ABSTRACT

of dissertation for the Philosophy Doctor (PhD) degree in specialty "8D05307 – Physics and Astronomy" by Konysbayev Talgar Kuntuganuly on the topic "**Dark matter and dark energy in different geometric scenarios**"

This PhD is devoted to the study of dark matter and dark energy in different geometric scenarios.

Relevance of the dissertation theme

Over the past decades, the number of confirmations of an outstanding result in modern cosmology, or rather, the existence of a cosmological constant that characterizes the current accelerated expansion of the Universe, has steadily increased. While this came as no surprise to some theorists who were considering interactions between a number of different types of observations at the time, for most it was a bombshell. The universe is not just expanding, it is expanding at an accelerating rate. The accelerated expansion of the Universe is one of the main problems of modern theoretical physics and cosmology. According to astrophysical observations, dark energy (69%) with negative pressure provides the right solution to the problem of the accelerated expansion of the Universe. On the other hand, according to the same observations, dark matter (26%) is necessary in order, for example, to form structures in which the rotation curves of galaxies were flat. The simplest model in modern cosmology is known as ΛCDM, where the cosmological constant, together with cold dark matter, makes up the bulk of the energy source of the universe, and the background dynamics is determined according to the theory of relativity. This model can explain the observed data, but in this case the problem of the cosmological constant arises. One of the first attempts to solve this problem was associated with the concept of dynamic dark energy: quintessence, phantom, quint and various holographic models. The accelerated expansion can also be explained with the help of the so-called dark liquids, for example, Chaplygin's gas (and its modifications). The approach of introducing dark energy models is widely used in modern cosmology, however, various modifications of the field equations at the Lagrangian level are of a more fundamental nature, where dark energy arises naturally. Another important topic in modern cosmology is the interaction between the dark components of the universe. On the one hand, observations show the possibility of interaction, on the other hand, there is no fundamental theory that answers the question why interaction should exist and how this connection arose. The observed accelerated expansion of the Universe is not the first phase of accelerated expansion in the history of the Universe. Yet we must remember that the physics and mechanism of inflation in the early Universe is completely different from the physics of the accelerated expansion of the Universe.

Recent cosmological observations of supernovae, the Wilkinson microwave anisotropy probe (WMAP) and Baryon Acoustic Oscillation (BAO) data have predicted that the modern universe is going through a phase of accelerated expansion that could be fueled by a new source of energy called dark energy. In observational cosmology, the expansion rate $H(z)$ is measured at various redshifts, which are useful for obtaining various cosmological parameters, namely the scale parameter and the deceleration parameter. Although the analysis of observational data gives us a satisfactory understanding of cosmological dynamics, it cannot give us a complete understanding of the evolution of the universe. Consequently, an additional contribution has recently been considered for observational analysis, namely, the cosmic growth of inhomogeneous parts of the Universe to form its structure. The growth of large-scale structures obtained from a linear perturbation of the matter density $\delta(z) \equiv \frac{\delta\rho_m}{\rho_m}$ of the Universe is considered as an important tool for limiting the parameters of the cosmological model. To describe the evolution of the inhomogeneous energy density, it is preferable to parametrize the growth function $f = \frac{d\ln\delta}{d\ln a}$ in terms of the growth index γ. Thus, the study of dark energy for understanding the accelerating Universe in cosmology is important, which can be analyzed using the observed data on the expansion rate ($H(z)$) and data on the growth of the matter density contrast $\delta(z)$ at the same time.

The concordance paradigm assumes that a fluid whose corresponding density ρ_{de}, under the form of a cosmological constant, Λ , with equation of state, say $\omega_{de} = \frac{P_{de}}{\rho_{de}} \equiv \omega_\Lambda = -1$, is sufficiently negative to counterbalance the action of gravity and to speed up the Universe today. Among the different possibilities of studying competing dark energy models, it could be possible to formulate some sort of thermodynamic acceleration, i.e., treating the Universe as a thermodynamic system, where thermodynamic considerations over the whole ensemble of fluids permit to accelerate the universe today, adopting a single fluid that unifies dark energy and dark matter. These models attempt to unify the dark sector since the logotropic fluid recovers dark energy and/or dark matter in limiting regimes, in analogy to the Chaplygin gas. A particular class of logotropic models has been recently introduced within the framework of Anton-Schmidt Equation of state. This class of models is similar to true logotropic paradigms and can be compared to modified versions of the Chaplygin gas.

Based on the modern problems of cosmology listed above, the dissertation: «**DARK MATTER AND DARK ENERGY IN DIFFERENT GEOMETRIC SCENARIOS**» is devoted to the study of the role of dark matter and dark energy in the formation of the structures of the Universe and its accelerated expansion.

The main goal of work

The study of logotropic and modified logotropic models that explain the accelerated expansion of the Universe through a single fluid that combines dark energy with dark matter.

The object of the research

Logotropic model with different values of the parameter *n*, modified logotropic model, dark energy, dark matter.

The subject of the study

Hubble parameter, dark energy equation of state, sound speed, cosmological parameters, growth factor, growth index.

Research methods

Analytical and numerical methods for solving differential equations, Levenberg-Marquardt nonlinear least squares method, Bayesian analysis method, Akaike analysis method, differential geometry, tensor analysis, Monte Carlo method, perturbation theory methods and successive approximation methods.

In order to achieve the above stated goal, it is necessary to carry out the following tasks:

1 Analysis and comparison of cosmological models.

2 Finding the values of the cosmological parameters of dark energy, dark matter, baryonic matter in the Universe for logotropic model.

3 For each model, the general equation of state for dark matter and dark energy, the cosmic growth function, and the ratio of the density flux to the scale factor are studied in comparison with observational data from different catalogs.

Scientific novelty of the dissertation results

For the first time in this work:

1 Based on the information criterion of Akaike and Bayesian, the best and worst logotropic cosmological models are determined.

2 For logotropic models (logotropic and modified), the values of the cosmological parameters of dark energy, dark matter and baryonic matter in the Universe are found.

3 The dependences of the general parameter of the state of dark matter and dark energy, the growth factor and density perturbation on the scale factor of the Universe are found.

The main provisions for the defense:

1 The logotropic equation of state for dark matter and dark energy is in the best agreement with the data of cosmological observations: growth function, supernova explosion, observational Hubble data, root-mean-square values of mass fluctuations according to the Akaike and Bayesian information criterion at $n = 0$.

2 The parameter n of logotropic models is related to the values of cosmological parameters for dark energy Ω_{de} and dark matter Ω_m: 1) for a free parameter n, from the observations it was obtained $n = 0,004$ and correspondingly $\Omega_{de} = 0,692$, $\Omega_m = 0,308$. 2) at $n = -1$, received $\Omega_{de} = 0,490$, $\Omega_m = 0,510$. 3) for $n = 0$, obtained $\Omega_{de} = 0,709$, $\Omega_m = 0,291$. 4) And for the modified logotropic model at $n = 0$, taking into account the cosmological parameter Ω_b, it is obtained $\Omega_{de} = 0,709$, $\Omega_{cdm} = 0,269$, $\Omega_b = 0,022$.

3 An increase in the scale factor leads to a decrease in the common parameter of the state of dark matter and dark energy, the growth factor, and the ratio of the density perturbation to the scale factor for all logotropic cosmological models, except for n=−1.

Practical and theoretical importance of the dissertation

The results obtained in this dissertation can be used to develop an analog system that makes it possible to study the physics of the large-scale Universe. The considered logotropic models can be used to explain the accelerated expansion of the large-scale Universe. They are also valuable for the development of relativistic astrophysics, cosmology, elementary particle physics and can be used in teaching at universities for the specialty "Physics and Astronomy".

The reliability and validity of the results are primarily determined by the fact that they are in good agreement with the existing observational data. In addition, the results obtained complement the known optical and kinematic properties of dark matter. In addition, the reliability and validity of the results are confirmed by the presence of publications in foreign journals with high impact factor and 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, and in the proceedings of domestic and foreign international scientific conferences.

The personal contribution of the author lies in the fact that the entire volume of the thesis, the choice of the research method and numerical calculations were performed by the author on his own. The setting of tasks and discussion of the results were carried out jointly with the supervisors.

Publications

According to the materials of the dissertation 17 publications were published: 2 in journals from the List of the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan for publication of the main results of the thesis for the PhD degree and 8 articles in foreign journals with impact factor included in the international information resource Web of Science (Clarivate Analytics) and Scopus, 7 abstracts in the Proceedings of International Scientific Conferences.

Approbation of the dissertation. The results obtained in the dissertation were presented and discussed:

– at the International Conference of Students and Young Scientists "FARABI ALEMI" (2020-2022, Al-Farabi Kazakh National University, Almaty);

– at the International Scientific Online Conference Sixteenth Marcel Grossmann Meeting, Rome, Italy, 07.07.2021.

Relation of the dissertation theme to the plans of scientific research

The dissertation work was partially carried out within the framework of the project of young scientists (2020-2022), financed from the state budget. Project topic: "Astrophysical consequences of white dwarf stars" and IRN: AP08052311

The scope and structure of the thesis

The thesis consists of an introduction, 3 sections, conclusion and list of references from 168 titles, contains 110 pages of basic computer text, including 44 figures, 182 formulas and 5 tables.