Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Andrey Tarkhov

PhD Program: Physics

Title of Thesis: Ergodization dynamics of the Gross-Pitaevskii equation on a lattice

Supervisor: Associate Professor Boris Fine, Skoltech

Name of the Reviewer: Natalia Berloff

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Signature:** N. Berloff **Date: 18-09-2020**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense. *If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.*
Reviewer's Report
Reviewers report should contain the following items: • Brief evaluation of the thesis quality and overall structure of the dissertation. • The relevance of the topic of dissertation work to its actual content • The relevance of the methods used in the dissertation • The scientific significance of the results obtained and their compliance with the international level and current state of the art • The relevance of the obtained results to applications (if applicable) • The quality of publications The summary of issues to be addressed before/during the thesis defense

The thesis entitled “Ergodization dynamics of the Gross-Pitaevskii equation on a lattice” by Andrey Tarkhov addresses an important questions of the ergodization dynamics of the time-dependent discrete Gross- Pitaevskii equation on a lattice that approximately describes dynamics of the coupled atomic Bose-Einstein condensates loaded into optical lattices. Understanding the footprints of chaos in quantum and classical many-body systems has been under debate for a long time and the thesis under consideration makes several important steps in this direction.

The main novelty of the material presented in the thesis comes from three important results: (1) method for extracting the largest Lyapunov exponent by monitoring equilibrium noise before and after time reversal (Loschmidt echo); (2) introduction of a new methodology that allows one to extract the ergodization time; (3) investigation of the dynamic thermalization of the system in 3d after fast thermal quenches and the role played by the topological defects while the system remains ergodic.

Chapter 1 gives the introduction to classical chaos, Lyapunov exponents, Loschmidt echoes and out-of-time-order correlators, Gross-Pitaevskii equation with its continuous and discrete forms and topological defects it can support. This provides a galloping view of the history of scientific studies, laying the foundation for the topics of the thesis.

Chapter 2 and 3 present experimentally feasible method for extracting Lyapunov exponents and ergodization time in interacting many-particle systems and confirms its applicability via extensive set of numerical simulations.

Chapter 4 investigats non-equilibrium quenches across a second-order phase transition by using DNLSE with particle number conserving dissipation. The quench is introduced and modulated in the system and the vortex dynamics is followed via time evolution. Topological defects in the form of closed-loop vortices are formed during the quench with lifetime that depends linearly on the system size. The mechanism considered is in a contrast with the well established Kibble-Zurek mechanism where the system starts from a high-temperature equilibrium state.

The results are important from the fundamental view point of studying the systems out-of-equilibrium and offer experimentally realisable protocols to study a variety of such systems including but not limited to ultracold atomic BECs, laser systems and CDW materials.

The methodology and results of the thesis are carefuly presented and validated by large scale numerical simulations. The relevance to experiments shows good familiarity with the state-of-the-art experimental implementations. The candidate also discusses the experimental limitations on the use of the methods he proposes and develops e.g. the lack of translational variance of optical lattices. A successful realization of this proposal may produce a a much sought direct experimental evidence that the dynamics of a typical many-particle system are chaotic.

Two papers that resulted from the thesis material were published (by Phys Rev B and the New Journal of Physics). The work was followed by other research groups, in particular, to study the echo dynamics of the Sherrington-Kirkpatrick model with transverse field under effective time reversal and the discrete non-integrable perturbed sine-Gordon equation. This illustrates the scientific significance of the results obtained and their compliance with the international level and current state of the art.

Overall, this thesis represents an impressive body of work on a series of problems in active and mordern condensed matter physics. The topics are unified by the common approaches based on the ergodization dynamics. Subject to satisfactory performance in the oral examination and implementation of the minor corrections arising from that exam, I find the thesis satisfies the requirements for award of the PhD.

Provisional Recommendation

☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*
☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*