LABORATOIRE DE PHYSIQUE ET MODELISATION
DES MILIEUX CONDENSES – UMR 5493

Grenoble, August 12th, 2025

Review of the PhD thesis manuscript by Maciej Marciniak

The PhD thesis manuscript by Maciej Marciniak, titled *'Super-Tonks-Girardeau effect in the low-dimensional Bose gases with competing interactions'* provides a very pedagogical and complete document addressing state-of-art theoretical advances on low-dimensional quantum gases. He combines several theoretical and numerical tools to obtain new original results for the properties of correlated quantum matter.

The manuscript is organized in three main parts. It is very well written, and it contains 100 references covering the previous works on the same topic. The author has made the choice of focusing on two of his works, but during his PhD he has other two articles published, showing an intense and fruitful work during his PhD.

In the first part of the manuscript, consisting of the first two chapters, Maciej Larciniak makes an introduction to the physical system under investigation, starting from an hystorical perspective, as well as covers the main concepts needed in quantum many-body physics, and the relevant experiments for one-dimensional gases. The presentation of the first chapter is very clear and I have very few suggestions : on page 2, he should specify why if the fermionic wavefunction vanishes when two coordinates meet, this implies that the two fermions cannot occupy the same quantum state. On page 4, he should specify that the Tonks-Girardeau wavefunction is the absolute value of the fermionic wavefunction only for the ground state (notice that the statement is not true for the excited states).

The second chapter is devoted to the numerical methods used during the thesis,a s the second quantization, the exact diagonalization and the DMRG method. I particularly appreciated that the presentation is very pedagogical and that several tests and exemples were provided. I have a few suggestions and corrections for this chapter. About Equation (2.3) it would be nice to state whether it cover all possible quantum states, with some explanation of why it is so. In Fig. 2.1b, would it be possible to estimate the law of convergence of the energy E to the exact energy ? Is it exponential ? Is it possible to study the dependence on particle numbers ? Concerning Fig 2.2b, if a Gaussian is taken instead of a contact interaction potential, one sees that it converges faster with k_max but to a value that it is higher than the one predicted for contact interactions. Is it possible to take into account this systematic shift in some way ? A discussion should be added. On page 33, it is mentioned that use of symmetries may speed up the numerical calculation. Although they were not specifically used in the current calculation, it would be interesting to add a short discussion of which would be the useful symmetries, how to implement them, and how much one would gain in efficiency in the calculation (the result of this analysis may finally justify why these symmetries were not implemented).

The second part of the manuscript, corresponding to Chapter 3, presents one of the two original results by Maciej Marciniak presented in the thesis manuscript. It is a very ingenious idea which combines sudden quenches and adiabatic ramps to reach by pumping an exotic excited state, which is characterized in full detail. This result is very original and fully understood, opening up to several perspectives as well as to possible experimental realizations. About this part, I have two corrections to suggest : first, about two-body correlations, it should be made clear that only density-density correlations of a Tonks-Girardeau gas coincide with the fermionic ones. One might consider other four-operator correlation functions, with different arguments of the field operators, which are not the same for bosons and fermions. Secondly, at the end of page 59, it is stated that only for odd particle numbers on a ring it is possible to map TG bosons onto fermions. This statement is inaccurate and needs to be corrected : as shown in the original work by Marvin Girardeau in 1960, it is also possible to provide an exact solution for even particle numbers, by mapping the bosons onto fermions with antiperiodic boundary conditions. The same result is also found by solving the Bethe Ansatz on a finite system length.

Finally, the third part of the manuscript focuses on a non-integrable model (except for N=2 particles) corresponding to an extended Bose-Hubbard model with attracting narest neighbours interactions. A very counterintuitive effect is found, denoted as « super-evaporation » where attractive bosons may expand instead of collapsing during their dynamics. Also in this chapter, a very pedagogical point of view is taken and the explanation of this phenomenon is provided in a step-by-step analysis. The numerical calculations are convincing and a perturbative approach is further provided in support. I urge the author to correct the caption of Fig 4.11 where energies are listed in units of 1/J instead of J.

Finally I noticed two small typos that need to be corrected : « (g<0 » needs to close the parenthesis, « nessesary » should be replaced by « necessary ».

In conclusion this thesis manuscript shows that Maciej Marciniak has obtained and fully understood several important results in the theory of quantum gases. His results open the way to experimental realizations and further theoretical advances. The manuscript is clear and well written. For all these reasons, I am favourable to proceed with the subsequent stages of the procedure, including the public defense.

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Konkluzja recenzji rozprawy doktorskiej
(Conclusion of dissertation review)

„Super-Tonks-Girardeau effect in the low-dimensional Bose gases with competing interactions"

Tytuł rozprawy *(Dissertation title)*: .....

Maciej Marciniak

Autor rozprawy *(Author of the dissertation)*: .....

☒ Pozytywna ocena *(Positive conclusion)*:

Stwierdzam, że przedstawiona mi do recenzji rozprawa spełnia wszystkie wymagania ustawowe i zwyczajowe stawiane rozprawom doktorskim i wnoszę o dopuszczenie jej do dalszych etapów postępowania doktorskiego, uwzględniając publiczną obronę.

*(I conclude that the presented dissertation meets the formal and customary requirements for doctoral dissertations and I recommend its admission to subsequent stages of the procedure, including the public defense.)**

☐ Ocena negatywna *(negative conclusion)*

Stwierdzam, że przedstawiona mi do recenzji rozprawa nie spełnia wszystkich wymagań ustawowych i zwyczajowych stawianych rozprawom doktorskim i dlatego nie rekomenduję dopuszczenia jej do dalszych etapów postępowania doktorskiego.

*(I conclude that the presented dissertation does not meet the formal and customary requirements for doctoral dissertations and therefore I do not recommend its admission to subsequent stages of the doctoral procedure.)**

Uzasadnienie powyższej oceny znajduje się w raporcie będącym załącznikiem 1.
(The justification of the above assessment can be found in the detailed report in the attachment 1.)

12/08/2025 .....

Data i podpis
(Date and signature)

Załącznik 1: Recenzja rozprawy doktorskiej
(Attachment 1: Review of the dissertation)

**Zaznacz ocenę (Please tick the box with your conclusion)*