OPINION

on a Dissertation Thesis
for the assignment of the scientific degree a Doctor of Philosophy
in the professional field 4.1 Physical Sciences,
scientific specialty 01.03.01 Theoretical and mathematical physics
by defense procedure at the Faculty of Physics (FzF)
of Sofia University "St. Kliment Ohridski"(Sofia University),

The opinion is prepared by: Prof. Radoslav Christov Rashkov, Dr. Habil,
Sofia University Faculty of Science, as a member of the scientific jury of the competition:
4.1. Physical Sciences (Theoretical and mathematical Physics) according to Order № РД -38-30 / 24.01.2023 by the Rector of Sofia University.

Dissertation title: "Critical phenomena and quantum metrology with strongly correlated quantum-optical systems"

Author of the dissertation: Radostina Zhekova Zheleva

I. General description of the presented materials

1. Data on submitted documents

The candidate Radostina Zhekova Zheleva has submitted a dissertation and an Author's abstract, as well as the mandatory tables for Physics from the Regulations for the terms and conditions for acquiring scientific degrees and holding academic positions at SU "St. Kliment Ohridski". All documents required for the defense (in the form of official notes and certificates from an employer, project manager, funding organization or project assignee, references and reviews, awards and other relevant evidence) as well as documents supporting the applicant's achievements are also presented.

The documents presented 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 data

(Short professional and biographical details of the applicant)

Radostina Zheleva was born in Stara Zagora, where in the period 2008-2013 she completed her secondary education at the Profiled Natural and Mathematical High School "Geo Milev".

From 2013 to 2017, he studied in a bachelor's program at the Faculty of Physics of Sofia University. For the period October 2017 to October 2018, he completed the master's program of the Faculty of Physics in Theoretical and Mathematical Physics.
She defended her diploma thesis with honors under the supervision of corr. member Prof. Stoytcho Yazadjiev. From January 2019 to January 2023, Radostina Zheleva is a PhD student in Physical faculty with head corr. member Prof. Stoytcho Yazadjiev.

3. General characteristics of the applicant's scientific work and achievements

The presented dissertation is based on three articles in the most prestigious journals: two in Physical Review D and one in Eur. Phys. Journal C, all in quartile Q1. The publications have 20 independent citations and Hirsch factor h=2.

The scientific research of Radostina Zheleva reflected in the presented dissertation is mainly focused on analytic and numerical construction and research of models in multi-scalar gravity theories. A more specific focus that can be traced in the papers is on investigating the existence of black holes in a multi-scalar theory of Gauss-Bonnet quasi-periodic modes from an accretion disk around space-time tunnels and numerical construction of spontaneous scalarization solutions.

The general characteristics of the research can be summarized as follows:

- The topic of Radostina Zheleva's research is among the most relevant in the last ten years. The experimental detection of gravitational waves, as well as the discovery of a non-zero cosmological constant, poses new challenges to modern physics. The expected new generations of spectrometers with extremely high accuracy provide opportunities for testing different gravity models. In this context, R. Zheleva's research is not only up-to-date, but also represents a contribution to the field.

- As I already noted above, R. Zheleva has published a total of 3 articles in the most renowned magazines with a high impact factor. The three articles on which the dissertation is based are from the highest quartile - Q1. This definitely shows the highest quality of research.

- Observed independent citations are over 20 and the Hirsch factor is h=2.

In conclusion, it can be motivated and definitely said that:

a) the scientific publications included in the dissertation meet the minimum national requirements (according to Art. 2b, paras. 2 and 3 of ŽRASRB) and, accordingly, the additional requirements of SU "St. Kliment Ohridski" for acquiring the educational and scientific degree "doctor" in the relevant scientific field and professional field, presented at:
https://www.uni-sofia.bg/index.php/bul/universitet_t/fakulteti
fizicheski_fakultet2proceduri_za_nauchni_stepeni_i_akademichni_dl_zhnosti)

b) scientific publications included in the dissertation work do not repeat those from previous procedures for acquiring a scientific title and academic position; (see the tables in the applicant's documents)

c) there is no proven plagiarism in the submitted dissertation and abstract.

4. Characterization and evaluation of the applicant's teaching activity

There is no data on teaching activity, which is not required by ZRASRB, PPZRASRB and PURPNSZADSU.

5. Content analysis of the candidate's scientific and scientific-applied achievements contained in the materials

The main focus of R. Zheleva's dissertation is on investigation of self-gravitating compact objects allowing non-trivial scalar fields in multiscalar theories of gravity, in particular those with Gauss-Bonnet topological invariant. The main goals of the dissertation are to prove the existence of solutions describing black holes and neutron stars in Gauss-Bonnet multiscalar theories of gravity, as well as a systematic analysis of the characteristics of such objects.

The **first chapter** is devoted to quasi-periodic oscillations of accretion disks around rotating space-time tunnels. The chapter begins by introductory notes on a class of stationary axisymmetric geometries proposed to describe the above space-time configurations by Teo and subsequently developed by Morris and Thorne. In this approach, the аутхор examines a class of metrics with integrable equations of geodesics. The interpretation of high-frequency quasi-periodic oscillations from the accretion disk enables a systematic study of the existence and stability of time-like circular orbits of geodesics in the equatorial plane. Analytical expressions for the epicyclic frequencies are derived which are universal for a sufficiently wide class of traversable space-time tunnels with integrable geodesic equations. An essential point is the deviations from the known behavior of Kerr black holes and the quasi-circular equatorial motion is in the possibility of different types of ordering in the parameter space. This opens up possibilities for a wider class of resonance phenomena and possibilities for further interesting research. Numerical studies are illustrated with numerous figures giving clear arguments for the conclusions drawn.

The **second chapter** is devoted to scalarized black holes in Einstein-Gauss-Bonnet multiscalar gravity. The chapter begins with a description of the mathematical formulation of the problem, with the dimensionaly reduced field equations derived. The reduced equations are very complicated, but the analysis of the conditions for the existence of black holes provides grounds for further numerical investigation of the problem. The reduced equations are very complicated, but the analysis of the conditions for the existence of black holes provides grounds for further numerical investigation of the problem. The focus is on different coupling functions realizing black holes with scalar hair. The existence of spherical- symmetric black holes in certain classes of multi-scalar Einstein-Gauss-Bonnet theories of gravity with linear and exponential coupling functions and those leading to spontaneous scalarization. The investigations were carried out for the cases of the above theories in three-dimensional maximally symmetric spaces, as well as in cases of non-trivial embedding into target space. A systematic analysis of the characteristics of black holes such as horizon area, entropy and

others has been carried out. The characteristics of spontaneously scalarized black holes are studied, and the bifurcation points from the Schwarzschild case are examined in detail. An interesting phenomenon of mass dependence was observed – the scalarized branch moves as the mass increases, and starts to decrease when reaching a maximum.

Along with considering the other characteristics of black holes, the space-time around the obtained solutions was investigated and a deviation from the standard general theory of relativity at small masses was observed.

The last **third chapter** containing the doctoral thesis is on scalarized non-topological neutron stars in multi-scalar Einstein-Gauss-Bonnet theories of gravity. The chapter begins with a brief presentation of the equations and spherically symmetric solutions of multiscalar gravitational theories followed by the appropriate set up of the problem for numerical description of spontaneously scalarized neutron stars. Solutions for multi-scalar Gauss-Bonnet theories for the case of maximally symmetric spaces are numerically constructed, and the characteristics of the objects are investigated.

The remaining three sections contain a list of publications, acknowledgments and bibliography.

In conclusion, I would like to point out that Radostina Zheleva's dissertation contains theoretical research related to new theoretical theories in the context of generalizations of the standard General Theory of Relativity. The existence of compact space-time objects is proved and studied their important characteristics and properties both analytically, as well as numerically. One can make conclusions about the quality of the studies from the journals in which they are published - all publications are in the Q1 quartile. The importance of the results can be argued by the interest to them - the works have been cited more than 20 times. The bibliographic reference is sufficiently complete, and the abstract correctly reflects the content of the dissertation.

6. Critical remarks and recommendations

I have no substantial critical remarks. The dissertation is composed in a coherent and easily followed manner, but for the reader/reviewer there is one inconvenience. It consists in the fact that in the dissertation and the author's abstract it is not explicitly stated from which articles are the relevant contributions to each particullar chapter of the dissertation and must be additionally searched for. This, of course, in no way downplays the value of the dissertation work.

7. Personal impressions of the candidate

I have known Radostina Zheleva since she was a last yaer student as a modest and excellent student.

8. 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 correspond to the

requirements of ZRASRB and the Regulations for its application and the relevant Regulations of the SU "St. Kliment Ohridski" for the acquisition of the scientific degree "Doctor of Philosophy". In particular, the candidate satisfies the minimal national requirements in the professional direction and no plagiarism has been found in the dissertation, abstract and scientific works submitted for the defence of the dissertation.

I give my **positive assessment** of the dissertation work.

II. General Conclusion

Based on the above, I recommend to the scientific jury to award the educational and scientific degree "Doctor of Philosophy“ in professional direction 4.1 Physical sciences, scientific specialty 01.03.01 Theoretical and mathematical physics to Radostina Zhekova Zheleva.

28.03.2023 Signature: ....

(Prof. Dr. Radoslav Rashkov)