

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.

The development of astrophysics and cosmology has led to a new understanding of the Universe and its mysterious components. Despite the significant achievements of recent years, many challenging problems still remain, motivating scientists to investigate various astrophysical objects and the physical phenomena associated with them. The largest source of visible light in the Universe is produced by thermonuclear fusion occurring inside stars. Supernova explosions lead to the formation of compact stars. A star undergoes gravitational collapse under its own weight when the outward pressure within the star can no longer counterbalance the force of gravity. Compact stars, such as neutron stars and white dwarfs, are formed during the final stages of stellar evolution. Compared with ordinary stars, compact stars possess larger masses and structures that are not significantly affected by high temperatures. Over the past few decades, the study of compact stars has attracted considerable attention within the scientific community. Stellar evolution, investigated through both isotropic and anisotropic pressure distributions in stable neutron-star configurations, provides insight into the nature, structure, stability, and life cycle of stars.

The study of compact stars possessing extremely strong gravitational fields within the framework of these theories provides a unique opportunity to test theoretical predictions under conditions that are inaccessible to laboratory experiments. Furthermore, accounting for pressure anisotropy inside compact stars, where the radial and tangential pressures differ significantly, plays an important role in their theoretical modeling. The traditional assumption of isotropic pressure is often a simplification that does not fully reflect the actual physical processes occurring within these objects. Therefore, the investigation of anisotropy offers valuable insights into the internal structure and stability of compact stars, enabling a deeper understanding of their physical properties.

Modern astronomical advances, particularly in the field of gravitational-wave detection, provide extensive and precise data on compact stars. Alongside gravitational-wave observations, electromagnetic observations carried out through missions such as the Neutron Star Interior Composition Explorer (NICER), the Square Kilometre Array (SKA), and the enhanced X-ray Timing and Polarimetry mission (eXTP) enable highly accurate measurements of neutron-star masses, radii,

and moments of inertia. These measurements provide independent information that can be used to test and compare the predictions of anisotropic models with real astronomical observational data. The high precision of modern measurements makes it possible to detect even small deviations from standard models, opening the way for the discovery of new physical phenomena and improving 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. Therefore, investigations of the anisotropic properties of compact stars in modified theories of gravity may lead to significant advances in our understanding of 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 distribution 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 criterion, 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 $B_0^2 = (1 + Sr^2)^2$, gravitational potential has been obtained, in which the influence of the charge distribution 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 anisotropic compact objects in $F(\tilde{T})$ gravity was 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 distribution parameter E_0 from 0 to $4 \cdot 10^{-6} \text{ km}^{-4}$ leads to a decrease in the central pressure from $1.136 \cdot 10^{35} \text{ Pa}$ to $6.350 \cdot 10^{34} \text{ Pa}$ 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 $F(R) = R + \alpha(e^{-\beta R} - 1)$ and the generalized power $F(R) = R - (1 - \delta)\gamma^2(R/\gamma^2)^\delta$ types with the ranges of parameters $\alpha \in [1.112, 333.340] \text{ km}^{-2}$, $\beta \in [0.003, 0.090] \text{ km}^2$, $\gamma \in [0.126, 0.327] \text{ km}^{-1}$, $\delta \in [0.567, 0.697]$ 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 from $2.22 \cdot 10^{38} \text{ kg m}^2$ to $4 \cdot 10^{38} \text{ kg m}^2$, 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 the study of compact stars, providing a more realistic description of their internal structure and physical properties by taking into account the effects of electric charge and pressure anisotropy. These findings can be applied to modeling the evolution of compact objects and assessing their role in the formation and evolution of galaxies. Furthermore, the obtained results may serve as a basis for future investigations in relativistic astrophysics and gravitational theory. This, in turn, facilitates the comparison of theoretical models with observational data and enhances their astrophysical applicability.

Author's personal contribution

The entire dissertation was written by the author personally, with revisions from scientific advisors and reviewers. The author performed the bulk of the

analytical and numerical analysis. Part of the work related to the numerical analysis of observational data was completed as part of an international scientific collaboration. The formulation of the problems and the choice of method were conducted jointly with scientific advisors.

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 $f(\tau)$ ширату скалярын анықтау // XXI Международная научно-практическая конференция «Молодежь, наука и инновации» – Актөбе: Актюбинский региональный университет имени К. Жубанова, 2025 - С. 406-409.

8 **Умбетова Ж.С.**, Абдижалилова У.У. $f(\tau)$ - 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 is composed of an introduction, three chapters, a conclusion, and a bibliography. It is presented in 106 pages and includes 41 figures, 160 equations, and 9 tables. The bibliography contains 163 references.