OPPONENT REVIEW

Competition for holding of academic position "Associate Prodessor", gazetted on 28 August 2020, No 67

One candidate: Galin Gyulchev

Procedure Notifier: Faculty of Physics, Saint Kliment Ohridski University of Sofia

Professional Direction: 4.1 Physical Sciences

Scientific Subject: General Relativity and Relativistic Astrophysics

Opponent: Prof. Michail Todorov, PhD, Dept of Mathematical Modeling and Numerical Methods, Faculty of Applied Mathematics and Informatics by the Technical University of Sofia, Bulgaria, by order РД 38-382/06.08.2020 of the Rector of St. Kliment Ohridski University of Sofia

1. Short biographical record of the applicant

Dr Galin Gyulchev was born in 1981. He undergraduated Faculty of Physics by the St. Kliment Ohridski University of Sofia in 2004 and two years later in 2006 he graduated the same faculty. Mean-while (2004-2008) he was physicist in the Institute of Astronomy – BAS. Since 2008 till 2019 he had been consecutively Assistant and Senior Assistant Professor in Department of Physics, Biophysics, and Rentgenology, Medical Faculty by the St. Kliment Ohridski University of Sofia. Since the fall of 2019 he has been a Senior Assistant Professor in the Faculty of Physics, SU. He took his PhD degree in Physics in 2010, thesis title "Gravitational Lenses". In 2019 he visited Germany for a short-term specialization.

2. General description of the competition documents

The applicant filled following compulsory documents: CV, copies of Master and PhD diplomas, document for academic position, certificate for a length of service, a certificate showing no previous conviction, information about minimal national requirements (NCID), list of citations, author information for the scientific and educational contributions related to the given competition supplied by PDF copies of all the articles in Bulgarian and English, advertisement in the official gazette, references „The Authors", and related to Article 112 of LDASRB.

3. General characterization of the research, teaching and applied activities

The results are presented in complement conferences and seminars in BG and abroad. The total scientific contribution of Dr Gyulchev consists of 28 works (10 journal papers with total IF=49.7, 12 papers in conference proceedings with SJR, 5 manuscripts submitted to `arXiv`, and one monography). All the works are with two or three co-authors. The applicant presents confirmation for equivalent co-authorship. All the journal works are cited many times like works [A.7, A.9, A.10] are cited 65, 64, and 70 times, respectively. Four works from the conference proceedings are cited 10 times totally – totally 337 citations (no autocitations), *h*-index = 7. Let me emphasize that all the citations are in top journals and publications with IF.

The applicant presents 18 works for the competition including 10 journal papers with IF belonging to quartile *Q1* and other 8 – conference proceedings. All of them are published in the period 2007-2019. The journal works are published in high ranked issues (*Physical Review D, Physical Review Letters, etc.*) The proceedings works are mainly in AIP CP with SJR. Dr Gyulchev presents monography entitled "Gravitation Lenses" co-authored by Prof. Stoycho Yazadjiev, published by the St. Kliment Ohridski publishing house. More details can be seen in

Table: Information about the works

	Abroad
Works – 10 numbers +8 numbers Monography – 1 number	*Physical Review D* – 6 numbers, *Physical Review Letters* – 1 number, *The European Physical Journal C* – 2 numbers, *Annals of Physics* – 1 item, *American Institute of Physics Conference Proceedings* – 6 numbers, *St. Kl. Ohridski Publishing House*
Reports on national and inter-national scientific events - 15.	*Conferences of Balkan Physical Union* – 2 times, *Application of Mathematics in Technical and Natural Sciences* – 2 times, *Marcel Grossmann Meeting on General Relativity, etc.*

The applicant announces about teaching classes in the Medical and Physics Faculties by the St. Kliment Ohridski University of Sofia – lectures (including in English), seminars, and practice on Theoretical Astrophysics and Introduction in the Physics of Black Holes, supervisor of one undergraduate thesis in the Astronomical Observatory of The Sofia University. Dr Gyulchev has taken part in 12 granted by Scientific Research Division of SU and National Science Fund of Republic of Bulgaria projects (including as a scientific leader). Also he has a short-term visit in the group of theoretical astrophysics in the University of Tuebingen (Germany). Dr Gyulchev collaborates with colleagues from Macedonia and Cyprus.

Having in mind the said above and according the Regulations in SU and in particular in the Faculty of Physics I can conclude that the applicant covers the requirements to hold the academic position of Associate Professor. Also, he covers and exceeds the minimal national regulations of LDASRB and has not any plagiarism in his works.

4. Analysis of the scientific and applied contributions

Dr Gyulchev presents impressive and very comprehensive author information where he claims his scientific and applied contributions. The problems into consideration can be grouped in 5 main directions:

- *Investigation of the relativistic effect of gravitational lens created by compact objects including black holes and naked singularities for large angles of light- rays deflection*

In works [А.6, А.9, А.10, Б.2, Б.6, Б.7, Б.8, В.1] a comprehensive investigation of the effect of gravitational lens and observable results is conducted. Object of investigation are the charged nonrotational black holes as well as charged rotational black holes subject to the dilaton gravity and the Einstein-Maxwell dilaton-axion gravity. Also, naked singularities according to the Einstein theory with massles scalar field and black holes within the frame of the Einstein anti-Maxwell-anti-dilaton gravity are considered.

In works [А.10, Б.7] it is established that the topology of axial symmetric steady-state space-time of Kerr-Sen's photon surface is 2D sphere. By using of conventional analytic technics the general power expansion of relativistic deviation angle of the light rays in a small vicinity of photon sphere is found and its logarithmic divergence for the rays over photon surface is established. The approximation in question is inapplicable for an extremal rotating black hole.

An essential result containing in [А.10] are the equatorial points of critical curves, for which a decrease along with the increase of the angle momentum and black hole charge is established.

In works [А.9, Б.6] the same technics for relativistic effect of gravitational lens for compact object without an events horizon is applied successfully. This object represents rotating axisymmetric naked singularity – a solution of the massless gravity field equations. The investigation conducted shows that for given values of the scalar charge and angle momentum the rotating naked singularity possesses photon 2d sphere-like region. It can produce relativistic images. One of the significant results shows that when a photon sphere is not present the strong naked singularity affects repulsively upon the light rays in the vicinity of singularity admitting negative deviation values. The latter demonstrates that the naked singularity has repulsive features as well as refracting ones.

The same analytic technics are applied in works [А.6, Б.2] as well, where the observable results of the gravitation-lens effect originated from possible existence of dark energy in the vicinity of black holes within the Einstein –(anti)Maxwell-(anti)-dilaton theory is studied. To this end the dark matter is modelled like a phantom scalar field and/or phantom electromagnetic field. It is established that the studied static black holes possess a photon sphere the latter allowing to be computed the actual relativistic images, the angular distance between the outer relativistic image and all the else relativistic images as well as the relation of their energetic ray flows.

In work [Б.8] numerical investigations of the relativistic effect of gravitational lens caused by the static and spherically symmetric dilaton Garfinkle-Horovitz-Strominger black hole are presented. The explicit impact of the dilaton field over the observable lens quantities is demonstrated. All the quantities related to the gravitation-lens effect are compared with the results for the light propagation around photon spheres obtained by Gibbons-Maeda-Garfinkle-Horovitz-Strominger and Reissner-Nordström.

In monography [В.1] a thorough analysis of the relativistic effect of gravitational lens is done. It is realized in the vicinity of photon regions of the compact objects where the time-space is significantly curved. A special attention is paid to the modern mathematical technics for analysis of the isotropic

geodesic flow in the simplest case of static and spherically symmetric space-time as the relativistic scenario of axial-symmetric space time needed for compact rotational objects.

- *Frequencies investigation of the quasinormal modes of black holes and their relation to the relativistic effect of gravitational lens. Quasiperiodic oscillations*

A course of getting of information for the physical features of different compact objects consists in quasinormal modes (QNM) of their gravitational waves. QNM allow to determine the kind of the compact objects - black holes and neutron stars as well as to delimit the gravity theories. They can predict different spectra and allow to specify the global asymptotic charges like the mass, the charge and angular momentum of the observable black holes and neutron stars.

The above idea is the base of the investigations in works [А.7, Б.5], consisting in fixing of relatively simple relations between QNM and the relativistic effect of gravitation lens. Also, a method to measure the QNM frequencies of spherically symmetric black holes by means the locations of observable relativistic images and the mutual growth of their light flows is developed. An essential contribution here is the analytic implementation of the equation of photon sphere for static and spherically symmetric space-time in the QNM frequencies and their direct relation to the measurable quantities of relativistic images. One more important result consists in the establishing of common analytic relationship between the Liapunov exponent, the time delay between the first and second relativistic image, and the relative energy flow as well as a relationship between the angular velocity of the last circular isotropic orbit and the time delay between the relativistic images. The relationships obtained can be applied for determination of locations of the gravitational-waves sources and getting of information about the frequencies of gravitational waves from a black hole we can expect. The latter acts both as a gravitational lens and a gravitational wave.

One more method of investigation of the space-time in the vicinity of black holes, massive stars, and gravity tests when the gravity fields are strong, are the quasiperiodic oscillations (QPO) of the roentgen flow from binary star systems [A.5]. Main possible application of QPO seems to be the angular moment of central massive object. The high-frequency QPO describe the nature of space-time in the vicinity of compact objects including black holes and neutron stars, while low- and middle-frequency QPO are considered as a result of physical processes in accretive discs. Basic hypothesis to create these QPO is the nonlinear-resonance model according which QPO are related to typical epicyclic and orbital frequencies of probe particles going round the compact object and subject to some nonlinear resonance relationship. Having in mind the above mentioned, in work [A.5] the properties of three typical frequencies of a propagating particle are studied. It is supposed to propagate in circular orbit in the equatorial plane of space-time symmetry in Tomimatsu-Sato, i.e., the radial, vertical, and orbital Keplerian frequency. To compute the frequencies variation methods over the equations of geodesic lines are applied. They are treated by specific numerical codding.

- *Obtaining the traces of compact objects including black holes and spatio-temporal tunnels*

Works [А.4, Б.1] are devoted to the modelling of the shadow of exotic compact objects and their analysis in different physical scenarios. The idea about shadow existence of compact objects including black

holes, naked singularities, and space-temporal tunnels is investigated intensively during the last 50 years. An experimental confirmation was recently attained - only few years ago.

Besides the black holes, the spatio-temporal tunnels and naked singularities possessing a photon sphere are able to create shadow images like those of black holes. Dr Gyulchev contributes essentially to this research topic, namely the shadow of rotating spatio-temporal disc, works [A.4, B.1]. The implemented investigations demonstrate that the spatio-temporal tunnels also possess photon sphere and hence they can form relativistic images. It is established that for given classes of spatio-temporal tunnels the throat plays the role of potential threshold for the light rays the latter impacting the shadow contour. Two solutions describing the spatio-temporal tunnels are considered and the structure of the images and formation mechanisms are studied. For some images the shadow contour is non-smooth curve at that the effect is due to the influence of two families of unstable spherical photon orbits. The studied solutions are examples of formation mechanism when the shadow contour can be described explicitly. Main contribution of the applicant is the creating of specialized program codes, which are unique and give an opportunity of the applicant to make important conclusions.

- *Constructing and investigation of relativistic images in compact-objects space-time including black holes and naked singularities*

In work [A.1] for first time is investigated the image of accretive disc around a compact object which is not a black hole. A naked singularity in presence of scalar field is considered and the accretive disk is approximated by a thin disk. The most important case, when the solution possesses photon sphere is chosen. The accretive-disk radiation is described by Novikov-Torn model. The relativistic images obtained are compared with accretive-disk image around Schwarzschield's black hole and it is shown that when photon sphere exists both compact objects produce qualitatively similar images. The applicant contributions cover the whole research process – the physical formulation and the mathematical model, unique highly specialized program codes creation. The latter integrate the isotropic equations of geodesic lines in an arbitrary axial-symmetric spatio-temporal metrics.

- *Investigation of the gravitational-lens effect caused by compact objects including black holes, naked singularities, and spatio-temporal tunnels for small deflection angles of light rays and particles*

In works [A.3, A.8, A.9, Б.4] the nonrelativistic effect of gravitational lens caused by class of phantom black holes and spatio-temporal tunnels are investigated. They also include charged, steady and axisymmetric dilaton-axion Kerr-Sen black hole, naked singularities in the Einstein field theory.

In work [A.3] in the beginning the light deviation angle caused by the Garfinkle-Horovitz-Strominger black hole and the Einstein-Maxwell theory with antidilaton field is investigated. The investigation is based on the optical geometry and Gauss-Bonnet theorem. The conducted investigations demonstrate eloquently the influence of phantom field on the gravitational-lens effect. Later on in the work the deviation angle in three kinds of spatio-temporal tunnels: tunnels with bounded and unbounded mass

function as well as ones with nonsensitive to red shift metrics are investigated. The gist of this investigation consists in predicting of light deviation angle by means of Gauss-Bonnet theorem, computing of Gauss optical curvature of the considered space-time supposing that the rays propagate in low-curved regions. Along with that standard analytic technics for the equations of isotropic geodesic lines are applied. The results obtained demonstrate that the given choice of the shape function and mass function both play crucial role for the deviation angle. In addition, in the work is constructed exact equation of the gravitational lens through that the nonrelativistic Einstein rings for small curving angles are predicted.

In works [А.8, Б.4] the effect of gravitational lens caused by charged steady axisymmetric dilaton-axion Kerr-Sen black hole is investigated analytically. In the frame of the approximation are derived solutions of perturbative isotropic equations of geodesic lines of third order. The main contribution is the computing of positions of both images created in weak gravitational fields and respective growths in post-Newtonian approximation.

In work [А.9] the effect of gravitational lens caused by massive compact objects in galactic kernels modelled as steady axisymmetric naked singularities in Einstein's field theory with massless scalar field are investigated analytically. For weak gravitational fields standard analytic technics for the positions of both created images and respective absolute growths as well as the centroidal curve in a post-Newtonian approximation is applied.

In addition, in work [А.2] for the purposes of experimental distinction the gravitational deviation of massive particles in the space-time of naked Janis-Newman-Winiker singularity and in rotating Kerr-like spatio-temporal tunnel is explored. The approach is based on a coordinate transformation that renders the linear spatio-temporal element isotropic. As an alternative the deviation angle is computed by means of Hamilton-Jacobi's equation that confirms the result.

- *Investigation of the nonrelativistic effect of gravitational lens caused by galactic cluster for small deflection angles of light rays*

The effect of gravitation lens as galaxies and cluster of galaxies is considered. The investigation in work [Б.3] aims to study the effect of gravitational lens of galactic cluster Coma Cluster (Abell 1656) specifying the magnitude of deviation angle and estimate the focal distance of the lens. The result obtained is that an observer on the Earth cannot observe the lens effect created by the cluster in case of remote light source. Another result indicates that dark matter in the galactic cluster Coma Cluster changes the focal distance of the gravitation lens 34 times.

5. Importance and contribution to the science and practice. Citations by other authors

The works of the applicant clearly indicate the achievements and accents in his scientific production. Beyond question they give directions to next important studies and predictions. All the publications contain original and useful results applied to considerable problems. Though the conducted investigations possess mainly theoretical significance they may be subject of experimental confirmation and prediction. Undoubtedly Dr Gyulchev holds and can apply effectively the mathematical methods, technics, and

algorithms which he complements by profound physical knowledge so needed for the successful research. The results obtained definitely got publicity and recognition clearly seen from the impressive number of citations as well as from the journal rank where they are cited.

6. Critical remarks and recommendations

I have not any remarks and criticisms. The documents are prepared diligently and give a real imagination about the scientific activity of the applicant. The statement demonstrates a deep understanding of the studied matter. The reference to the regulations for holding of academic positions demonstrate explicitly that Dr Gyulchev covers and even exceeds the minimal scientific criteria for associate professor: Group A – 50 points, required 50; Group B – 175 points, required 100; Group Г – 235 points, required 200; Group Д - 140 points, required 50. The works are belonging to quartile *Q1*. The number of citations is considerable – 337 in qualitative issues. In my opinion, the applicant is well qualified and can teach specialized classes on astrophysics and astronomy and this is my main recommendation to his future activity. Yet, the gained level of knowledge requires Dr Gyulchev to keep developed this research topic attracting postgraduated students to train.

7. Personal impression

I have known Galin Gyulchev since 2002 when he took part in workshops on Gravity, Astrophysics, and Strings (GAS) held in Kiten. Then he had graduate student. Few years later he took part in AMEE'07 and AMiTaNS'10 in Sozopol presenting reports and publishing peer-reviewed papers in AIP CP. He strikes me as a high had level and motivated young professional deeply penetrated in complicated field of study.

Conclusion

Gaining an impression for the all-round scientific and research activity of the applicant and having in mind the legal rules and criteria (LDASRB and its regulations in the Sofia University) as well as the specific rules in Faculty of Physics I **rate positively** the entire activity. On the strength of virtue of the law **I propose Dr Galin Gyulchev** for academic position Associate Professor in Faculty of Physics, Professional Direction 4.1 Physical Sciences, Scientific Subject: General Relativity and Relativistic Astrophysics.

Opponent

(Prof. Michail Todorov)

Sofia, November 15th 2020