ANNOTATION

dissertation for the degree "Doctor of Philosophy" (PhD)
in the specialty "8D05306 - Physics"

MALYBAYEV ALGIS NURGISAEVICH

VARIOUS ASPECTS OF DYON-LIKE DILATONIC BLACK HOLES

The dissertation work is devoted to the study of various aspects of dilatonic black holes of the dyon type in the 4-dimensional theory of gravity.

Relevance of the topic.

The relevance of this work is associated with the recent discovery of gravitational waves. The discovery of gravitational waves reinforced the long-standing interest of the international scientific community in the study of quasi-normal modes (QNM) predicted by Vishweshvara in 1970. The detected gravitational waves were emitted during the final stage of the merger of two black holes. The frequencies of these waves were determined by superpositions of damped oscillations, i.e. QNM. A thorough analysis of this and subsequent observations is very important, since it directly reveals the properties of gravitation in the strong field regime and is able to shed light on its nature.

At present, there is interest in spherically symmetric solutions, including black hole solutions, which appear in gravitational models with scalar fields and antisymmetric forms (including models of superstring origin) and can be related to Lie algebras and Toda chains.

At the same time, a special subclass of 4-dimensional solutions in the gravity model with scalar (including dilaton) fields and fields of 2-forms with dilaton coupling of exponential type has not yet been sufficiently studied, including from the point of view of QNM.

Objective.

Obtaining and detailed study of the exact solution for the dilaton-dyon black hole arising in the 4-dimensional theory of gravity with two scalar fields and two fields of 2-forms, which will allow one to determine such characteristics as gravitational mass, scalar charges, Hawking temperature, entropy, parametrized post-Newtonian parameters and, on their basis, check the first law of thermodynamics and the Smarr relation, as well as obtain and investigate the QNM spectrum for a massless test scalar field in the eikonal approximation (EA).

Object of study.

Dilaton-dyon black hole.

Subject of study.

Physical characteristics of a dilaton-dyon black hole, such as gravitational mass, electric and magnetic charges, scalar charges, Hawking temperature, Bekenstein-Hawking entropy for a black hole, parameterized post-Newtonian parameters, QNM.

Research methods.

Numerical and analytical methods, investigations of nonlinear differential equations, methods of differential geometry and methods of variational calculus were used to solve problems necessary to achieve the objectives.

To achieve the purpose of the dissertation the following tasks have been posed:

1. Try to find the exact spherically symmetric dilaton-dyon black hole solution using the equations of motion for the model under consideration.
2. Calculate physical characteristics such as gravitational mass, scalar charges, Hawking temperature, black hole entropy, parametrized post-Newtonian parameters using the exact dilaton-dyon black hole solution.
3. Using the obtained physical characteristics check the first law of thermodynamics and the Smarr relation.
4. Calculate the QNM spectrum of a test massless scalar field in the eikonal approximation.
5. Check the Hod conjecture, connecting the damping rate of the quasi-normal modes and the Hawking temperature.

The novelty of the work.

The novelty and originality of research lies in the fact that for the first time:

1. The possibility of the existence of an exact non-extremal dilaton-dyon black hole solution in the gravitational 4d model with two scalar (dilaton) fields and two 2-forms with exponential dilaton coupling is investigated.
2. The physical parameters of non-extremal dilaton-dyon black hole, such as gravitational mass M, doublet of scalar charges $\vec{Q}_{\varphi}$, electric and magnetic charges Q_1, Q_2 are calculated.
3. The Hawking temperature and the Bekenstein-Hawking entropy are determined in the gravitational 4d model with two scalar fields and two 2-forms with exponential dilaton coupling. The first law of black hole thermodynamics and the Smarr relation is verified.

4. QNM spectrum of test electrically neutral scalar field in eikonal approximation ($l \gg 1, l \gg n$, where l is the orbital quantum number, and n is the number of overtons) in the background of the black hole metric is obtained.

5. The Hod conjecture, connecting the damping rate of the quasi-normal modes and the Hawking temperature is studied in the eikonal approximation ($l \gg 1$) with the lowest value of the overtone number $n = 0$.

Provisions for protection:

1. In the gravitational 4d model with two scalar (dilatonic) fields and two 2-forms with exponential dilaton coupling governed by two 2-dimensional dilaton coupling vectors $\vec{\lambda}_1$ and $\vec{\lambda}_2$, there exists an exact non-extremal dilaton-dyon black hole solution with values $\vec{\lambda}_1, \vec{\lambda}_2$ obeying $\vec{\lambda}_1(\vec{\lambda}_1 + \vec{\lambda}_2) > 0, \vec{\lambda}_2(\vec{\lambda}_1 + \vec{\lambda}_2) > 0$.

2. The physical parameters of non-extremal dilaton-dyon black hole, such as gravitational mass M, doublet of scalar charges $\vec{Q}_\varphi$, electric and magnetic charges Q_1, Q_2, are related by the relation: $2(GM)^2 + \vec{Q}_\varphi^2 = Q_1^2 + Q_2^2 + 2\mu^2$, where $\mu > 0$ is the extremality parameter, G is the gravitational constant.

3. The product of the Hawking temperature and the Bekenstein-Hawking entropy does not explicitly depend upon the coupling vectors $\vec{\lambda}_s$ and the charges Q_s.

4. QNM spectrum of test electrically neutral scalar field in eikonal approximation ($l \gg 1, l \gg n$, where l is the orbital quantum number, and n is the number of overtons) in the background of the black hole metric depends upon a dimensionless parameter a ($0 < a \leq 2$), which in the limit $a = +0$, corresponding to the Schwarzschild black hole agrees with the result of B. Mashhoon and at $a = 2$, corresponding to the Reissner–Nordström charged black hole agrees with the result of N. Anderson.

5. The Hod conjecture, connecting the damping rate of the quasi-normal modes and the Hawking temperature is valid in the eikonal approximation ($l \gg 1$) with the lowest value of the overtone number $n = 0$: a) for all values of the (collective) charge $Q > 0$ and $0 < a \leq 1$, b) for small enough values of the charge Q: $Q/M < q_{crit}(a)$ and $1 < a \leq 2$.

Theoretical and practical significance of a dissertation.

Obtaining exact solutions and their analysis in the gravitational 4d model with scalar fields and two 2-forms, as well as the calculation of QNM spectrum of test scalar field in the background of metric are important tasks for understanding the nature of strong-field regime of gravity.

Reliability and validity of the results.

The results obtained in this work are reliable because they are based on well-known research methods, used in the works of a large number of well-known authors. In addition, the obtained results of analytical calculations agree with previously known solutions for particular and limiting cases. The main results of the work were published in high impact factor journals and were presented at international scientific conferences abroad.

The author's personal contribution lies in the fact that the entire volume of the dissertation work, the choice of the method of solving the problems and the numerical calculations were performed by the author independently. The setting of tasks and discussion of the results were carried out together with scientific supervisors.

Publications.

According to materials presented in the dissertation 8 publications have been published in total: 2 articles in journals indexed in: Web of Knowledge (Thomson Reuters, USA), Scopus (Elsevier, Netherlands); 1 article in journal indexed in Scopus (Elsevier, Netherlands); 5 works in collections of international scientific conferences.

Approbation of the dissertation.

The results of the work were presented and discussed at the following local and foreign international conferences:

- at the scientific seminars of the Theoretical and Nuclear Physics Department at Al-Farabi KazNU;
- at the International Scientific Conference of Students and Young Scientists "FARABI ALEMI", Almaty, April 6-9, 2020;
- at the International Scientific Conference of Students and Young Scientists "FARABI ALEMI", Almaty, April 6-8, 2021;
- at the International Scientific Conference of Students and Young Scientists "FARABI ALEMI", Almaty, April 6-8, 2022;
- at the 5th International Conference on Particle Physics and Astrophysics, Moscow, October 5–9, 2020;
- at the International Workshop on Relativistic Astrophysics and Gravitation, Tashkent, May 12-14, 2021;
- at the International Scientific Online Conference «Sixteenth Marcel Grossmann Meeting» Rome, Italy, 2021.

Volume and structure thesis.

The dissertation work consists of an introduction, 4 chapters, 2 appendices and list of references from 87 titles, contains 108 pages of basic computer text, including 10 figures and 2 tables.