question by providing introduction to the field of many-body localization, quantum many-body scars, and Hilbert space fragmentation. They provide the main candidates for the mechanisms of ergodicity breaking.

The author carries out a systematic analysis to explore possible answers to the open questions addressed in the thesis. The analysis is based on numerical studies of several interacting quantum model Hamiltonians. The main novelty of the thesis is the introduction of several new measures to define the breakdown of ergodicity. These studies are implemented using state-of-the-art methodology, and the author carries out a thorough analysis of the numerical as well as certain analytical results. This makes all the key parts of the thesis of high quality.

The above considerations make apparent that the thesis addresses fundamental questions in this research field, which has not been addressed before in such detail. In doing this the author provides us with a map for understanding the various ways that non-ergodic behavior may emerge, with the emphasis on the machine learning techniques to detect such behavior. The thesis is well-organized and written pedagogically. It is hence suitable also for non-experts in the field. The presentation of the open questions and the discussion of the results is clear.

Based on these considerations, I conclude that the PhD dissertation by Tomasz Szol̄dra represents a new contribution to scientific research of non-ergodic quantum many-body systems. It is my pleasure to propose a positive grade of the dissertation to the PhD committee.

Yours sincerely,

Lev Vidmar

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