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: "Constraining strong regime gravity through analysis ofcompact astrophysical objects"

Author of the dissertation: Victor Ivaylov Danchev

I. General description of the presented materials

1. Data on submitted documents

The candidate Victor Ivaylov Danchev 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)

Victor Ivaylov Danchev completed his secondary education at "Dr. Petar Beron" Secondary School, Cherven Bryag with profiled study of the English language, with a grade of 5.93.

From 2014 to 2018, he studied in the bachelor's program "Quantum and Space Theoretical Physics" at the Faculty of Physics of Sofia University. For the period October 2018 to October 2019, he completed the Master's program "Theoretical and Mathematical Physics" of the Faculty of Physics. He completed both programs with the excellent grade of 6.00 and defended his thesis with honors under the supervision of a Prof. Stoycho Yazadzhiev. From January 2020 to January 2023, Viktor Danchev is a full-time doctoral student at the Faculty of Physics with a supervisor member-cor. Prof. Stoycho Yazadzhiev. He worked as a physicist, mission director and technical director at EnduroSat AD, Sofia.

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

Viktor Danchev is a (co-)author of a total of ten publications. 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 22 independent citations and Hirsch factor h=3.

Victor Danchev's scientific research reflected in the presented dissertation is mainly focused on compact objects in modified theories of gravity with the aim of limiting them in a strong gravity regime by means of various available observations. A more specific focus that can be traced in the papers is on the study of a new class of compact objects called topological neutron stars within tensor-multi-scalar theories (TMST) of gravity. In particular, their properties, universal ratios, and also the important observational characteristics are investigated.

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

- The topic of Viktor Danchev'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, V. Danchev's research is not only up-to-date, but also represents a contribution to the field.

- As I already noted above, Viktor Danchev has published a total of 8 articles, 4 of which are in the most reputable journals 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 22 and the Hirsch factor is h=3.

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 presented dissertation work is written in 144 pages divided into 7 chapters, 27 figures, acknowledgments and cited literature. In three of the chapters, the original results of the dissertation are presented. The cited literature covers 157 titles. The abstract consists of 56 pages including a bibliography of 82 titles, and correctly reflects the content and contributions of the dissertation work.

The main focus of the presented dissertation of V. Danchev is on different classes of alternative theories of gravity and compact objects in them, which could be candidates for the generations of OTO, subject to all the limitations imposed by observations on a cosmological and astrophysical scale. Specifically, the views are on topological neutron stars within the framework of tensor-multi-scalar theories (TMST) of gravity.

The main goal of the dissertation is the study of compact objects in these theories, as an important element, along with the universal properties, is what are the constraints on them in a strong gravity regime by means of various available observations.

The first chapter is introductory. It provides an overview of the field and presents some of the problems in it. A justification of the tasks set before the dissertation was made. The structure of the dissertation is also presented. The analysis made subsequently gives an idea of the location of the problems considered in the dissertation work and the achieved results.

The second chapter is devoted to modern gravitational theories starting in the first section with the General Theory of Relativity (GRO). The next four sections examine various modifications of gravity. An analysis of the need for modified gravity theories is made, considering scalar-tensor theories, tensor-multiscalar theories of gravity. In the last section, Gauss-Bonnet gravity is considered.

In **the third chapter** compact objects are systematically introduced and their properties are described. This involves systematic analysis of equation states. Obviously, they are strictly limited by the observational data obtained in different observations. The equations are extremely complex, but the presence of symmetries allows their reduction and simplification. This in turn makes it possible to construct alternative theories of gravity. In this context, several important cases such as equations in the static case and the case of slow rotation are considered. An analysis of the metrics outside the objects was done, i.e. the properties of spacetime outside compact objects. An important point in research of this nature is to find universal relations between characteristic quantities, in this particular case moment of inertia, mass, radius and normalization of moment of inertia and fit for inverse compactness, giving general properties of compact objects. In the next section, gravitational waves from binary systems are considered, as an example of the possibility of experimental confirmation of the theoretical results.

The fourth chapter is dedicated to the numerical methods used in the research. These range from numerical integration and differentiation, through solving algebraic equations to Monte Carlo Markov chain.

The **next three** chapters are devoted to the original results obtained by V. Danchev. **Chapter Five** Slow-rotating Topological Neutron Stars and Their Universal Relations are considered. The following results were obtained:
- the relevant equations of state (EOS) of static and slowly rotating compact objects for this class of theories are derived, and the results for two coupling functions and several parameters are presented.

- the results for the moment of inertia of slow-rotating topological neutron stars and the obtained universal ratios are presented.

Within the framework of the dissertation work, the independence of two normalizations of the moment of inertia as a function of the compactness was confirmed, and the obtained results for these graphs were compared with the analogous ones for neutron stars in GR. The obtained quantities for topological neutron stars differ significantly from those for GR only under certain conditions on the coupling function. These priovide options using the observations distinguish between theories of gravity and confirm or declare failure of GR at stronger fields. However, these require more precise and systematic observations.

The sixth chapter is devoted to universal relations in scalarized neutron stars at the point of maximum mass for scalar tensor theories. The following results were obtained:

- results were obtained for a new class of universal ratios for compact objects obtained from a relationship between physical quantities at the maximum mass of a given branch of solutions.

- a new type of universal ratios in CTT for quantities around the local maximum of the mass for a given branch of solutions have been confirmed.

In Chapter Seven, the constraints on scalarization in Gauss-Bonnet theories are analyzed through observations of binary pulsars.

The following results were obtained:

- the results regarding constraints of scalar Gauss-Bonnet theories of gravity by direct Bayes analysis on neutron star-white dwarf pairs with very precisely measured orbital decay rates are presented.

- results for different cases of the parameters characterizing the systems are presented.
- an analysis of the results obtained in this chapter is presented.

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

In conclusion, I would like to point out that Viktor Danchev dissertation contains research related to substantially new results in the context of generalizations of the standard General Theory of Relativity. 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 22 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. This is a rare case when the dissertation is composed in a coherent and easily followed manner.

7. Personal impressions of the candidate

I have known Victor Danchev since he was a third year bachelor student as a modest and excellent student. He is very open and bright person which his golleagues alway wanted to communicate.

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 requirements of the scientific degree "Doctor" (PhD). 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**" (PhD) in professional direction 4.1 Physical sciences, scientific specialty 01.03.01 Theoretical and mathematical physics to **Victor Ivaylov Danchev.**

30.04.2023   Signature: ....
                                                        (Prof. Dr. Radoslav Rashkov)