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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: Sergei Filippov

I confirm the absence of any conflict of interest	**Date: 10-09-2022**

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

Brief evaluation of the thesis quality and overall structure of the dissertation. The PhD project is devoted to the study of dynamics and equilibration of classical and quantum one-dimensional systems (primarily spin chains in chapters 2 and 3 but also a discrete model of particle decoherence in chapter 4). The thesis reports mostly on numerical results (for relatively modest dimensions) accompanied by the physical explanation of expected dependences and their interpretation. From physics viewpoint the results are extrapolated to larger systems; however, no mathematically rigorous theorems are deduced. Physics is described rather well though, so the thesis quality is good. The thesis also contains an introductory material and a chapter with conclusions and outlook. The thesis structure is straightforward.

The relevance of the topic of dissertation work to its actual content. The thesis title "Dynamics of exceptional states in many-body systems" describes the actual content of the thesis main chapters.

The relevance of the methods used in the dissertation. The methods used rely on the fundamental equations of quantum physics, standard approaches in linear algebra, and numerical analysis. The methods allowed the author to study systems composed of up to about 20 spins. The author often resorts to the numerical diagonalization of Hamiltonians, however, more advanced numerical methods exist in the literature that enable one to extract useful information, e.g., to find the ground state of a local Hamiltonian within the matrix-product-state ansatz.

The scientific significance of the results obtained and their compliance with the international level and current state of the art. The results are of interest to the international scientific community because many researchers in the world scrutinize the origins of decoherence, thermalization, irreversibility in quantum dynamics starting from different approaches. The thesis adds some new knowledge to the field. Some numerical methods could be further improved though.

The relevance of the obtained results to applications (if applicable). The thesis contains a description of how almost complete revivals can potentially find applications in benchmarking quantum simulators, quantum sensors, and delayed disclosure of a secret.

The quality of publications. Publications' quality if sufficient for PhD dissertation.

The summary of issues to be addressed before the thesis defense

1) The weak point of the thesis is the quality of presentation. The choice of the language used is sometimes ambiguous or unclear. Some general statements are based on considering particular system Hamiltonians only. Below are the points to be addressed before the thesis defense:
2) The author refers to a distribution in Fig. 1-1 (a) as "uniform", which is rigorously not the case. Physically, it may be close to uniform or uniform at a large scale. I believe that the scientific description of phenomena must be as precise as possible. Some improvements in this case are definitely possible.
3) It is not clear, what the author means in the phrase "Such states may be constructed for almost arbitrary non-interacting spin Hamiltonian" at page 22. Non-interacting spins are apparently not an interesting case to explore. Likely the author meant "non-integrable" but in this case no justification for such a general claim is presented.
4) It would be better if the diagram elements in Figure 2-1 would follow the same order as the images below the diagram; currently they are in the reverse order.
5) Relation between q and n at page 34 should be given ibid.
6) Stability of the transient regime is not fully discussed in the thesis. Namely, Figure 2-6 suggests that the transient regime can be either unstable (L=18) or stable (L=6); however, the both cases correspond to similar periodic Lyapunov exponents in Figure 2-4(b). In my opinion, the so-called "stable" transient regime may eventually become unstable after time t=10^3. Either a proof of stability or corrections to the statements made are needed.
7) In the algorithm at page 45, step 2, it is not clear whether a displacement is made for a single spin or many spins.
8) The author claims that "spin length affects the relative strength of different terms in the Hamiltonian (2.1)", so my question is what prevented the inclusion of the length renormalization into (2.1)?
9) Summation limits in footnote at page 49 contain a mistake, in my opinion.
10) Section 2.5.2 starts with a mention of the entanglement entropy, however, no partition is specified. While reading I thought about 1 spin vs. rest of the spins. Finally, it turned out that it was a partition into halves. Readers need clarification in advance.
11) The author mentions that the particular system is not integrable at page 52. A justification is needed.
12) The first sum in Eq. (3.9) can be simplified in view of the fact that the matrix u is unitary.
13) Figures 3-4 and 3-5 refer to Hamiltonian (2.1) which is irrelevant in Chapter 3. I believe this is a mistake. There should be references to Hamiltonian (3.14).

14) The Bloch vector components at page 71 are normalized in a way that the "length" equals 1/2. This is admittable but the normalizations throughout the text are different. Previously the length was chosen to be the square root of S(S+1). Some unification is needed.
15) Figure number is needed at pages 72, 74 (instead of ??).
16) While describing possible applications at page 78, the author writes the following: "We further note that the observation of ACR of only one qubit for sufficiently large τ indicates that the overlap between the desired initial many-qubit state and the experimentally prepared one is close to 1". This statement deals with a many-qubit system and seems to be in contradiction with the result in Figure 3-4. So the explanation is needed.
17) In the list of publications, the surnames of Sinai, Lyapunov, Boltzmann, and Bose are written lowercase. Correction is needed.
18) English must be fully revised. Being a non-native speaker, I have noticed so many misprints and errors to be corrected, so I cannot even imagine how many more I missed. For instance, "unable be able" at page 6, "referred to as" instead of "referred as" at page 14, "is known" instead of "is know" at page 15, last but one sentence in section 1.1.1, "then" instead of "than" at page 16, the first sentence of the last paragraph at page 16, "phenomena … demonstrate" instead of "phenomena … demonstrates" at page 21, "(2.1" instead of "(2.1)" at page 29, missing space in "Lyapunov exponents" at page 40, missing "a" in "trajectories" at page 40, comma missing in the caption to Figure 2-8, "at the same" at page 49, redundant "a" in "a transitional" at page 49, missing "e" in eigenenergies at page 50, repeated "between" at page 52, missing "n" in "pattern" at page 69, "a random rotation" not "the random rotation" at page 65, "a Bloch sphere" throughout the text should be replaced by "the Bloch sphere", "indices" instead of "indexes" at page 73, "a phenomenon" instead of "a phenomena" at page 91, "this phenomenon" instead of "this phenomena" at page 92.

The summary of issues to be addressed during the thesis defense

1. Particular results of Chapter 2 are obtained for a specific family of Hamiltonians, but in section 2.6 "Discussion" the results are somehow generalized as if they are true for a large class of Hamiltonians. How big is the class of such Hamiltonians? How can they be characterized? What justifies such a generalization?
2. Does the magic number 6 in Chapter 2 may originate from a factor 2 in front of YY interaction component in (2.1)? Say, this factor is changed to 3. What would be a new magic number (if any)?
3. At page 89 the author writes that "our numerical data suggest that while the weak EDH holds, the strong EDH is violated by rare nonclassical outlier eigenstates with a particle coherence length on the order of the system size". My question is what is the physical structure of these outlier eigenstates? Do they have any pattern?

Provisional Recommendation

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

10.09.2022

/Sergei Filippov/