STAND

of a dissertation

for the acquisition of the educational and scientific degree "doctor"

in professional direction 4.1 "Physical sciences", scientific specialty 01.03.01 "Theoretical and mathematical physics",

by defense procedure at the Faculty of Physics (F.Phys.)

of Sofia University "St. Kliment Ohridski" (SU)

The stand was prepared by: Assoc. Prof. Dr. Sava Dimitrov Donkov, IA with NAO, BAS, in his capacity of a member of the scientific jury according to Order No. RD 38-30 / 24.01.2023 of the Rector of Sofia University.

Dissertation topic: "Structure and astrophysics of self-gravitating objects in multiscalar theories"

Author of the dissertation: Radostina Zhekova Zheleva

I. General description of the presented materials

1. Data on the submitted documents

The candidate, Radostina Zhekova Zheleva, has submitted a dissertation and an abstract, as well as the mandatory tables for the Faculty of Physics from the Regulations for the Terms and Conditions for Acquiring Scientific Degrees and Holding Academic Positions at SU "St. Kliment Ohridski". 7 other documents are also presented (master's diploma and its appendix, autobiography, declaration of authorship by the doctoral student, table with author reference for the contributions of the doctoral student, application from the doctoral student to the supervisor, as well as a protocol on the originality of the dissertation work and statement in relation to the procedure for the prevention of plagiarism from the academic supervisor) supporting the applicant's achievements.

The documents submitted by the candidate for the defense correspond to the requirements of the ZRASRB, PPZRASRB and the Regulations for the terms and conditions for acquiring scientific degrees and occupying academic positions at SU "St. Kliment Ohridski" (PURPNSZADSU).

2. Applicant personal data

Radostina Zhekova Zheleva was born on 31.03.1994. in Stara Zagora. She is a Bulgarian citizen. In 2013 graduated from the profiled natural and mathematical high school "Geo Milev" in Stara Zagora. In 2017 graduated from the undergraduate program "Quantum and Cosmic Theoretical Physics" at the "Theoretical Physics" Department of F.Phys. of SU "St. Kliment Ohridski". The diploma thesis is on the topic of "Hawking emission" with scientific supervisor Prof. Dsc. Stoycho S. Yazadzhiev. In October 2018, she completed the master's program of the same department with a thesis on the topic "Tidal perturbations of space-time tunnels - Lov numbers", again under the supervision of Prof. Dsc. Stoycho S. Yazadzhiev. From January 2019 to January 2023, she is a doctoral student of Prof. Dsc. Stoycho S. Yazadzhiev and is preparing a dissertation on "Structure and astrophysics of self-gravitating objects in multiscalar theories".

Radostina Zheleva's scientific interests are in the field of theoretical and mathematical physics. Mathematical tools of General Relativity. Space-time tunnels and their geometry. Black holes. QFT in warped space-time. Differential geometry and topology. And others.

She speaks English and French at a good level.

3. General description of the candidate's scientific achievements

As the thesis clearly explains, the recent detection of gravitational waves paves the way for gravitational-wave astronomy, which together with electromagnetic observations forms multi-messenger astronomy. It, in turn, is a powerful tool for exploring the universe, as well as for searching for new fundamental fields and new exotic objects. Although the general relativity is in complete agreement with the experiments and observations, scientists always have reasons to look for new physics beyond the accepted model of gravity. Scalar fields are the simplest to consider, and so they are involved in extensions of the Standard Model and in alternative theories of gravity. In these theories, gravity is described both by the metric tensor and by one or more scalar fields. Such are multiscalar Gauss-Bonnet theories, in which scalar fields are coupled to the curvature of space-time. These theories predict new phenomena and a new kind of objects (such as space-time tunnels). This in turn gives rise to new interesting astrophysics related to these objects.

The present dissertation shows the existence of scalarized self-gravitating compact objects supporting non-trivial scalar fields in multiscalar theories of gravity (in particular, in Einstein-Gauss-Bonnet gravity), where scalar fields interact with the curvature of space-time by means of the topological invariant of Gauss-Bonnet. In the dissertation, the existence of scalarized black holes and neutron stars with rapidly decreasing "scalar hair" in multiscalar Gauss-Bonnet theories, whose scalar space is maximally symmetric three-dimensional Riemannian space, is numerically shown.

The obtained solutions make it possible to search for new astrophysical objects with a distinct scalar signature. As an example, quasi-periodic oscillations from the accretion disks of rotating space-time tunnels have been studied, and the differences with similar oscillations in Kerr black holes have been analyzed, which will help distinguish the two types of objects in future observations.

Summarizing, I can say that Radostina Zheleva works actively and competently in a very modern field of contemporary theoretical physics and astrophysics, which, above all else, requires extremely good knowledge of mathematics (differential geometry, differential equations, numerical methods, etc.). The mentioned results show that the research is carried out at the edge of modern knowledge about the compact objects in the universe, which requires a great strain of the intellect and entails a scientific risk. The latter creates the character of a true scientist, and I wish that Radostina and her colleagues' hard and patient work will be rewarded with observational evidence to confirm their solutions.

The results described above have been published in three scientific papers: two in PHYSICAL REVIEW D, and one in The European Physical Journal C. Both journals are in Q1. In one of the articles, the doctoral student Radostina Zheleva made a significant contribution. There have been established 20 independent citations of her works. At this stage she has an h-factor of 2. She has also given one talk at a scientific seminar. Based on this, I can confidently say that Radostina Zheleva meets and even significantly exceeds the minimum national requirements (according to Art. 2b, par. 2 and 3 of the ZRASRB) and, accordingly, the additional requirements of the F.Phys. of SU "St. Kliment Ohridski" for the acquisition of the educational and scientific degree "doctor" in the relevant scientific field and professional direction, mentioned at the beginning of this document.

Also, the scientific publications included in the dissertation do not repeat those from previous procedures for acquiring a scientific title and academic position, and there is no proven plagiarism in the submitted dissertation and abstract, as evidenced by the protocol of originality and the opinion of her scientific supervisor Prof. Dsc. Stoycho Yazadzhiev.

4. Content analysis of the scientific and scientific-applied achievements of the candidate contained in the materials for participation in the competition

This analysis of the candidate's scientific achievements is based on the structure of the dissertation work.

Chapter 1 presents the results of the study of quasi-periodic oscillations of accretion disks around rotating traversable space-time tunnels. The linear stability of the circular geodesic orbits in the equatorial plane was investigated and analytical expressions for the epicyclic frequencies were derived. The difference of quasi-circular oscillations of space-time tunnels compared to those of Kerr black holes is shown, which makes it possible to distinguish them in astrophysical observations. It turns out that much more diverse resonances and correspondingly stronger visible signals can be observed in space-time tunnels.

In Chapter 2, multiscalar Einstein-Gauss-Bonnet gravity is derived through its action. Next, the dimensionally reduced field equations describing black holes in the theory are presented. Numerical solutions describing maximally symmetric scalar space black holes for several coupling functions are given. A systematic study of the characteristics of black holes and the properties of the space-time around them (area of the horizon, entropy, radius of the photon sphere) was made. The solutions are found to be of zero scalar charge and therefore the scalar dipole emission is sup-

pressed, implying much less observational constraints. Non-uniqueness of the scalarized solutions was established for one of the coupling functions.

Chapter 3 discusses equations and solutions describing neutron stars in multiscalar Einstein-Gauss-Bonnet gravity. Numerical solutions representing spontaneously scalarized neutron stars with maximal scalar space symmetry are presented. The relations mass-central density, mass-radius and the relation of the binding energy to the baryon mass were constructed, which also carry information about the stability of a neutron star.

In conclusion, I can say that the obtained original results are new non-trivial solutions to key problems in multiscalar Einstein-Gauss-Bonnet gravity, which open possibilities for the detection of new fields and objects from multi-messenger astronomy. The latter would expand the limits of our knowledge of compact objects in the universe. This is work at the edge of science and I wish success and luck to both Radostina and the entire team.

Regarding the formal metrics, I'll repeat that the results were published in three Q1 papers as follows:

1. Efthimia Deligianni, Jutta Kunz, Petya Nedkova, Stoytcho Yazadjiev, and Radostina Zheleva, Quasiperiodic oscillations around rotating traversable wormholes, Phys. Rev. D 104, 024048, Published 19 July 2021.

2. Daniela D. Doneva, Kalin V. Staykov, Stoytcho S. Yazadjiev, and Radostina Z. Zheleva, Multiscalar Gauss-Bonnet gravity: Hairy black holes and scalarization, Phys. Rev. D 102, 064042, Published 15 September 2020.

2. Staykov, K.V., Zheleva, R.Z., Scalarized non-topological neutron stars in multi-scalar Gauss-Bonnet gravity, Eur. Phys. J. C 82, 108 (2022), Published 04 February 2022.

20 independent citations of Radostina Zheleva's works have been noted. She has an h-factor of 2. She has a significant contribution in the last work (above under number 3).

5. Critical notes and recommendations

I have no critical notes.

6. Personal impressions of the candidate

My personal impressions are only from the presentation of the pre-defense, which was presented very well.

7. Conclusion

After having familiarized myself with the presented dissertation work, abstract and other materials, and based on the analysis of their significance and the scientific and scientific-applied contributions contained in them, I confirm that the scientific achievements meet and even exceed the requirements of ZRASRB and the Regulations for its application and the corresponding Regulations of the SU "St. Kliment Ohridski" for acquiring the educational and scientific degree "doctor". In particular, the candidate satisfies the minimum national requirements in the professional direction and no plagiarism has been found in the dissertation, abstract and scientific works submitted for the competition.

I give my positive assessment of the dissertation work.

II. General conclusion

Based on the above, I recommend the scientific jury to award the educational and scientific degree "doctor" in professional direction 4.1 "Physical sciences" to Radostina Zhekova Zheleva.

10.03.2023 Reviewer: .....

(Assoc. Prof. Dr. Sava Donkov)