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Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Igor Ermakov

PhD Program: Physics

Title of Thesis: Dynamics of exceptional states in many-body systems

Supervisor: Professor Boris Fine
Co-supervisor: Dr. Oleg Lychkovskiy

Name of the Reviewer: Dr. Anton Trushechkin

I confirm the absence of any conflict of interest	**Date: 13-09-2022**

Reviewer's Report
The thesis is devoted to the problem of thermalization in classical and quantum many-body systems, which is a well-known fundamental problem in theoretical physics. From experiments and everyday life we know that many-body systems reach thermal equilibrium with the time. However, later, it was understood that, strictly speaking, this is not a general behaviour since the dynamics starting from certain exceptional initial states does not lead to thermalization. The thesis is devoted to such exceptional initial states. Thus, the thesis is devoted to a very interesting modern topic. The thesis consists of introduction (Chapter 1), three chapters of the main body of the thesis (Chapters 2-4) and conclusions (Chapter 5). Three chapters are devoted to three different cases of exceptional non-thermalizing initial states. In Chapter 2, periodic orbits of a non-integrable classical and quantum spin-chains are analyzed. Two different regimes of dynamics are identified for classical spin chains: libration and rotation as well as their quantum counterparts. The Lyapunov exponents of the periodic trajectories are numerically calculated for the classical systems. In most cases, the periodic trajectories are unstable, but in some instances, they are stable. Periodic dependence of the Lyapunov exponents is discovered and analytically explained. A number of other issues are analyzed. Thus, a thorough analysis of this model is performed. In Chapter 3, examples and a general theory of almost complete revivals in spin chains is developed. Namely, special initial states are considered, where hidden non-local regularities reveal themselves in a certain time instant after an apparent thermalization. Moreover, possible applications of this phenomenon is proposed for all three directions of quantum technologies: quantum computations, quantum cryptography and quantum sensing. Chapter 4 is devoted to the so called eigenstate decoherence hypothesis, which (analogously to the well-known eigenstate thermalization hypothesis) states that decoherence of subsystems of a many-body system can be explained by the properties of the eigenstates of the many-body Hamiltonian. For an integrable model of a heavy particle in a fermionic gas, it is shown that the eigenstate decoherence hypothesis is satisfied for most eigenstates corresponding to eigenvalues in the middle of the spectrum,

but also there are distinct exceptional eigenstates which does not satisfy this hypothesis.

In Chapters 2 and 4, the author uses mainly numerical methods but also analytical estimations. Chapter 3 is more analytical.

The results are very interesting and significant. I think, they reveal complex mathematical structures in the considered models yet to be explored. The significance an international level of the results is confirmed by publications in central physical journals: Physical Review A and Europhysics Letters (EPL). The text of the thesis is well-written and very interesting to read.

I have a question-comment concerning the discussion of relations between the existence of scar-like states and suppression of thermalization (Sections 2.5.1-2.5.2). It is suggested that thermalization process for the case $S \geq 3/2$ is noticeably slower due to the presence of the eigenstates with high overlap with the initial non-equilibrium state (scar-like states). However, it seems that such effect would not slower thermalization, but prevent it. So, it would be desirable to extend the plots on Figs. 2-10 and 2-11 to larger times to check whether the termalization takes place (though slower) or the considered mean value of a local observable converge to a non-zero (non-thermal) value.

Also, the plots on Figures 2-12 and 2-13 show the normalized entanglement entropy and overlaps. It is interesting to know also their actual values (or, equivalently, the actual value of the normalization factor) depending on the system size L. On p. 52, it is written that the entanglement entropy of the scar-like states converges to 1 in the thermodynamic limit. But this cannot be seen from the plots.

Finally, minor comments:

1. Fig. 2-11 on p. 48. The value of L (the system size) for the case of infinite temperature initial state is not indicated.

2. Eq. (2.14) on p. 50. The left-hand side is a quantum state, but the right-hand side is a number. Probably, argmax instead of max is meant in the right-hand side.

All these comments do not reduce the quality of the thesis.

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*

Dr. Anton Trushechkin 13.09.2022