ABSTRACT

of the dissertation for the degree of Doctor of Philosophy (PhD)

in the specialty "6D060400- Physics"

BEKOV SABIT

Investigation of the modified theory of gravity with a non-canonical lagrangian of matter

The dissertation work is devoted to the study of the early and late epochs of the evolution of the Universe within the framework of the modified theory of gravity, the obtained cosmological solutions do not contradict modern observational data.

Relevance of the dissertation theme

It is now generally accepted that our Universe arose about 14 billion years ago after the Big Bang, where its temperature was unusually high ($T > 10^{28}$) and it began to expand rapidly. The first minutes of its expansion are known to us as the inflationary stages of the expansion of the Universe, which was proposed back in 1981 by Alan Guth. Further, the expansion of the Universe began to slow down, and its temperature, respectively, to decrease. After the inflationary stage of expansion, the process of birth and interaction of elementary particles in the Universe begins. Then the era of matter began, where stars, galaxies, etc. began to form, that is, the structure of our Universe was formed. In the late 1990s, long-term observations of Type Ia supernovae revealed that our universe was expanding rapidly again. In modern literature, this epoch is known to us as the epoch of the late expansion of the Universe. The reason for this expansion of the Universe is still not known to us, but a hypothesis has been proposed that some kind of dark energy and dark matter dominate in the Universe. It is believed that dark matter (hidden matter) makes the galaxies in the universe rotate at high speed, and dark energy plays the role of antigravity and has a large negative pressure.

In modern cosmology, various generalizations of the standard theory of gravity, that is, the general theory of relativity, are used to explain the phenomenon of accelerated expansion of the late evolution of the Universe. Usually, such generalizations of the theory can be divided into two types:

- these are models where, in the Lagrange function in action, they generalize the components responsible for the geometry of four-dimensional space-time, for example, the $f(R)$ theory of gravity (where R is the Ricci scalar), teleparallel gravity, $f(T)$ gravity (where T is the torsion scalar) and their various modified or combined theories . For example, teleparallel gravity is an alternative theory of the general theory of relativity and was previously proposed by A. Einstein himself to combine gravitational and electromagnetic fields.

- models where new components of matter fields are added to the Lagrange function in action, such as scalar fields, quintessennia, phantom fields, tachyon fields, Higgs boson or fermion fields are capable of describing both the early and late dynamics of the expansion of the Universe, but which of them is more realistic and does not contradict the basic laws of physics will be shown by further experimental and observational data.

There are two ways to find the field motion equations. The first of these is the standard metric formalism, in which the field equations are determined by the variational metric tensor g_{ik}. In this formalism, the affine relation Γ^i_{jk} depends on the metric tensor g_{ik}. The second way to derive the equations of motion is that the metric tensor g_{ik} and the affine connection Γ^i_{jk} are independent variables. This method is known to us as the first-order formalism (Palatini formalism), since when varying with respect to the independent metric and connection, instead of the second-order system of equations, the metric formalism uses the system of first-order differential equations. This way, in a sense, facilitates the search for solutions to the equations of motion. The two considered approaches lead to different equations of the gravitational field for the nonlinear Lagrange, while for the general theory of relativity they are identical to each other. Another good method for solving field equations widely used in cosmology is the Noether theorem approach based on the connection between conservation laws and symmetry.

Over the past few years, important technology programs have emerged, such as Python, Maple, Wolfram Mathematica, which help improve the process of collecting, analyzing and storing data. But in any study, it is difficult to solve any problem without conducting direct experiments. In a sense, this is a problem in general relativity, since it is not possible to conduct direct experiments on the universe. But some problems can be answered with machine learning methods. Machine learning is currently one of the most popular and interesting areas of research in cosmology.

The purpose of the research

Theoretical study of the dynamics of the first and second phases of the evolution of the accelerated expansion of the Universe in the framework of a modified theory of gravity with a non-canonical Lagrangian of matter. Use modern analytical and numerical methods to solve field equations, as well as compare the results obtained with observational data.

To achieve the goal, it was necessary to solve the following **tasks**:

1. To describe the dynamics of the early (inflationary) stage of the evolution of the Universe in the theory of $f(R)$ gravity and the formalism of Palatini. To determine for the models under consideration the modes of slow rolling of the scalar field and compare them with observational data;
2. To reconstruct the potentials of the quintessence of dark energy according to the Bayes information criterion. To study the problem of the tension $H(z)$ of the Universe, characterized by quintessential dark energy;
3. To compare the obtained cosmological solutions with observational data using the approach using the Noether theorem in cosmological models with a scalar and fermionic fields;

Object of research

Evolution of a homogeneous and isotropic Universe in various cosmological models.

The subject of research

Search for cosmological solutions that correctly explain the stages of the evolution of the Universe.

Research methods

Numerical and analytical methods for solving differential equations. Bayesian analysis method, tensor analysis, differential geometry, metric formalism and Palatini formalism, Noether theorem approach.

Scientific novelty of the work

– The parameters that determine the dynamics of the early (inflationary) period of the evolution of the Universe are determined using the Palatini formalism and the theory $f(R)$ of gravity with a scalar field for the metric formalism. In comparison with the observational data, it has been established that the cosmological parameters determined using the Palatini formalism for the $f(R)$ gravity model characterize the inflationary period of the evolution of the Universe more accurately.

– Using the values determined by the methods of differential age and the Baryon Acoustic Oscillator (BAO), using the machine learning method of types of quintessential potential of the quintessence dark energy model, the quintessence dark energy potential for the Hubble parameter determined in the Planck and Hubble missions is reconstructed.

– Approach using Noether's theorem in cosmological models with a scalar and fermionic fields, the solutions obtained from the considered cosmological models were compared with observational data.

The main provisions for the defense

1. The Palatini formalism effectively describes the inflationary period of the evolution of the Universe, when the e-fold number is $N=65$ in the $f(R)$ theory of gravity.

2. For the values of the Hubble parameter $H_0 = 67.40 \pm 0.5 km\, s^{-1} Mpk$ and $H_0 = 73.52 \pm 1.62 km\, s^{-1} Mpk$ potential of dark energy determined by machine learning is consistent with the quintessence model.

3. In the theory of $f(T,B)$ gravity, in which the fermionic field and the gravitational field are non-minimally related, the parameter m: 1) at $m=-1$, equation of state $\omega = 1/3$, this solution describes the period when pre-inflationary radiation dominated; 2) at $m>4$, $\omega<-1$ the equation of state corresponds to the phantom field model; 3) when $1<m<3$ the equation of state parameter is in the interval $-1<\omega<-1/3$ corresponds to the quintessence model; 4) $m=3$, $\omega=-1$ the result obtained corresponds to the dark energy model.

The theoretical and practical significance of the research outcomes

The methods indicated in the dissertation are aimed at constructing specific cosmological models and their comparison with observational data, application in theoretical and experimental cosmology. Also, the results obtained can be used in creating models of the accelerated expansion of the Universe, as well as in teaching specialized disciplines in higher educational institutions.

Personal contribution of the author

In the course of scientific research, the author was directly involved in all stages of writing dissertations and articles. The setting of tasks, the choice of research methods and the discussion of the results were carried out jointly with scientific consultants.

Approbation of the dissertation

The results of the dissertation were presented at the following conferences and seminars:

– 15th International Scientific Conference Marcel Grossmann Meeting, Rome, Italy. – 2018 July 1-7;

– 8th International Conference on Mathematical Modeling in Physical Sciences International Scientific Conference, Bratislava, Slovakia. – 2019 August 26-29;

– III International Scientific Conference "Astrophysics, Gravity and Cosmology", – Astana, Kazakhstan. – 2016;

- XI International Scientific Conference, Science and Education - 2016. - Astana, Kazakhstan. – 2016;

- Lomonosov - 2018 International Scientific Conference, - Astana, Kazakhstan. – 2018;

In addition, the results obtained were discussed at the Department of General and Theoretical Physics of the Eurasian National University named after L.N. Gumilyov at the seminars of the Physics Department of the California State University (Fresno), USA.

Publications

Based on the results of the dissertation work, 20 articles were published, 1 article in a journal with a non-zero impact factor included in the international information resources Web of Science (Clarivate Analytics, USA) and Scopus (Elsevier, the Netherlands); 5 articles in foreign scientific conferences and 3 articles in periodicals recommended by the Committee for Quality Assurance in Science and Higher Education of the Republic of Kazakhstan; 5 articles and 3 thesis in the materials of international conferences in the Republic of Kazakhstan, 3 articles published in scientific journals of the Republic of Kazakhstan.

1. Bekov S., Myrzakulov K., Myrzakulov R., Gómez D.S.-C. General slow-roll inflation in $f(R)$ gravity under the Palatini approach// Symmetry.- 2020. - Vol. 12. - P. 1–13. (Q2)

2. Myrzakulov K., Bekov S., Myrzakulov R. Some cosmological solutions of F(R) gravity with $f-essence$ // Proceedings of the «Marcel Grossmann Meeting XV» Meeting on General Relativity, University of Rome «La Sapienza». -– Italy. – 2018. ISBN 978-3-030-83714-3.

3. Myrzakulov N., Bekov S., Myrzakulov K. Cosmological model of $f(T)$ gravity with fermion fields in (2+1) dimensions // Proceedings of the

«Marcel Grossmann Meeting XV» Meeting on General Relativity, University of Rome «La Sapienza». -– Italy. – 2018. ISBN 978-3-030-83714-3

4. Myrzakulov N., Bekov S., Myrzakulova S., Myrzakulov R. Cosmological model of $f(T)$ gravity with fermion fields via Noether symmetry// Journal of Physics: Conference Series. – 2019. – Vol. 1391.

5. Myrzakulov Y., Bekov S., Myrzakulov K. Noether symmetry approach in $f(T,B)$ teleparallel gravity with a fermionic field// Journal of Physics: Conference Series. – 2021. – Vol. 2090. – P. 12058.

6. Tsyba P., Razina O., Bekov S., Barkova Z.,Myrzakulov, R.Scenario of the evolution of the universe with equation of state of the Weierstrass type gas// Journal of Physics: Conference Series. – 2019. –Vol. 1391. – P. 12162.

Relation of the dissertation topic with the plans of scientific works

Separate parts of the dissertation work were carried out within the framework of the program of the Ministry of Science and Higher Education of the Republic of Kazakhstan “Grant financing of fundamental and applied scientific research of young scientists under the "Zhas Galym” project for 2022-2024” with funding from the state budget. Project name: AP14972745 "Investigation of cosmological models with scalar and fermionic fields with some application of Noether's theorem".

Scope and structure of the dissertation

The dissertation consists of an introduction, four chapters, a conclusion and a list of references. The work is presented on 108 pages of typewritten text, contains 10 figures and graphs, 337 formulas, 1 table, the list of references contains 153 titles.