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Dissertation Report

Title of the PhD Thesis: **Low-dimensional Bose gases with competing interactions: Non-linear effects in beyond-mean-field frameworks**

Name of the candidate: **Jakub Kopyciński**

The dissertation presented by Jakub Kopyciński studies dark solitons and quantum droplets in low-dimensional systems beyond the mean-field approximation. In particular, he addresses one-component gases with contact interactions, two-component gases with competing contact interactions and one-component gases with dipolar interactions. I consider that this PhD Thesis constitutes a valuable contribution to the field providing timely and original results. The Thesis presents sound results that have been submitted to high impact journals, including a Physical Review Letters. It is also worth noticing that Jakub is first author in all the publications included in the dissertation and that some of them have been developed in collaboration with other research groups. He is also coauthor of four additional publications (not discussed in the dissertation). It is clear that the candidate is completely able to carry out scientific work independently.

The dissertation is separated in two parts. The first part contains a broad introduction to the research topic of the PhD Thesis. It starts by fixing the broad context, places the scientific problem in the general state-of-the-art of the field and elaborates on the significance of the scientific challenge that it is addressed. After this general introduction a detailed description of the methods and key concepts is provided. In addition, a summary of the main results included in the publications is provided. The second part of the dissertation includes the four original publications of the candidate.

The main strength of the dissertation is that it covers rigorously an important and interesting open problem consisting of the modelling of situations in which the validity of the mean field approximation is not guaranteed due to the role of the interactions. For instance, the use of the Lieb-Liniger Gross-Pitaevskii equation (LLGPE), based in a hydrodynamics approach, has been benchmarked for a one-dimensional Bose gas with repulsive interactions in a box and has been also tested for a quasi one dimensional dipolar Bose gas in the presence also of strong contact interactions. The Quantum MonteCarlo density functional theory is also applied in the case of two component Bose mixtures with competing intra and inter-component interactions to get the LLGPE for mixtures. The GPE with Lee-Huang-Yang corrections is also used in the case of mixtures. It is evident that the dissertation presents more than enough theoretical knowledge to award the doctoral degree.

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Apart from the solid used mathematical approaches, the obtained results are sound and open new avenues in the field. In my opinion, one of the most remarkable ones is the prediction of the coexistence of a quantum droplet and a dark soliton.

Thus, the Thesis is very solid and it evidences that Jakub has a deep understanding and background of the field. Nevertheless, I found some minor weaknesses, namely, the general discussion of some concepts and the selection of specialized references in section 1 of the first part of the dissertation. I give some examples in the following: (i) as the first experimental demonstration of Bose Einstein condensation (BEC), only the reference of the group of Prof. Wieman and Prof. Cornell is provided but there are missing the ones of the groups of Prof. Ketterle and also of Prof. Hulet; (ii) the book of Pethick and Smith is provided but also the book of Pitaevskii and Stringari could be cited; (iii) only the credit to the first experimental demonstration of dark solitons is given to the groups of Prof. Sengstock and Prof. Lewenstein at the University of Hannover but there is another nearly simultaneous experiment in the group of Prof. Phillips at NIST. Although it is not the topic of the dissertation, for completeness, a comment about the existence of bright solitons for attractive interactions would be desirable. Also, some additional references on dipolar BECs and droplets would give more strength to the discussion. I would like to emphasize that all these points are minor and some are covered later in the dissertation. I consider that the dissertation presented by the Candidate is an outstanding Thesis at the forefront of research. The presented results open new avenues to the field and I would like to propose it for the distinction.

Therefore, I conclude that the presented dissertation meets the formal requirements for a Ph.D. thesis and recommend admission of the Candidate to the subsequent stages of the procedure, including the public defence.

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día 18/06/2024 con un
certificado emitido por AC
DNIE 004
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Verònica Ahufinger
Full Professor
Physics Department
Universitat Autònoma de Barcelona

Konkluzja recenzji rozprawy doktorskiej
(Conclusion of dissertation review)

**Low-dimensional Bose gases with competing interactions:
Non-linear effects in beyond-mean-field frameworks**

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

Jakub Kopyciński

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.)

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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)