REFEREE REPORT

On the application for the academic position of "Associate Professor" in Professional Field "4.1 Physical Sciences" at the Faculty of Physics of Sofia University "St. Kliment Ohridski", opening call published in „State Gazette", issue 63 of July 30, 2021

This Referee Report was prepared by: **Prof. Dr. Sc. Svetlana Jordanova Pacheva**, Institute for Nuclear Research and Nuclear Energy , Bulgarian Academy of Sciences (retired), in her quality as a member of the Selection Jury in Professional Field "4.1 Physical Sciences" according to Order No.RD-38-488/01.10.2021 of the Rector of Sofia University "St. Kliment Ohridski".

There is a single applicant for the announced position – **Dr. Tsvetan Ivanov Vetsov**, senior assistant professor at the Faculty of Physics of Sofia University "St. Kliment Ohridski".

I.General Description of the Appication Documents

1. Information about the Application

The documents submitted by the applicant for the current academic procedure satisfy the official requirements according to the National Law for Academic Staff Development of the Republic of Bulgaria and the Regulations for the application of the latter Law, as well as the Regulations for Acquiring Academic Staff Positions in Sofia University "St. Kliment Ohridski".

For his participation in the current competition for the announced academic position the applicant has submitted **18** scientific publications, which are published in leading international journals with a high impact-factor (IF) or impact-rank (JSR). Among them **11** papers are in **Q1**, **1** paper is in **Q2**, **1** paper in **Q3**, 1 papers in **Q4**, **3** publications are with **IF** and/or **JSR,** and one publication is a separate chapter in a published book.

The applicant has also provided a list of independent citations, a list of his principal research contributions, a reference for his teaching work, a reference on the fulfilment of the Minimal National Requirements for the "Associate Professor" position, and also a declaration by Prof. Dr.Sc. Radoslav Rashkov confirming the applicant's contributions in their collaborative publications.

The documents submitted for the application confirm that the scientific achievements of the applicant satisfy (and even exceed) the Minimal National Requirements according to the National Law for Academic Staff Development as well as the additional Requirements of Sofia University "St. Kliment Ohridski" for the academic position "Associate Professor".

2. Information about the Applicant

Tsvetan Ivanov Vetsov was born on August 8, 1996, in the town of Razlog, Bulgaria. In 2011 he graduated at the Faculty of Physics of Sofia University "St. Kliment Ohridski" obtaining a M.S. degree in theoretical and mathematical physics. In 2015 he defended successfully his Ph.D. thesis "String Approach towards Gauge Theories" under the supervision of Prof. Dr**.** Sc. R.

Rashkov. Starting 2015 until today he is a senior assistant-professor at the Department of Theoretical Physics of the Faculty of Physics. The applicant was a scientific supervisor of the theses of 3 B.A. students which were successfully defended, 2 in 2016 and 1 in 2018.

The applicant was an active participant in 14 scientific projects: 7 of them financed by grants from the Bulgarian National Science Foundation(he has been a project leader of one of these projects); 6 projects financed by Sofia University "St. Kliment Ohridski" (of 2 of them he was a project leader) and 1 bistate project with the Russian Federation. The applicant was an organizer of the International School for young scientists "PhD Training Seminar-School , New trends in High Energy Theory'" which took place at the Faculty of Physics in Sofia University in 2017.

The applicant has participates numerous times in several respectable international conferences, both abroad as well as in Bulgaria and given talks at most of them.

3. General Description of the Research Papers and Achievements of the Applicant

The topics of the scientific papers of the applicant belong to the following currently most actively developing worldwide modern areas of theoretical and mathematical physics - string theory of elementary particles at ultra-high energies, including the celebrated gauge-gravity duality ("holography") and its numerous applications in the following fields:

(1) Gravity, cosmology and theoretical astrophysics – black hole physics in modern modified gravity theories which generalize the standard Einstein's general relativity;
(2) Condensed matter physics, in particular studying the effects of quantum entanglement (entanglement entropy).

On the basis of the documents supplied by the applicant for this procedure one can definitely conclude that:

(a) The scientific publications of the applicant satisfy (even with excess) the Minimal National Requirements (according to art. 2b (2) and (3) of the National Law for Academic Staff Development of the Republic of Bulgaria) as well as the additional regulations of Sofia University "St. Kliment Ohridski" regarding acquisition of the academic position "associate professor" in the Professional Field "4.1 Physical Sciences";
(b) The submitted research works by the applicant have not been previously submitted for consideration in other procedures for academic degrees and/or other academic positions.
(c) There is no legally detected evidence of plagiarism of any kind in the submitted scientific publications by the applicant.

4. General Assessment of the Teaching Experience of the Applicant

As an outside (with respect to the University) member of the Scientific Jury I can assess the teaching experience on the basis of the relevant documents submitted by the applicant for this Procedure. It is clear that during the years 2017-2020 the applicant has had average 400 hours of teaching duties per year, more of them have been at the University. Thus, teaching duties of 1600 hours for 4 years look a very loaded teaching activity. The applicant has given lectures on

various modern topics of theoretical and mathematical physics, in particular lectures on modern elementary particle theory at ultra-high energies, as well as on quantum field theory in the presence of gravity. The applicant has also been a teaching instructor in seminars on basic lecture courses for undergraduate students. He has as well been a scientific supervisor of 3 successfully defended B.A. theses.

5. Detailed Analysis of the Scientific Achievements of the Applicant Contained in the Submitted Documents

The scientific works of the applicant belong to several current modern topical areas as follows:

(1) ***Information Geometry: – Entanglement Entropy , Fisher Metric***

Here enter publications [6]- [9], [14], [18], [19], [21]-[23] from the submitted "List of Publications for "Associate Professor".

Information geometry is a field of probability theory and statistics which uses the concepts and methods of differential geometry. The entanglement entropy is a measure of the connectedness of two mutually complementary subsystems of a given quantum system, e.g. quantum spin chain, quantum field theory, etc. Entanglement entropy has a direct analogy to the black hole entropy in general relativity. One can define and calculate the Fisher information metric, which is a specific Riemannian metric on statistical manifolds of classical and quantum systems. Entanglement entropy and Fisher information metric are important instruments for investigating the thermodynamic properties, , including the behavior of the systems in the neighborhood of phase transition points. Thus, through the Fisher metric one can identify the phase transition points even without invoking the order parameters (e. g., the presence of divergent points of the scalar curvature of the Fisher metric signals the presence of phase transitions).

(1A) Fisher metric

One of the principal contribution of the applicant is the implementation of the fundamental approach based on the Fisher information metric to the investigation of black hole thermodynamics in nontrivial extensions of the classical Einstein general relativity. In [6] a specific extension of General Relativity is considered which contains higher derivative terms and its black hole solution - Deser-Sarioglu-Tekin (BST) black hole solution is studied.

The main result here is an appropriate modification of the DST black hole thermodynamics aimed at accounting for the fluctuations of the "dark matter" parameter.

The approach based on the Fisher metric has been also applied to calculate the physical characteristics of 3-dimensional black holes in the context of gauge(conformal field)-gravity duality (in this case ,"holographic" **AdS_3/CFT_2** duality) such as: thermodynamical stability, mass estimates, nonperturbative corrections to the entropy. The thermodynamic information geometry and the conditions for local and global stability have been used to obtain nontrivial restrictions on the central charges of the dual conformal field theories.

Furthermore, Fisher information metric has been applied to study the properties of the dynamics of a quantum string system on homogeneous plane wave gravitational background – entanglement entropy in the ground state; identifying phase transition points through the singularities of the Fisher Riemannian curvature; determination of the type of the interaction from the overall curvature sign.

Further interesting applications of information geometry are the calculation of the Fisher metric in discrete systems such as coupled Pais–Uhlenbeck oscillators as well as in holographic models

with non-relativistic symmetry in Schroedinger spaces, where the validity of the holographic duality has been explicitly established. Let us note, that the Schroedinger group is the nonrelativistic version of the conformal group and is the symmetry group of the Schroedinger spaces.

(*1B*) *Entanglement Entropy*

The entanglement entropy has been calculated in the following systems: (a) In discrete systems of higher-derivative oscillators of Pais-Uhlenbeck; (b) In the quantum dynamics of string systems moving in homogeneous plane wave space-times, in particular the entanglement entropy behavior in different space-time dimensions has been investigated; (c) In systems of condensed bosonic and fermionic matter the effectiveness of the thermo-field formalism has been demonstrated for calculating the corresponding entanglement entropy;(d) In dissipative quantum systems – the general expression for the non-equilibrium entanglement entropy has been calculated and the transition of the non-equilibrium entropy to an equilibrium one at asymptotically large times is traced.

(2) ***Physics of Black Holes and Compact Dark Objects in Astrophysics***

Here enter publications [6], [8], [15], [16] from the submitted "List of Publications for "Associate Professor".

The thermodynamics of DST black hole in 4-dimensional modified gravitational theories is investigated in detail and consistently generalized in order to take into account the effects of "dark matter". Here for the first time in the literature the DST black hole mass has been explicitly calculated.

The thermodynamics of 3-dimensional rotating Lifshitz black hole in massive gravity has been studied, where the Smarr relations among the thermodynamic parameters and non-perturbative entropy corrections as a result of the fluctuations of the black hole macro-parameters have been calculated.

In [15] and [16] the optical appearance and apparent radiation flux of a geometrically thin accretion disk around the static naked singularity of Janis-Newman-Winicour has been studied in the following cases (a) when the solution possesses a photon sphere - publication[15]; (b) when the solution does not possess a photon sphere –publication [16]. In both cases the solutions are compared with the case when a Schwarzschild black hole is at the position of the naked singularity This analysis, in particular, allows the observations to distinguish between the cases of naked singularity and Schwarzschild black hole. In both publications the applicant has a definite contribution to the numerical and graphical modelling of relativistic images of thin accretion disks in strong gravitational fields around dark compact objects.

Let us note that publication [15] is "golden"- it has the most independent citations – 27, according to Web-of-Science.

(3) ***String Theory and Gauge-Gravity Duality***

Here enter publications [17], [20], [11]- [13] from the submitted "List of Publications for "Associate Professor".

The study of string dynamics within the context of the "holographic" gauge-gravity duality via semi-classical quantization of strings moving in non-trivial gravitational space-time backgrounds in various space-time dimensions is an important integral part of the applicant's research . It

contains his significant contributions. The works on these problems could be grouped into relativistic AdS/CFT holography [17], [20] and non-relativistic Schr/CFT$_{\text{dipole}}$ holography [11] – [13].The applicant has studied in detail classes of string solutions of types "spikes", magnons and "folded" strings, where the explicit form of the equations of motion has been derived, a class of quasi-classical solution found and the anomalous dimensions of the operators in the corresponding dual quantum field theory have been computed. The 3- and 4-point correlation functions of the quantum field operators in the dual theory corresponding to the folded string solutions have been calculated as well. **Let us note that publication [17] has 23 independent citations according to Web-of-Science and is "at second citation place", after the publication [15].**

(4) ***String T-Duality and Supergravity***

Here enter publications [17], [20], [11]- [13] from the submitted "List of Publications for "Associate Professor".

T-duality (target-space duality) is a fundamental symmetry in string theory relating two different string theory models with different geometries of the gravitational space-time background but possessing equivalent physical properties. In this respect it is of essential interest to study new non-trivial solutions with non-abelian T-duality in the context of supergravity theories – to this end let us recall that supergravity theories are low-energy limits of superstring models. In the publications on this topic the applicant has substantial contributions in: (a) Exhibiting the explicit form of the non-abelian T-duality transformations for the fields of the supergravity multiplet; (b) Explicit derivation of a non-abelian T-duality supergravity solution dual to the Penrose limit of the well-known Pilch-Warner supergravity solution.

The scientific works of the applicant represent contributions to the creation of novel theoretical models and novel methods to study the fundamental laws of Nature at ultramicroscopic and, accordingly, cosmological scales of space-time.

As an overall evaluation of the scientific achievements of the applicant the latter are contributions to the all-encompassing long-term program of the worldwide community of scientists in the area of elementary particles and high-energy physics, astrophysics and cosmology in searching adequate answers to such fundamental phenomena as "dark matter" and "dark energy", presence or absence of extra space-time dimensions, presence or absence of supersymmetry, etc.

I would like to add, that according to INSPIRE-HEP , which is the most complete data base in theoretical and mathematical physics, and which is the field of the present application, , the applicant has **125** independent citations and **h-index = 6.**

6. Critical Remarks and Recommendations

I don't have any significant critical remarks. Here I would like to emphasize the positive features of the applicant's activity: in his scientific research he has demonstrated his skill to successfully

"switch" from one interesting problem to another in a broad range topics, at the same time showing ability to handle complex modern mathematical apparatus, as well as expertise to solve numerically complex problems in theoretical and mathematical physics.

7. Personal Impressions about the Applicant

I have known the applicant from contacts and discussions during participation in conferences, as well as from collaboration within the framework of our previous joint research projects financed by the Bulgarian National Science Foundation. I have entirely positive personal impressions.

8. Concluding Remarks about the Application

Upon getting acquainted with the submitted material by the applicant including the full texts of his publications, and based on the analysis of their impact and the evaluation of the significant scientific results contained therein, **I firmly reiterate my conclusion**, that these scientific achievements certainly satisfy the requirements by the National Law for Scientific Staff Development, the Regulations for enforcing the latter, as well the corresponding Regulations of Sofia University "St. Kliment Ohridski" for acquiring of the position of "associate professor" in the Professional Field "4.1 Physical Sciences". In particular, the applicant evidently satisfies the Minimal National Requirements for obtaining the academic position in question, and no evidence of plagiarism has been detected in the submitted scientific publications.

Therefore, I declare without hesitation my positive assessment of the present application.

II. OVERALL CONCLUSION

On the basis of the above consideration I do recommend to the honorable Selection Jury to propose to the competent Selection Body at the Faculty of Physics of Sofia University "St. Kliment Ohridski" to award the position of "associate professor" to Tsvetan Ivanov Vetsov in the Professional Field "4.1 Physical Sciences".

November 19, 2021 Referee:

Prof. Dr. Sc. Svetlana Pacheva