OPINION

on the dissertation

for obtaining the educational and scientific degree "Doctor"

in the professional field 4.1 Physical Sciences,

Theoretical and Mathematical Physics,

under the procedure for defense at the Faculty of Physics (FoP)

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

The review was prepared by: Prof. DSc Radoslav Hristov Rashkov, Faculty of Physics, SU "St. Kliment Ohridski"
(academic position, scientific degree, name, middle name, surname - workplace)
in his capacity as a member of the scientific jury according to Order No. RD 38-323 / 17.06.2024 by the Rector of Sofia University.

Title of the dissertation: "Optical Effects in Curved Spacetime: Gravitational Lenses, Shadows, and Light Polarization"

Author of the dissertation: Valentin Olegov Deliyski

I. General Description of the Submitted Materials

1. Information on the Submitted Documents

The candidate, Valentin Olegov Deliyski, has submitted a dissertation and an abstract, as well as the mandatory tables for the Faculty of Physics, according to the Regulations on the Conditions and Procedures for Obtaining Scientific Degrees and Holding Academic Positions at SU "St. Kliment Ohridski." Other documents have also been submitted (in the form of official notes and certificates from employers, project leaders, funding organizations, or project commissioners, references and reviews, awards, and other appropriate evidence) supporting the candidate's achievements.

The documents submitted by the candidate for the defense comply with the requirements of the Act on the Development of the Academic Staff in the Republic of Bulgaria (ZASRB), the Regulations for the Application of the ZASRB, and the Regulations on the Conditions and Procedures for Obtaining Scientific Degrees and Holding Academic Positions at SU "St. Kliment Ohridski".

2. Information about the Candidate

Professional and Biographical Data of the Candidate

The limited biographical information I have primarily comes from Valentin Deliyski's studies at the Faculty of Physics at Sofia University. Valentin Deliyski's interests lie in the field of gravity, particularly in gravitational lensing effects, numerical methods in physics, the dynamic evolution of the Einstein-Hilbert field equations, self-gravitating systems, and more.

Mr. Deliyski defended his bachelor's thesis, "Black Hole Shadows," with distinction, and his master's thesis, also defended with distinction, was on the topic of "Gravitational Lenses." The supervisor of both theses was Corresponding Member Professor DSc Stoycho Yazadjiev. From July 2021 to July 2024, he has been a Ph.D. student in the Department of Theoretical Physics, with scientific supervisors Corresponding Member Professor DSc Stoycho Yazadjiev and Associate Professor Dr. Falin Gyulchev. During his Ph.D. studies, Valentin Deliyski has performed exceptionally well, not only in his specialized exams and the doctoral minimum requirements but also by conducting an extensive amount of research. I will comment on the quality of his dissertation below. In addition to his academic work, he has worked (and continues to work) at EnduroSat as a GNC (Guidance, Navigation, and Control) engineer.

3. **Overview of the Candidate's Scientific Achievements**

The presented dissertation is positioned within the realm of advanced theories of gravity and their generalizations, making it highly relevant to current research. The dissertation is well-structured, featuring a general section that offers in-depth information on the field and its specific challenges, followed by a special section that presents the candidate's original research results. The thesis spans 138 pages, consisting of 9 chapters, including an Introduction, Conclusion, and Overview of the Results. It also includes a List of Scientific Activities, 4 Appendices, a List of Figures, and a bibliography citing 86 references.

It can be stated with assurance that:

a) The scientific publications included in the dissertation not only meet but exceed the minimum national requirements (as per Article 2b, paragraphs 2 and 3 of the ZRASRB) and the additional requirements of Sofia University "St. Kliment Ohridski" for obtaining the degree of "Doctor" in the relevant scientific field. These publications, of high quality, significantly contribute to the field. The dissertation is based on two papers published in *Physical Review D*, one in the *Journal of Physics: Conference Series*, and another on *arXiv.org*. Additionally, the candidate has presented three papers at international conferences, underscoring the recognition of his work in the global scientific community.

b) It is important to note that the publications included in the dissertation are original and do not duplicate any submitted in other procedures for scientific titles or academic positions, highlighting the candidate's independent contribution to the field.

c) Moreover, I have not observed, nor am I aware of, any instances of proven plagiarism in the dissertation or its abstract. The integrity of the candidate's work remains intact, with no evidence of academic misconduct.

The dissertation not only fulfills formal requirements but also contributes significantly to the study of generalized gravity theories. The candidate demonstrates a strong understanding of complex concepts and advances in the field. A detailed analysis of these achievements and their implications will follow in the next sections.

4. **Evaluation and Assessment of the Candidate's Teaching Activity**

During his doctoral studies, Valentin Deliyski conducted seminar classes on "Statistical Physics." It is important to note the positive feedback from students regarding his performance as a teacher.

5. **Substantive Analysis of the Scientific and Applied Achievements of the Candidate Contained in the Defense Materials**

The presented dissertation thoroughly and comprehensively examines the observational characteristics of two distinct types of exotic compact objects that lack an event horizon: spacetime tunnels and naked singularities. These studies are inspired by the significant results achieved by the Event Horizon Telescope (EHT) collaboration, which has for the first time achieved sufficient observational resolution to directly capture the immediate surroundings of supercompact objects located in the cores of the M87 galaxy and at the center of the Milky Way.

The primary goal of this dissertation is to explore in detail the potential for distinguishing exotic compact objects from black holes, utilizing available observational data and providing a solid foundation for interpreting future observations by the EHT collaboration. Such spacetime structures typically arise within generalized theories of gravity and play a crucial role in their validation. Specifically, this dissertation aims to investigate the possibility of clearly and conclusively differentiating exotic objects from black holes, which is essential for a deeper understanding of these mysterious entities and their place in the universe.

Challenges:

The most important characteristics for describing these objects and addressing the research goals include three main observational aspects: the morphology of the obtained images, their variability, and the polarization of their emission. These features are crucial for understanding the nature of the studied objects and distinguishing them from similar phenomena.

One major challenge faced by the research arises from the complex nonlinear interactions with magnetohydrodynamic processes occurring in the emitting environment around these objects. These interactions can significantly affect the observed characteristics and complicate their interpretation.

Another challenge is the presence of a broad range of exotic compact objects, which, despite significant differences among them, may leave qualitatively similar imprints in observations. This similarity can lead to difficulties in distinguishing between them based on existing data.

Furthermore, the observational signature of objects with qualitatively different optical manifestations, due to the gravitational lensing effect, may be obscured by limitations in resolution or other observational challenges, further complicating the task of accurate identification.

Conducted Research:

The research includes optical, morphological characteristics, and variability studies. The complex calculations and image generation of the objects require advanced numerical skills. In addition to mastering existing codes - a highly non-trivial task - Valentin Deliyski has developed the proprietary Mjølnir code. Along with other software packages, this code has achieved notable results in generating images of exotic objects and comparing them with Schwarzschild black holes. Without delving into specifics, it is worth noting that the results provide promising prospects for analyzing future observational data from the EHT collaboration.

Results:

The results presented in the publications on which the dissertation is based can be summarized briefly as follows:

a) Images of individual orbits were obtained using a well-known semi-analytical approach for image generation.

b) It was found that the images of two classes of exotic compact objects exhibit significantly different morphology from that of Schwarzschild black holes.

c) Using a simplified analytical model of radiation and the author's code, Mjølnir, conclusions were drawn regarding how direct and indirect images are influenced by the magnetic field, as well as by spacetime. It was shown that even with the expansion of the telescope array, the images remain morphologically similar to those of black holes.

d) It was established, within the working hypothesis, that the reconstructions become sensitive to the central ring structure, with the appearance of a clear central maximum in the depression. The presence of such observational data could serve as an indicator of the existence of exotic compact objects.

In the article by Valentin Deliyski, Galin Gyulchev, Petya Nedkova, and Stoytcho Yazadjiev, titled "Polarized image of equatorial emission in horizonless spacetimes: Traversable wormholes" (Phys. Rev. D, 106:104024, Nov 2022), Valentin Deliyski made an essential contribution, as confirmed by the other co-authors.

Undoubtedly, the results obtained in the dissertation not only advance current achievements but also take a step forward. The numerical simulations of the images of exotic objects pave the way for new hypotheses regarding their existence, dynamics, and detectability. The developed custom code essentially provides a new tool for analysis in this specific field.

The contributions of Valentin Deliyski's dissertation have not only scientific merits but also applied scientific aspects.

Publications:

The candidate has published a total of 4 works: 2 papers in *Physical Review D*, 1 conference report published in *Journal of Physics: Conference Series*, and 1 paper on *arXiv.org*. Notable independent citations: 9; h-index: 2.

6. Critical Remarks and Recommendations

I have no critical remarks regarding the dissertation or the abstract. The candidate demonstrates excellent skills in setting up, presenting, and analyzing data. Additionally, I would highlight his commendable literary awareness and depth of knowledge.

7. Personal Impressions of the Candidate

I have known the candidate since his student years. He is exceptionally focused, with deep knowledge at a professional level. Valentin Deliyski is a responsive colleague, dedicated to science. I can confidently state that Valentin Deliyski is a well-established young scientist with great potential.

8. Conclusion

After reviewing the presented dissertation, Author's Abstract, and other materials, and based on the analysis of their significance and the scientific and applied contributions contained within them, I confirm that the scientific achievements meet the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria (ZRASRB) and the regulations for its implementation, as well as the corresponding regulations of Sofia University "St. Kliment Ohridski" for obtaining the educational and scientific degree of "Doctor" with a large margin. Specifically, the candidate satisfies the minimum national requirements in the professional field, and no plagiarism has been detected in the submitted dissertation, Author's Abstract, and scientific works.

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

II. Overall Conclusion

Based on the above, **I confidently recommend** that the academic jury award the educational and scientific **degree of PhD (Doctor)** in the professional field **4.1 Physical Sciences**, Theoretical and Mathematical Physics, to Valentin Deliyski.

Date: 05.09.2024

Prepared by the reviewer: Radoslav Rashkov

Digitally signed by Radoslav Rashkov
Date: 2024.09.13 11:39:13 +03'00'

(Prof. DSc Radoslav Rashkov)