ANNOTATION
to the dissertation work (series of articles) submitted for the degree of Doctor of Philosophy (PhD) in the educational program "8D05306 – Physics"

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APPLICATION OF FIELD THEORIES TO ASTROPHYSICAL PROBLEMS

General characteristics of the work

Modern developments in gravitational physics imply the active use of field theories for phenomena that cannot be fully described within the framework of classical General Relativity (GR). In this context, models in which gravity interacts with additional scalar and vector fields are of particular interest, as such configurations allow for the description of a wider class of astrophysical objects.

This dissertation is devoted to the theoretical study of gravitational effects arising from the inclusion of additional fields in the structure of spacetime and their application to specific problems of modern astrophysics. The main focus is on the analysis of the motion of test particles and photons near black holes (BHs), as well as on deviations from the predictions of GR. The aim of the work is to identify such deviations that can potentially be tested using existing observational instruments.

The following models are considered:

Regular BH models, derived from nonlinear electrodynamics – Fan-Wang and Dymnikova BHs. For the Fan-Wang solution, the geodesic motion of massive and massless particles, as well as photons in the effective geometry, is investigated. Perihelion shift, light deflection are analyzed. In addition, using the Novikov-Thorne thin accretion disk formalism, the radiation properties of accretion disks in both Fan-Wang and Dymnikova spacetimes are studied: radiative flux distribution, temperature, differential and spectral luminosities, and the efficiency of mass-to-radiation conversion.

Dilatonic black holes with two scalar and two vector fields. Circular geodesic trajectories of massive particles are studied. Effective potentials, orbital energy and angular momentum are determined, along with the radii of innermost stable circular orbits (ISCO). The dependence of these physical characteristics on the coupling parameter of the dilaton field and electric charges is established.

Thus, the dissertation demonstrates methods of comparing different field theories with classical GR using the above-mentioned BH models. It also shows that modifications introduced by the topological magnetic, electric charges and the dilaton coupling parameter manifest themselves in astrophysically significant observable effects. The employed approach combines exact analytical and numerical solutions of the equations of motion with perturbative methods, making it possible to relate the results to phenomena observed in accretion disks, stellar dynamics near BHs, gravitational lensing, and high-energy processes.

Relevance of the topic

The relevance of this dissertation is determined by the current stage of astrophysics, where high-precision observations enable the testing of fundamental theories of gravity in both strong and weak-field regimes. Modern instruments such as gravitational-wave interferometers (LIGO, VIRGO, KAGRA), the Event Horizon Telescope project, and spectroscopic observations of stellar orbits provide opportunities to explore the nature of compact objects. Mergers of BHs and neutron stars have been detected, and images of the shadows of supermassive BHs in the centers of M87 and the Milky Way galaxies have been obtained.

Classical BH solutions (Schwarzschild, Reissner-Nordström, Kerr) in many cases successfully describe observations, but they face fundamental problems such as singularities. Regular BH models, such as those of Fan-Wang and Dymnikova, based on nonlinear electrodynamics, make it possible to avoid singularities while preserving asymptotic consistency with GR. Dilaton solutions naturally arise in string theory, where scalar and gauge fields play an important role. Each solution introduces physical parameters (topological magnetic and electric charges, dilaton interaction parameters).

It should be emphasized that comparison with observational data allows one to set constraints on the parameters of BH models.

In this regard, research aimed at obtaining solutions for the equations of motion, orbital stability and shifts, light propagation is of both fundamental and applied importance. It contributes to distinguishing between classical and alternative BH models and shows how these models can be connected to real astrophysical objects.

The purpose of the research

Theoretical analysis of gravitational effects in black hole (BH) models including additional fields (nonlinear electromagnetic and dilaton fields).

The objects of the research

Black holes, nonlinear electromagnetic field, dilaton field.

The subject of the research

Motion of test particles and photons; gravitational effects (perihelion shift, light deflection); accretion disks.

Methods of research

The following methods were employed in the dissertation:

- Analytical and numerical solutions of the geodesic equations;
- Methods of differential geometry and tensor analysis;
- Lagrangian formalism and perturbation methods;
- Numerical modeling.

Research tasks

To achieve the stated purpose, the following objectives were set:

1. To study classical effects of general relativity in the spacetime of the Fan-Wang regular BH;

2. To investigate the radiative properties of accretion disks around Fan-Wang and Dymnikova regular BHs;

3. To analyze circular orbits in the spacetime of dilatonic BHs with two scalar and two vector fields.

Scientific novelty and main results

For the first time, this work has obtained the following results:

- For the Fan-Wang spacetime, analytical expressions for perihelion shift and deflection of massless particles and photons were derived. It was shown that nonlinear electrodynamics introduces corrections to the Schwarzschild results that can, in principle, be distinguished observationally.

- For the Fan-Wang and Dymnikova BHs, the radiative flux, temperature, luminosity, and conversion efficiency of accretion disks were calculated. It was demonstrated that for non-zero electric and magnetic charge parameters the ISCO moves closer to the horizon, leading to higher disk temperature and enhanced efficiency of mass-to-radiation conversion compared to the Schwarzschild BH.

- For the dilatonic BHs, solutions for circular geodesic orbits of massive particles were obtained. The dependence of ISCO radius, orbital energy and angular momentum on the coupling parameter and charges was established, revealing deviations from the Schwarzschild and Reissner-Nordström solutions.

Provisions for the defense:

1. In the Fan-Wang regular black hole model, the effects of nonlinear electrodynamics lead to a weakening of gravitational phenomena, including perihelion shift, photon and massless particle deflection, as the magnetic charge increases. A direct application to observational data for the perihelion shift of the S2 star orbiting Sagittarius A* allows us to constrain the magnetic charge to the value $l \approx 4.34 * 10^{-11}$ Wb.

2. Accretion disks around the Fan-Wang and Dymnikova regular black holes are characterized by higher differential luminosity than those around the Schwarzschild black hole. The efficiency of converting mass into radiation reaches 11.43% (Fan–Wang) and 8.7% (Dymnikova) exceeding the Schwarzschild value by 2 and 1.5 times, respectively. In the binary system Cygnus-X1, the maximal possible temperature of a disk surface is: $6.70 * 10^6$ K (Fan-Wang) and $5.45 * 10^6$ K (Dymnikova), exceeding value for the Schwarzschild black hole by 1.75 and 1.43 times, correspondingly.

3. For the dilatonic black holes, the innermost stable circular orbit radius, and efficiency of conversion mass into radiation increase monotonically with increasing dilaton coupling parameter a, with the Schwarzschild ($a = a_{min} = 0$), Sen ($a = 1$) and Reissner-Nordström ($a = a_{max} = 2$) solutions emerging naturally as limiting cases of the theory.

The theoretical and practical significance of the research

The theoretical significance lies in the advancement of BH physics within models that take additional fields into account. The practical significance is associated with the possibility of applying the obtained results to model processes in the vicinity of compact objects—radiation from accretion disks, gravitational lensing, and stellar orbital dynamics. The derived analytical dependencies can be used to constrain parameters of alternative BH models from observational data in real astrophysical systems.

The reliability and validity of results

The results and conclusions of the study are supported by publications in peer-reviewed international and domestic scientific journals. Their reliability is confirmed by consistency with modern theoretical models, with observational data, with conclusions on the nature of similar physical objects, as well as with the results of studies conducted by other authors.

Author's contribution

The author took part in selecting the research methods in collaboration with scientific advisors. Numerical calculations and analysis of the obtained results were carried out, and conclusions were formulated. The results were presented at international scientific conferences and prepared for publication in peer-reviewed journals.

Publications

The main results contained in the work were published in 9 scientific papers, including:

High-impact articles published in journals included in the international scientific databases Thomson Reuters and Scopus:

1. Boshkayev K., **Suliyeva G.**, Ivashchuk V., Urazalina A. Circular geodesics in the field of double-charged dilatonic black holes //The European Physical Journal C. – 2024. – V. 84. – №. 1. – P. 19. (**WoS:** Impact Factor – 4.8, Q2. **Scopus:** 91%).
2. Mychelkin E., Makukov M., **Suliyeva G.**, Jafari N. On the weak and strong field effects in antiscalar background //General Relativity and Gravitation. – 2024. – V. 56. – №. 4. – P. 44. (**WoS:** Impact Factor – 2.8, Q2. **Scopus:** 73%).
3. Kurmanov Y., Boshkayev K., Konysbayev T., Luongo O., Saiyp N., Urazalina A., Ikhsan G., **Suliyeva G.** Accretion disks properties around regular black hole solutions obtained from non-linear electrodynamics // Physics of the Dark Universe. – 2024. – V. 46. – P. 101566. (**WoS:** Impact Factor – 6.4, Q1. **Scopus:** 84%).
4. **Suliyeva G.**, Boshkayev K., Konysbayev T., Kurmanov Y., Luongo O., Muccino M., Quevedo H., Urazalina A., Dalelkhankyzy A. Geometric properties versus particle motion in the Fan-Wang spacetime // Chinese Journal of Physics. – 2025.– V. 96. – P. 1065. (**WoS:** Impact Factor – 4.6, Q1. **Scopus:** 85%).

Articles in publications recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan:

1. Kurmanov Y., Boshkayev K., Konysbayev T., Muccino M., Urazalina A., Ikhsan G., Saiyp N., Rabigulova G., Karlinova M., **Suliyeva G.**, Taukenova A., Beissen N. Analysis of dark matter profiles in the halos of spiral galaxies // Physical Sciences and Technology. – 2023. – V. 10. – №. 3-4. – P. 4-16.
2. **Suliyeva G.**, Kurmanov Y., Konysbayev T., Boshkayev K., Urazalina A., Luongo O. Finite temperature effects within Scalar Field Dark Matter model // Eurasian Physical Technical Journal. – 2024. – V. 21. – №. 2. – P. 92-101.
3. Kurmanov Y., Konysbayev T., **Suliyeva G.**, Ikhsan G., Saiyp N., Rabigulova G, Urazalina A. Radiative characteristics of accretion disks around

rotating regular black holes // International Journal of Mathematics and Physics. – 2024. – V. 15. – №. 1. – P. 57-67.

4. **Suliyeva G.**, Mychelkin E., Makukov M. Two types of scalar field visualization //Reports of NAS RK. – 2025. – V. 2. – P. 79-93.

Publications in the proceedings of international and domestic scientific conferences:

1. Suliyeva G.B. Circular geodesics in the field of double-charged dilatonic black holes // International Scientific Conference of students and young scientists “Farabi Alemi” of Al-Farabi Kazakh National University, Almaty – 2023. P. 29.

Approbation of work

The results obtained in this work were presented and discussed:

- at scientific seminars of the Department of Theoretical and Nuclear Physics of Al-Farabi Kazakh National University;
- at the international scientific conference of students and young scientists “Farabi Alemi”, Almaty, April 6-8, 2023 y.;
- at the international conference «Abdildin Readings. Actual Problems of Modern Physics», Almaty, April, 15-18, 2023 y.;
- at the international conference «New Trends in Theoretical Physics», Tashkent, October 23-28, 2023 y.;
- at the international conference «International Conference on Theoretical Physics and Astrophysics», Tashkent, May 13-18, 2024 y.

Connection of the topic with the research plan

The research work was carried out within the framework of the project of the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan: “AP19680128 Motions of test particles and photons in the gravitational field of dilatonic black holes” (AP19680128).