REFEREE REPORT

on a competition for holding the academic position of "Associate Professor"
in professional field 4.1. Physical Sciences
(General Theory of Relativity and Relativistic Astrophysics)
for the needs of the Faculty of Physics of Sofia University "St. Kliment Ohridski"
(announced in the State Newspaper, issue 30 on April 15, 2022)

The referee report was prepared by **Assoc. Prof. Dr. Galin Nikolaev Gyulchev**, Department of Theoretical Physics, Faculty of Physics, Sofia University "St. Kliment Ohridski", in his capacity as a member of the scientific jury according to Order No. RD-38-260/27.05.2022 of the Rector of Sofia University "St. Kliment Ohridski".

Only one candidate has submitted documents to participate in the announced competition, **Ch. Asst. Prof. Dr. Kalin Vilianov Staykov**, Department of "Theoretical Physics", Faculty of Physics, Sofia University "St. Kliment Ohridski".

I. General description of the submitted materials

1. Application data

The documents submitted in the competition by the candidate meet the requirements of the DASRBA, RIDASRBA, Rules on the conditions and procedure for acquiring science degrees and holding academic positions at Sofia University "St. Kliment Ohridski" (PURPNSZADSU) and the document „Additional requirements to the candidates for acquiring science degrees and holding academic positions at the Faculty of Physics of the Sofia University "St. Kliment Ohridski".

To participate in the competition, Kalin Staykov has submitted a list of 13 publications in foreign scientific journals. Data on the number of independent citations of the presented publications in the Scopus database and information on the impact factor/rank of these works (IF/SJR) are given.

Submitted documents for the competition include a curriculum vitae, master's and doctoral degree diplomas, a list and copy of publications, summaries of peer-reviewed papers, a reference to meet the minimum national requirements, a reference to citations, an author's reference to scientific contributions, a copy of the announcement in the State Newspaper and data from the "Authors" system. Attached are a certificate from the employer and copies of pages from the employment contract proving that the candidate's more than 5 years of work at the date of submission of the competition documents took place in the Faculty of Physics of the Sofia University "St. Kliment

Ohridski" as Chief Assistant Professor. Attached is a service report and copies of the individual reports on the academic employment of Ch. Asst. Prof. Kalin Staykov, official note for successful scientific supervision of 3 diploma theses – 2 for a bachelor's degree (2019 – 1 and 2021 – 1) and 1 for a master's degree (2021), given information (acronym and contract number) about his participation in 4 national research projects and management of 1 national project co-financed by the Bulgarian Scientific Research Fund. Ch. Asst. Prof. Kalin Staykov has also submitted a copy of a letter certifying his joining from November 8, 2021, as an associate member of the LISA consortium, a space mission of the European Space Agency and NASA designed to detect gravitational waves. Distinctive evidence of the candidate's work and achievements is the prize awarded to him for the best dissertation for 2016 at the Faculty of Physics of Sofia University "St. Kliment Ohridski" and the prestigious "Pythagoras" award 2022 of the Ministry of Education and Science for a young scientist in the field of natural and engineering sciences.

2. Applicant data

The candidate Ch. Asst. Prof. Kalin Staykov was born in 1990 in Lom. In 2013, he graduated with a bachelor's degree in engineering physics from the Faculty of Physics of the Sofia University "St. Kliment Ohridski", and in 2014 – a master's degree in "Theoretical and Mathematical Physics". From January 2015 to December 2016, he was a Ph.D. student at the Faculty of Physics, where he defended and received a doctorate in professional field 4.1. Physical Sciences (Theoretical and Mathematical Physics) with the thesis topic "Numerical modeling of the structure and properties of compact objects in astrophysics" under the guidance of Prof. DSc. Stoytcho Yazadjiev. From June 2017 until now, he holds the academic position of Ch. Asst. Prof. at the "Theoretical Physics" Department of the Faculty of Physics of SU "St. Kliment Ohridski". From March 2018 to June 2019, the candidate was managing editor of the Bulgarian Physical Journal. In the consecutive periods April 2019 – September 2019, April 2020 - September 2020, and April 2021 – September 2021, Kalin Staykov is a three-time postdoctoral fellow (R2 researcher) at the Faculty of Physics of SU "St. Kliment Ohridski". In July 2014, June 2015 – July 2015, and July 2019, the candidate has been on three one-month visits as a visiting scientist in the Theoretical Astrophysics group at the University of Tübingen, Germany. In 2017 Ch. Asst. Prof. Kalin Staykov become a member of the organizing committee of the summer school NewCompStar School 2017 – "Neutron stars: theory, observations and gravitational waves emission", held in Sofia, Bulgaria. From 2017 to 2021, the candidate was also a deputy delegate on the management board of COST action CA16214, The multi-messenger physics and astrophysics of neutron stars (PHAROS). Ch. Asst. Prof. Kalin Staykov has also been a peer-reviewer for European Physical Journal C, International Journal of Modern Physics A and Universe.

3. General characteristics of the scientific works and achievements of the candidate

Ch. Asst. Prof. Kalin Staykov has attached a list of 21 titles of scientific publications. 18 of these works are in reputable journals with an impact factor, and 3 are in conference proceedings (2 with an impact rank), of which he is a co-author and provides data on 322 independent citations (*Scopus*) and a Hirsch index $h = 10$ (*Scopus*). According to the *INSPIRE High Energy Physics Database,* the candidate's independent citations are 405, and the Hirsch index (excluding self-citations) is 11. In the list of all articles, the ones published in the journals Physical Review D – 8 (*Q1*) and European Physical Journal C – 5 (*Q1*) prevail; the other works have been published in the following journals: Journal of Cosmology and Astroparticle Physics – 3 (Q2), European Physical Journal Plus – 1 (Q2), Astrophysics and Space Science – 1 (Q3). 3 articles in refereed and indexed proceedings of international conferences have also been presented, of which 1 report has been published in the Proceedings of the 14th Marcel Grossmann Meeting and 1 in the AIP Conference Proceedings. The highest number of articles are those published in Q1 journals, while 4 have been published in Q2 and 1 has been published in Q3. From the attached list of scientific works, 2 articles in places [1] and [2] have been published before the acquisition of a doctoral degree, and 2 articles in places [3] and [4] have been in support of successfully occupying the position of "chief assistant professor".

13 publications have been submitted for participation in the "Associate Professor" competition, of which 11 in *Q1*, 1 in *Q2*, and 1 in *Q3,* and in 9 of them Dr. Kalin Staykov made a significant contribution. It is noteworthy that the majority of presented articles are in *Q1*, which together with the large percentage of articles in which the candidate has a leading role, states a high level of competence in the scientific topic and the quality of the presented scientific production. In general, the candidate's scientific results are concentrated on the modeling of compact objects, such as black holes and neutron stars, and the study of their parameters and properties in modified theories of gravity. Specifically, research is devoted to the quasinormal modes of gravitational waves created by these objects and the study of space-time nearby them. The scientific results of Dr. Kalin Staykov, having a significant contribution to the submitted publications for the competition, have been obtained in cooperation and under the guidance of Prof. DSc. Stoytcho Yazadjiev, the head of the Sofia Relativity Group.

Ch. Asst. Prof. Kalin Staykov presented a list of 81 independent citations of the publications selected for the competition. One of the publications [1], in which the candidate is a first author, has 50 citations, while a publication [8], in which the candidate is a second author, has 31 independent citations. The applicant's submitted number of citations exceeds the minimum of 50 independent citations, which fulfills the national state requirements and the additional requirements of the Faculty of Physics for holding the academic position “Associate Professor”.

The applicant's attached detailed report on the meeting of the minimum national requirements under Art. 2b, para. 2 and 3 of the Law on the Development of the Academic Staff in the Republic of Bulgaria and, accordingly, of the additional requirements of the Faculty of Physics of SU "St. Kliment Ohridski" for holding the academic position of “Associate Professor”, was prepared in good faith on the basis of publications [5] – [17] and the analysis of the evidentiary materials is in full compliance with the requirements. The 13 scientific publications submitted for participation in the competition ([5] – [17]) have not been used in previous procedures for acquiring a scientific degree and holding academic positions, implement new ideas and concepts, and no plagiarism has been proven according to the law. It is evident from the attached Table that the candidate exceeds the required points in the various groups of indicators and fully meets the requirements for the academic position of "associate professor" in the Faculty of Physics at Sofia University “St. Kliment Ohridski”.

4. Characteristics and assessment of the candidate's teaching activity

The teaching activity of Ch. Asst. Prof. Kalin Staykov started in the 2016/2017 academic year at the Faculty of Physics of SU “St. Kliment Ohridski” and continues until now. He led lectures and exercises in 6 different disciplines, including lectures on “General Theory of Relativity”, “Vector and Tensor Analysis”, and “Ordinary Differential Equations” and seminar exercises on “Mathematics”, “Ordinary Differential Equations”, “Vector and Tensor Analysis”, “Complex Analysis” and “Partial Differential Equations”. According to the submitted official reference for the candidate's educational employment from the "Educational Activities" department of the SU "St. Kliment Ohridski" for the 5 years between the academic years 2016/2017 - 2020/2021, he had 1942 hours of classroom employment and a total of 2115.5 hours of academic employment. It is clear from the accompanying documentation regarding the educational activity that the reported educational activity of Ch. Asst. Prof. Kalin Staykov significantly exceeds the minimum required commitment of 540 hours, specified as a criterion in the additional requirements of the Faculty of Physics for holding the position of “Associate Professor”.

In addition to the teaching activity, the candidate has been a scientific supervisor of 3 successfully defended theses in the “Theoretical Physics” Department of the Physics Faculty of SU “St. Kliment Ohridski”. Ch. Asst. Prof. Kalin Staykov is the supervisor of Zehra Abdrahim's BA thesis on “Thin accretion disk around a compact object” defended in 2019, of Chrysostomos Xanthis' BA thesis on “Scalar radiation from a particle in Schwarzschild geometry”, defended in 2021 and on Zehra Abdrahim's MA thesis on “Universal Relations for Slow-Rotation Neutron Stars” defended in 2021.

5. Content analysis of the scientific achievements of the candidate contained in the materials for participation in the competition

The scientific achievements of Ch. Asst. Prof. Kalin Staykov are mainly related to the numerical modeling of compact objects, including black holes and neutron stars, and the study of their physical parameters, properties, and quasinormal modes in modified theories of gravity. The candidate has expertise both in obtaining numerical solutions for black holes and neutron stars and studying their properties in Gauss-Bonnet gravity with multiple scalar fields and in studying different types of universal relations for neutron and quark stars and obtaining radial and epicyclic frequencies around neutron stars in scalar-tensor and $f(R)$ theories of gravity that can have a clear observational manifestation and be experimentally confirmed.

The candidate's scientific contributions received after acquiring the doctorate and holding the position of "Chief Assistant Professor" are described in detail and substantiated in the submitted author's report and can be divided into the following 3 main directions:

I. Gauss-Benet Gravity (publications [5], and [8]);

II. Gauss-Bonnet gravity with multiple scalar fields (publications [6], [7], and [9]);

III. Scalar-tensor theories and $f(R)$ theories of gravity (publications [9], [14], [15], [16], [17]);

Direction includes 2 of the publications with which the candidate participated in the competition. In this series of scientific papers, (publications [5] and [8]) the axial quasinormal modes of black holes with scalar hair in Gauss-Bonnet gravity with a massive self-interacting scalar field are studied and the existence of black holes in extended scalar-tensor-Gauss-Bonnet gravity with the presence of a massive scalar field is numerically demonstrated. The studies have been performed in a modified theory of gravity in which the scalar field is coupled to the Gauss-Bonnet invariant. It is the only theory with a quadratic curvature invariant, whose field equations are of the second order, and not of the fourth order as in the case of theories with quadratic curvature invariants, which coupled with a scalar field modify the GR and lead to the appearance of Ostrogradsky instability and ghost fields. Gauss-Bonnet gravitational theories have a dimensional coupling parameter with a dimension of a reciprocal length, which on the one hand, gives the possibility of obtaining the most strong constraints in systems with the presence of compact objects such as black holes and neutron stars. On the other hand, Gauss-Bonnet theories allow circumvention of the "no hair" theorems and predict the existence of black holes with scalar hair. These theories make it possible to find two types of scalar hair solutions – ones where scalar hair solutions represent the entire branch and solutions with scalarization. The second case is realized with coupling functions that allow General Relativity (GR) as a solution with zero scalar field. Two types of scalarization have been observed – spontaneous scalarization and non-linear scalarization, and in both cases, the source of scalarization is the large curvature of the space-time.

In publication [8], Ch. Asst. Prof. Kalin Staykov made a significant contribution in obtaining numerical solutions describing black holes with scalar hair and in studying their parameters in Gauss-Bonnet gravity with a massive scalar field. The candidate has analyzed linear and exponential coupling functions and a coupling function allowing for spontaneous scalarization. In publication [5], Ch. Asst. Prof. Kalin Staykov also contributed significantly to the numerical analysis of quasinormal modes of black holes in Gauss-Bonnet gravity with a massive self-interacting scalar field. Numerical solutions have been obtained for black holes in the presence and absence of spontaneous scalarization. Furthermore, by means of the time evolution of the equation of axial perturbations, the profiles of the created gravitational waves were obtained, from which the frequencies and attenuation times were subsequently estimated.

Direction II includes 3 publications with which Ch. Asst. Prof. Kalin Stoykov participates in the competition. In the series of scientific papers (publications [6], [7], and [9]) scalarized non-topological neutron stars in Gauss-Bonnet gravity with multiple scalar fields are studied, and a multiscalar extension of Einstein-Gauss-Bonnet gravity is considered. Numerical analyses show the existence of black holes in the presence of scalarization. The candidate also computes the orbital and epicyclic frequencies of particles moving around neutron stars in the context of a massive scalar-tensor theory of gravity with a self-interacting scalar field. The studies have been performed in gravitational theories, where the Gauss-Bonnet invariant is coupled with up to n dynamic scalar fields, taking values on a target space representing an abstract Riemannian manifold. In non-trivial mapping between the space-time and the target space, the increase in scalar degrees of freedom leads to new types of compact objects, such as topological neutron stars. Like single scalar field Gauss–Bonnet theories, in multiscalar Gauss–Bonnet theories, it is possible to circumvent the “no hair” theorems and demonstrate the existence of black holes with scalar hair. What is interesting about these theories is that there is a possibility of an appropriate choice of the coupling function that determines the existence of black holes with scalar hair or the occurrence of solutions of the field equations with a zero scalar field and the appearance of spontaneous scalarization, the source of which is the curvature of space-time.

In publication [9], Ch. Asst. Prof. Kalin Staykov made a significant contribution to obtaining numerical solutions of black holes and to the study of their properties in Gauss-Bonnet gravity with multiple scalar fields. The obtained results are for both linear and exponential coupling functions, as well as for coupling functions that allow spontaneous scalarization. Thus, in his research Ch. Asst. Prof. Kalin Staykov has demonstrated the existence of spontaneous scalarization, also caused by curvature in multiscalar Gauss-Bonnet theories. In publication [6], Ch. Asst. Prof. Kalin Staykov made a significant contribution to obtaining solutions for scalarized non-topological neutron stars with a zero scalar field at their center in Gauss-Bonnet gravities with multiple scalar fields. The solutions obtained in this case are also for a coupling function that allows spontaneous scalarization,

as in this case, the source of the scalarization is the space-time curvature. In publication [7], in which Ch. Asst. Prof. Kalin Staykov also made a significant contribution, branches of scalarized black holes have been found. In this case, it has been established the existence of a region of the parametric space where stable scalar black holes most likely coexist with stable Schwarzschild black holes. Such a phenomenon can have a clear observational manifestation.

Direction III includes 5 of the publications with which Ch. Asst. Prof. Kalin Staykov participates in the competition. In the series of scientific works (publications [9], [14], [15], [16], [17]), the subjects of studies are the moment of inertia of neutron stars in alternative and modified theories of gravity, universal relations between the normalized moment of inertia of neutron stars and their compactness in scalar-tensor theories and in $f(R)$ gravity, oscillations of neutron and quark stars in R^2 gravity, and the effect of rapid rotation on the universal relation between the normalized moment of inertia I and the quadrupole moment Q for scalarized neutron stars. The studies have been performed in the scalar-tensor theories of gravity, which, as the most natural generalization of GR, have one or several non-minimally coupled scalar degrees of freedom. On the other hand, $f(R)$ theories, in which a function of the Ricci scalar replaces the Ricci scalar in the Einstein-Hilbert action, are equivalent to a particular class of scalar-tensor theories and possess a scalar degree of freedom. Namely, in this direction, Ch. Asst. Prof. Kalin Staykov has significantly contributed to the study of $f(R) = R+aR^2$ gravity, specifically.

In a series of scientific works (publications [15], [16], [17]), Ch. Asst. Prof. Kalin Staykov investigates universal relations between different combinations of dimensionless neutron star parameters or of the frequencies of their quasinormal modes. Universal relations do not depend on the equation of state of matter in the neutron star, which helps to investigate modified theories of gravity, whose modifications can lead to deviations comparable with those due to the indeterminacy of the equation of state for dense matter greater than nuclear. In publication [15], Ch. Asst. Prof. Kalin Staykov has contributed to the study of universal relations between the normalized moment of inertia of neutron stars and their compactness in scalar-tensor theories and in $f(R)$ gravity. The studies included relations for two different normalizations of the moment of inertia, as Dr. Stajkov constructed the numerical models of the rotating neutron stars and the relations. More specifically, the relations $I/(MR^2)(M/R)$ и $I/M^3(M/R)$ for slow and fast rotating neutron star models are studied, and their universality is established. The universal relations for the maximal masses of sequences of rapidly rotating neutron stars with constant angular momentum have also been investigated. In particular, the relations $M/M_{\rm TOV}(J/J_{\rm Kep})$ and $M/M_{\rm Kep}(J/J_{\rm Kep})$, have been studied, where $M_{\rm TOV}$ is the mass corresponding to a spin-free model with the same central density and $M_{\rm Kep}$ is the maximal mass of a sequence rotating in the Keplerian limit (mass shedding limit). In publication [17], Ch. Asst. Prof. Kalin Staykov has also contributed significantly to the study of the so-called *I-Love-Q* universal relations representing the relation between the moment of inertia, the Love numbers, and the

quadrupole moment of the neutron star. Relations of this type have been considered in scalar-tensor theories of rapidly rotating neutron stars, where the relation $I/M^3(-Q/(M\,J^3))$ have been studied in particular, and their universality has been established. n publication [15], Ch. Asst. Prof. Kalin Staykov significantly contributed to studying asteroseismological relations for the *f*-modes of oscillations of neutron and quark stars in $f(R)$ gravity obtained in the Cowling approximation. More specifically, the relations $M\omega(\eta)$, $M\omega(M/R)$, $\omega(R^3/M)^{1/2}$ $(M/M_{\rm sun})$, and f(kHz)$((M/R^3)^{1/2})$ have been studied, where $\eta = (M^3/I)^{1/2}$.

Another aspect of the studies, published in a publication [9], in which Ch. Asst. Prof. Kalin Staykov made a significant contribution is expressed to the calculation of the radial and epicyclic frequencies around neutron stars in scalar-tensor theories with a massive self-interacting scalar field. The studies are critical in the observational testing of modified theories of gravity by modeling compact objects such as neutron stars and black holes due to the possibility of studying electromagnetic signals emitted near the compact object, most often around the last stable circular orbit of the particles.

Also Ch. Asst. Prof. Kalin Staykov made a significant contribution to the study of the ratio of the moment of inertia of the crust to the total moment of inertia of a neutron star obtained in scalar-tensor theories and $f(R)$ gravity. The obtained results, published in publication [14], can be used to explain the sudden increases in the angular velocity of neutron stars, called glitches, after which the star relaxes to its initial state. The research is motivated by the fact that in GR, the moment of inertia of the crust is insufficient to explain the transfer of angular momentum between the inner and outer crust of the neutron star. Therefore, another possibility is to study these ratios in the modified theories of gravity.

6. Critical remarks and recommendations

I have no critical comments regarding the presentation of the considered problems, the approaches to setting and solving the scientific tasks, and the results obtained. I also have no objections in principle to the credibility of the presented results and conclusions.

The materials submitted by the candidate allow us to conclude that he participated actively and at a high professional level in modeling and performing the numerical calculations, processing the results, and their interpretation and description. The manner of exposition and explanation suggests that the author thoroughly knows and understands the matter under consideration. I believe the candidate has contributed significantly to all scientific directions described in the submitted documents for the competition. An indicator of the productivity and importance of scientific publications is also the high Hirsch index of the candidate (h = 10), as well as the fact that the majority of all 13

scientific works with significant contributions have been published in authoritative journals with the highest rank *Q1* and with impact factor exceeding 4.5.

The report on the meeting of the minimum national requirements under Art. 2b, of DASRBA for acquiring scientific degrees and holding academic positions at SU "St. Kliment Ohridski" in professional field 4.1. Physical Sciences shows that Ch. Asst. Prof. Kalin Staykov meets and exceeds the minimum national requirements for holding the academic position of "Associate Professor": group A – 50 points at a minimum of 50; group B – 100 points with a minimum of 100; group D – 210 points with a minimum of 200; group D – 162 points with a minimum of 100. Ch. Asst. Prof. Kalin Staykov meets and significantly exceeds the additional requirements of the Faculty of Physics: successfully defended graduates – 3 with a minimum of 1; the number of group I publications in the last 3 years – 3 with a minimum of 1; the number of publications from group I in groups of indicators B and D – 12 with a minimum of 7; the number of publications in groups of indicators B and D with significant contribution of the candidate – 9 with a minimum of 4; *h*–factor 10 at a minimum of 5; teaching experience – 1942 hours with a minimum of 540.

Ch. Asst. Prof. Kalin Staykov has the necessary qualifications to teach specialized courses on gravitation and theoretical astrophysics, building on the standard courses on GR in the Faculty of Physics, and has the ability to attract postgraduate students who, after training, could become future specialists in this scientific field.

7. Personal impressions of the candidate

I have known Dr. Kalin Staykov ever since he took up the academic position of "Chief Assistant Professor" in the "Theoretical Physics" department at the Faculty of Physics of Sofia University "St. Kliment Ohridski". My personal impressions are excellent.

8. Conclusion on the application

After getting acquainted with the materials and scientific papers presented in the competition and based on the analysis of their significance and their scientific contributions, I confirm that his **scientific achievements meet the requirements** of DASRBA, the Regulations for its application, and the respective Regulations of Sofia University "St. Kliment Ohridski" (PURPNSZADSU) for holding the candidate for the academic position "Associate Professor" in the scientific field and professional field of the competition. In particular, the candidate satisfies the minimum national requirements in the professional field and no plagiarism has been established in the scientific papers submitted at the competition.

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

II. OVERALL CONCLUSION

Based on the above, I **strongly recommend** the scientific jury to propose to the competent authority for the selection of the Faculty of Physics at Sofia University "St. Kliment Ohridski", to choose Kalin Vilianov Staykov to take the academic position of "Associate Professor" in professional field 4.1. Physical Sciences (General Theory of Relativity and Relativistic Astrophysics) for the needs of the Faculty of Physics at Sofia University "St. Kliment Ohridski".

22.08.2022 г. Report prepared by:.....

(Assoc. Prof. Dr. Galin Gyulchev)