ABSTRACT

of dissertation for the Philosophy Doctor (PhD) degree in specialty "6D060400-Physics" by

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on the topic **"ANISOTROPIC MODELS OF COMPACT STARS IN MODIFIED THEORIES OF GRAVITY"**

The dissertation is devoted to the study of anisotropic compact stars in the Universe within the framework of modified theories of gravity**.**

Relevance of the dissertation theme.

Advances in astrophysics and cosmology have significantly expanded our understanding of the Universe and its enigmatic components. Despite considerable progress, numerous unresolved questions remain, stimulating ongoing research into the physical characteristics and evolution of stellar objects. The largest source of visible light in the Universe arises from nuclear fusion occurring within stars. Supernova explosions give rise to compact stars. A star collapses under the weight of its mass when the internal pressure can no longer resist the force of gravity. Compact stars, such as neutron stars, white dwarfs, and black holes, are formed as a result of the final stages of stellar evolution. Compact stars have a small radius, large masses, and structures that are largely unaffected by high temperatures compared to normal stars. Over the past few decades, gravitational theories have shown considerable interest in the study of compact stars. Stellar evolution, examined through isotropic and anisotropic pressures inside stars with a stable configuration of neutron stars, describes the nature, structure, stability, and life cycle of a star.

The interest in this topic lies in unresolved questions such as the nature of dark matter and dark energy. Modified theories of gravity offer alternative approaches to explaining these phenomena, avoiding the need to introduce non-standard forms of matter. The analysis of compact stars, which possess the strongest gravitational fields, within the framework of these theories provides a unique opportunity for experimentally test predictions under conditions inaccessible to laboratory studies.

In addition, taking into account the pressure anisotropy inside compact stars, where radial and tangential pressures differ significantly, influences their theoretical modelling. The traditional assumption of isotropic pressure is a simplification that does not reflect the actual physical processes in these objects. The study of anisotropy opens prospects for a deeper understanding of the internal structure and stability of compact stars.

Modern astronomical achievements, especially in the field of gravitational wave detection, provide extensive and precise data on compact stars. Alongside gravitational wave observations, electromagnetic observations conducted by missions such as the Neutron Star Interior Composition Explorer (NICER), the Square Kilometre Array (SKA) radio interferometer, and enhanced X-ray Timing and Polarimetry (eXTP) space observatory, allow for high-precision measurements of the

mass, radius, and moment of inertia of neutron stars. These measurements offer independent information that can be used to test and compare the predictions of anisotropic models with actual astronomical observational data. The high accuracy of modern measurements allows for the detection of even small deviations from standard models, opening the way to discovering new physical phenomena and refining our understanding of gravity under extreme conditions. These data serve as a valuable tool for validating and refining theoretical models, including anisotropic models of the internal structure of compact stars within the framework of modified theories of gravity.

Thus, studies of the anisotropic properties of compact stars in modified theories of gravity can lead to a breakthrough in understanding the fundamental laws of gravity and the structure of the Universe.

Based on the contemporary issues in theoretical physics outlined above, the dissertation **"Anisotropic models of compact stars in modified theories of gravity"** is dedicated to the investigation of anisotropic compact stars in the Universe within the framework of modified gravity.

The main goal of work

Study of the influence of modified theories of gravity on the structure, properties, and stability of compact stellar objects, to expand the theoretical framework for describing astrophysical phenomena under conditions of strong gravity.

To achieve the above goal, the following **tasks** must be accomplished:

1. Construction of an exact solution for anisotropic compact stars in general relativity, taking into account the charge parameter.

2. Construction of models of anisotropic compact stars in modified $F(R)$ gravity with analysis of pressure and energy density distributions.

3. Construction of models of anisotropic compact stars, considering the effects of torsion and electric charge in $F(\tilde{T})$ gravity.

The object of the research. The object of this research is compact astrophysical objects and their behavior under the influence of modified theories of gravity.

The subject of the study

Gravitational field equations, structural configurations of compact objects, stability analysis of models using the Harrison-Zeldovich-Novikov criterion6 equilibrium analysis using the Tolman-Oppenheimer-Volkoff (TOV) equation, physical acceptability of models, and fundamental physical characteristics.

Research methods

Analytical and numerical methods are employed to model the properties of the studied objects, using metric formalism, the Durgapal–Fuloria ansatz, the Buchdahl ansatz, as well as for comparing theoretical predictions with available observational data.

Scientific novelty of the dissertation results

The scientific novelty of the dissertation lies in the following contributions, obtained for the first time:

1. An analytical solution with the $B_0^2 = \left(1+Sr^2\right)^2$, gravitational potential has been obtained, in which the influence of the charge parameter on the main characteristics is investigated while maintaining full stability of the model, allowing for the description of massive compact objects.

2. An analytical solution of the gravitational field equations for anisotropic compact stars in $F(R)$ gravity has been derived, and an assessment of the model parameters has been performed by comparing them with the corresponding observational data.

3. A field equation for an anisotropic compact object in $F(\tilde{T})$ gravity has been obtained, taking into account anisotropy, the torsion parameter, and the charge function, which enables a more accurate description of the internal structure of these objects.

The main provisions submitted for defense

1. In the model of an anisotropic compact star with a radial electric field, an increase of the charge parameter E_0 from 0 to $4\cdot10^{-6}$ leads to a decrease in the central pressure from $1.136\cdot10^{35}$ Pa to $6.350\cdot10^{34}$ Pa and to increase in the allowable radial coordinate from 0 to 10 km while maintaining the stability of the system.

2. The solutions obtained in the models of the modified theory of gravity of the exponential $F(R)=R+\alpha\left(e^{-\beta R}-1\right)$ and the generalized power $F(R)=R-(1-\delta)\gamma^2\left(R/\gamma^2\right)^{\delta}$ types with the ranges of parameters α=11.112÷333.340, β=0.003÷0.090, γ=0.126÷0.327, δ=0.567÷0.697 satisfy the causality conditions of compact objects.

3. In the theory of modified teleparallel gravity, an increase of the torsion parameter ζ_1 in the range 1.00-1.04 for the linear function $F(\tilde{T})=\zeta_1\tilde{T}+\zeta_2$ results in the maximum mass of a compact star increasing from 2.22 $M_\odot$ to 2.68 $M_\odot$ with radii of 9.31-10.83 km, while the moment of inertia reaches $4\cdot10^{45}$ g cm^2, while the system remains stable, which is consistent with the observed properties of neutron stars.

Theoretical and practical significance of the work

The results obtained in this dissertation contribute to the expansion of the theoretical framework for studying compact stars, allowing for a more realistic description of their internal structure and physical properties, taking into account charge and anisotropy. They can be used for modeling the evolution of compact objects and assessing their role in the formation of galaxies. In addition, the results obtained can be applied in related fields, such as elementary particle physics and condensed matter physics. This helps to explain observational data and to make new predictions that can be tested by future observations.

Author's personal contribution

The entire volume of the dissertation and its main results were obtained by the author. Numerical calculations and graphical analyses were carried out independently

by the author. The formulation of the research problems and the choice of methods were performed in collaboration with the scientific supervisors.

Reliability and validity of the results

The reliability of the scientific results is confirmed by citations of the author's publications by foreign researchers, as well as by the fact that the results have been published in high-impact international journals.

Publications on the topic of the dissertation

Based on the results of the dissertation, 8 scientific papers have been published. Among them, 6 articles were published in high-impact international journals, 1 article in a journal included in the list of journals recommended by the SHEQAC MSHE RK, and 1 paper in the proceedings of an international conference.

1 Maurya S. K., Errehymy A., Singh K. N., Jasim M. K., Myrzakulov K., & **Umbetova Z.** Modeling self-bound binary compact object with a slow rotation effect and effect of electric field gradient on the mass-radius limit and moment of inertia //Journal of High Energy Astrophysics. – 2024. – Vol. 44. – P. 45-59.

2 Kumar J., Maurya S. K., Chaudhary S., Errehymy A., Myrzakulov K., & **Umbetova Z.** Physically viable and stable charged perfect fluid solution within F(Q) gravity // Physics of the Dark Universe. – 2024. – Vol. 46. – P. 101593.

3 Maurya S. K., Errehymy A., Daoud M., Myrzakulov K., & **Umbetova Z.** Effect of torsion and electric charge parameters on the configuration of anisotropic compact stars in f(T) gravity // Physics of the Dark Universe. – 2024. - Vol. 46. - P. 101586.

4 Kumar R., Maurya S. K., Errehymy A., Myrzakulov K., **Umbetova Z.**, & Pathak V. N. Anisotropic model of stellar objects in modified f(R) gravity // Chinese Journal of Physics. – 2024. – Vol. 92. – P. 1-22.

5 Kumar J., Maurya S. K., Kiroriwal S., Errehymy A., Myrzakulov K., & **Umbetova Z.** Dynamics of relativistic wormholes in the presence of dark matter density profile within f(Q, T) gravity // Physics of the Dark Universe. – 2024. – Vol. 46. – P. 101636.

6 Maurya S. K., Errehymy A., **Umbetova Z.,** Myrzakulov K., Ibragimov I., Dauletov A., & Rayimbaev J. Implication of f(Q, T) gravity on the formation of the charge compact stars and constraining their mass-radius relations in lower mass gap region // Journal of High Energy Astrophysics. – 2025. –Vol.47. - P. 100391.

7 Абдижалилова У.У., **Умбетова Ж.С.** Сфералық-симметриялық анизотропты жұлдыз үшін телепараллель гравитациясындағы f(τ) ширату скалярын анықтау // XXI Международная научно-практическая конференция «Молодежь, наука и инновации» – Актобе: Актюбинский региональный университет имени К. Жубанова, 2025 - С. 406-409.

8 **Умбетова Ж.С.,** Абдижалилова У.У. f(τ) - телепараллель гравитациясындағы анизотропты компактты жұлдыздардың эволюциясының динамикасы // Научный журнал «Доклады НАН РК» - 2025 – Т. 354, № 2. – С. 105-120.

Approbation of the dissertation

The scientific results and key findings of the dissertation were presented and discussed at the following conference:

– The XXI International scientific and practical conference “Youth, science and innovation” K. Zhubanov Aktobe regional University, Aktobe, April 14, 2025.

– at scientific seminars of the department of general and theoretical physics of the L.N. Gumilyov Eurasian National University.

Connection of the dissertation topic with the plans for the scientific work

The dissertation was carried out within the framework of the following scientific projects: under grant funding for scientific and/or scientific-technical projects for 2024–2026, IRN: AP23487178 "Study of some problems of modern cosmology in modified theories of gravity using Bayesian machine learning methods"; under grant funding for young scientists “Zhas Galym” 2025–2027, IRN: AP25794707 program titled "Investigation of anisotropic compact stars in the framework of the theory of gravity"

Structure and score of the dissertation

The dissertation consists of an introduction, three chapters, a conclusion, and a list of references. The total length is 103 pages and includes 41 figures, 160 equations, 9 tables, and 150 references.