ANNOTATION

of the dissertation thesis for the degree of Doctor of Philosophy (PhD) in the educational program "6D061100− Physics and Astronomy"

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SCALE INVARIANCE OF GRAVITATIONAL WAVES ON A COSMIC STOCHASTIC BACKGROUND

General characteristics of the work

The work is devoted to the study of the scale invariance of self-similar signals of gravitational waves, as well as the development and application of methods for their detection and classification. The dissertation analyzes gravitational waves in a cosmic stochastic background, which requires the use of new theoretical approaches and effective data processing tools. The research examines both the theoretical aspects of weak gravitational waves and numerical methods for their registration, including information-entropy approaches and machine learning algorithms.

The first chapter describes the current state of research on the nature of gravitational waves, the rationale for their existence from the general theory of relativity, and discusses their sources and methods of registration. Brief information is provided on the theoretical foundations of gravitational-wave astronomy and the problems of recording signals against the background of cosmic noise using laser interference methods.

The second chapter is devoted to the study of the scale-invariant nature of weak gravitational waves far from the source. In the well-known equation, the wave number is defined in terms of Lagrange points where the modulus of the scale factor of the expansion of the Universe is assumed to be equal. The phase space of the obtained solution has a scaling index of one-sided evolution (expansion) corresponding to ZhF (Zhanabaev fractal) and observation catalogs.

The third chapter focuses on the application of conditional information about the difference between the entropy of phase space and conditional entropy, proposed by Zhanabaev Z.Zh., for the analysis of LIGO data. The method used makes it possible to detect gravitational wave signals without using model templates, which is especially important for analyzing waves arising against the background of cosmic noise.

The fourth chapter examines the classification of gravitational waves coming from various sources, such as mergers of black holes and neutron stars, using conditional information about the difference in entropy. Approaches to training neural networks based on LIGO collaboration data to improve the accuracy of wave detection and classification are described.

In conclusion, the importance of developing methods of nonlinear physics, probabilistic methods for studying gravitational waves and detecting them against the background of cosmic noise is emphasized, which opens up new opportunities for research in the field of cosmology and astrophysics.

Relevance of the research topic

The study of gravitational waves and their interaction with the cosmic stochastic background is one of the key tasks of modern astrophysics and cosmology. Since the first direct detection of gravitational waves in 2015, observations of these waves have opened a new window into the study of the universe. Gravitational waves provide information about such extreme astrophysical processes as mergers of black holes and neutron stars, which are inaccessible to observations by traditional methods.

However, one of the main problems is the difficulty of isolating weak gravitational wave signals against the background of noise from various space and terrestrial sources. In these conditions, it is especially important to develop new analysis methods, such as information-entropy methods, which improve the accuracy of signal detection, as well as the study of nonlinear probabilistic characteristics of gravitational waves, which helps to describe their behavior in a background noise environment.

The relevance of this work is determined by the need for further development of methods for detecting and classifying gravitational waves, as well as an in-depth theoretical analysis of their nature and interaction with the cosmic background. These studies are important for solving fundamental questions about the structure and evolution of the universe, as well as for understanding the role of gravitational waves in cosmological processes.

The aim of the work is to study the scale invariance of gravitational waves on a cosmic stochastic background, as well as to develop and implement new methods for their detection and classification.

Research objectives:

1 analysis of signals of gravitational wave equations, taking into account their fractal nature and their relation to the Hubble parameter;

2 application of a new method of conditional entropy difference information for quantitative detection of gravitational waves in conditions of chaotic and stochastic noise without using model templates;

3 application of conditional information methods, self-similar information values, and machine learning to classify gravitational waves by their sources;

Object of research: Gravitational waves caused by the merger of binary massive compact objects such as black holes or neutron stars.

Research methods:

1. Investigation of the equations of weak gravitational waves based on the general theory of relativity, determination of the fractal dimension of the attractor and its comparison with the data from the catalogues of galaxies.

2 Creation of algorithms using the information-entropy approach for detecting gravitational waves without the need to use model signal patterns, which makes it possible to increase the efficiency of wave detection.

3 Application of machine learning algorithms, such as neural networks, to classify gravitational waves by source (mergers of black holes, neutron stars, and black hole–neutron star systems).

The main provisions submitted for defense

1. The attractor of weak gravitational waves has a fractional part of the fractal dimension of 0.465 and is related to the Hubble parameter, which makes it possible to identify scale-invariant properties of gravitational wave signals.

2. A new method for detecting gravitational waves based on conditional information about the difference between the entropy of phase space and conditional entropy makes it possible to register gravitational-wave signals at a low signal-to-noise ratio (SNR).

3. Classification of sources of gravitational waves from binary mergers of black holes and neutron stars using conditional information about the difference in entropy and theoretical values of their self-similarity (Zhanabaev Z.Zh. criteria) ensures accurate identification of their signals at a low SNR level.

The scientific novelty of the work lies in the fact that for the first time:

1 For the first time, a fractal model has been proposed to describe the scale invariance of gravitational waves, which makes it possible to explain the expansion of the universe without involving the concepts of dark energy.

2 Algorithms have been developed for the entropy difference conditional information method, a new information–entropy method for detecting gravitational waves that does not require the use of model signal patterns.

3 Machine learning methods have been applied to classify gravitational waves based on conditional information about the entropy difference.

Theoretical and practical significance of the work

The theoretical significance of the work lies in the development of a fractal model describing the scale invariance of gravitational waves and the expansion of the Universe without involving the concept of dark energy, which expands the understanding of the structure of the Universe and the wave nature of gravitational waves. The practical significance of the work lies in the creation of an information-entropy method for detecting gravitational waves, which increases the accuracy of signal registration, as well as in the application of machine learning methods for their classification, which contributes to the automation of data processing and the further development of gravitational wave astronomy.

Personal contribution of the author

The results of the analysis were received personally by the applicant. Problem statement and discussion of the results were conducted jointly with scientific consultants.

Reliability of the results:

The calculations are based on the equations of general relativity and fractal theory, which gives theoretical rigor to models of the expansion of the universe and gravitational waves. The use of the information-entropy method for detecting gravitational waves has been tested on real and synthetic data from the LIGO collaboration, which confirms its effectiveness and correctness. Numerical experiments and simulations were carried out using modern software tools such as PyCBC, which ensures the accuracy and reproducibility of the results. The use of machine learning methods for classifying gravitational waves is also confirmed by data analysis, which indicates the reliability of the proposed approaches.

Approbation of the work:

The results obtained in the dissertation were reported and discussed:

– at the International Scientific Conference of Students and Young Scientists "Farabi Alemi" (2021 Almaty, Kazakhstan);

Based on the results obtained, 8 publications have been published.

Articles with a high impact factor in the Thomson Reuters database or in publications included in the international scientific database Scopus:

Ussipov N., Zhanabaev Z., Almat A., Zaidyn M., Turlykozhayeva D., Akniyazova A., & Namazbayev T. (2024). Classification of Gravitational Waves from Black Hole-Neutron Star Mergers with Machine Learning. Journal of Astronomy and Space Sciences, 41(3), 149–158.

Articles in publications recommended by the KOKSNVO RK:

Ussipov N., Akhmetali A., Zaidyn M., Akniyazova A., Sakan A., Kalambay M., & Shukirgaliyev B. (2024). Fractal Dimension of Star Clusters. Eurasian Physical Technical Journal, 21(3).

Усипов Н., Ахметали А., Зайдын М., Акниязова А., Акнур С., & Субебекова Г. (2024). Entropy of Gravitational Waves. Доклады НАН РК, (3), 47–56.

Жанабаев З. Ж., & Усипов Н. М. (2023). Information-Entropy Method for Detecting Gravitational Wave Signals. Eurasian Physical Technical Journal, 20(2 (44)), 79–86.

Жанабаев З. Ж., Усипов Н. М., Хохлов С. А. Scale-invariant and wave nature of the Hubble parameter //Eurasian Physical Technical Journal. – 2021. – Т. 18. – №. 2 (36). – С. 81-89.

Жанабаев З. Ж., & Усипов Н. М. (2019). Scale-Invariance of Many Galaxies. Вестник Казахского национального университета. Серия физическая, (2), 27–32.

Publications in collections of abstracts:

Ахметали А., Үсіпов Н. М. Информациялық-энтропия әдісімен гравитациялық толқын көздерінің классификациясы. Материалы международной конференции студентов и молодых ученых «Фараби әлемі». – Алматы, 2024.

Акниязова А. Ж., Жәңгірбай Д. М., Үсіпов Н. М. Галактикалардың корреляциялық өлшемділіктерін анықтау. Материалы международной конференции студентов и молодых ученых «Фараби әлемі». – Алматы, 2019.

The relationship of the thesis topic with the plans of scientific work

The dissertation work was carried out in accordance with the plans of applied scientific research of the Committee of the Ministry of Education and Science of the Republic of Kazakhstan "Grant financing of scientific research" on the topic: "AP14872061 - Classification of types of modulation of a noise mixture of MIMO signals".

The structure and scope of the dissertation

The dissertation consists of an introduction, four sections, a conclusion, and a list of sources used. The work is presented on 92 pages of typewritten text, illustrated with 42 figures, 10 formulas, 5 tables, the list of sources used contains 108 titles.