ABSTRACT

of dissertation for the Philosophy Doctor (PhD) degree in specialty "6D061100 – Physics and Astronomy" by Kurmanov Yergali Berzhigitovich on the topic "**Optical and kinematic properties of dark matter with non-zero pressure**"

This PhD dissertation is devoted to the study of the kinematic and optical properties of dark matter with non-zero pressure.

Relevance of the dissertation theme.

According to modern conceptions about the substantial structure of the Universe, it contains 68.3% dark energy (often identified with the vacuum of space), 26.8% dark matter and 4.9% baryonic matter – primary plasma and radiation. In the process of evolution of the Universe, these types of substances play different roles. Thus, the cosmic vacuum is responsible for the expansion of the Universe, dark matter ensures the stability of its large-scale structures (galaxies and their clusters), and baryonic matter is the "building" material of the galaxies themselves, star clusters, stars and planets.

The structure, morphology and evolution of galaxies are currently based on two important assumptions: 1) the presence of a supermassive black hole at the center of almost every spiral galaxy and 2) the existence of a dark matter halo surrounding each galaxy.

Modern theoretical models of the formation of supermassive black holes do not explain the distribution of masses of black holes with distance. It is not clear how and when supermassive black holes were formed, i.e. their formation is much less studied. It is known that a large number of candidates for supermassive black holes with a mass of a billion times the mass of the Sun were observed in the early Universe. The most striking example is the black hole candidate ULAS J1342+0928 with a mass measured in the range of $\sim 800 \cdot 10^6 M_\odot$ and located at distance z = 7.54, i.e. close enough to the Big Bang.

Currently, with the exception of Sgr-A* in the Milky Way and the supermassive black hole candidate in the galaxy M87, the most common method used to determine the mass of such objects is to measure the spectra emitted by their accretion disks.

The theory of black hole accretion was developed by Novikov and Thorne (1973), and Page and Thorne (1974), and over the last years it has been successfully applied to astrophysical black hole candidates to explain the features of their observed spectrum. However, the observations are almost always interpreted as supposing the presence of a black hole in a vacuum. Only in last years, several attempts have been made to study the theoretical properties of accretion disks in geometry other than the Kerr metric.

Unlike ordinary visible/baryonic matter, dark matter does not participate in electromagnetic interactions. It manifests itself only through gravity and therefore there are no direct methods for observing it yet. Also, dark matter was used to

explain one of the fundamental problems of modern physics and cosmology – the baryon asymmetry of the Universe; to describe the origin of various types of dark matter; to find the masses of dark matter particles.

Considerable attention of researchers was also attracted by questions about the influence of dark matter on the formation of galaxies. Astronomical observations show that dark matter is mainly concentrated around large-scale space objects such as galaxies and their clusters.

The existence of dark matter is indirectly confirmed by observing the movement of hot gas in galaxy clusters and the effect of gravitational microlensing. However, the nature of dark matter is still unknown, since no suitable candidates for a dark matter particle have been found, so far.

Some models suggest that dark matter consists of a class of weakly interacting massive particles, and others of light particles. It is believed that different phenomenological density distribution profiles explain the observed rotation curves in galaxies. For example, for the Milky Way galaxy, different dark matter profiles are used to obtain information about the rotation curves from the central part of the galaxy to the halo.

Dark matter halos stretch across the galaxy from the outer regions to the center. Therefore, it is worthwhile to consider the possibility that the central distribution may affect the geometry of the region.

One of the relevant issues of our time concerns the problem of the influence of the distribution of dark matter on the motion of test particles in an accretion disk in the gravitational field of a black hole, as well as on the differential and spectral luminosity of the disk. In the literature, similar problems have so far been considered for dark matter only with isotropic (radial) pressure.

Based on the modern problems of cosmology listed above, the dissertation: "**OPTICAL AND KINEMATIC PROPERTIES OF DARK MATTER WITH NON-ZERO PRESSURE**" is devoted to the study of the role of dark matter with anisotropic pressure with all the ensuing consequences.

The main goal of work.

Investigation of the influence of dark matter on the rotation curves of spiral galaxies, including the Milky Way, as well as on the physical characteristics of an accretion disk in the gravitational field of a supermassive black hole.

The object of the research.

Galaxies: U11454, U5750, ESO0140040 and the Milky Way; dark matter, static black hole and accretion disk.

The subject of the study.

Luminosity of the accretion disk: differential and spectral; radial and tangential pressure of dark matter, dark matter mass, speed of sound, refractive index.

Research methods.

Methods of numerical integration of differential equations, Levenberg-Marquardt nonlinear least squares method, Bayesian analysis method, Akaike analysis method, differential geometry, tensor analysis.

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

1 Calculation of the angular velocity, angular momentum of test particles in an accretion disk around a static black hole surrounded by dark matter with anisotropic pressure.

2 Determination of the test particles energy, electromagnetic radiation flux, and differential luminosity of the accretion disk depending on the characteristic parameters of dark matter models.

3 Investigation of the behavior of the spectral luminosity of an accretion disk.

4 Computation of the radiation efficiency of the accretion disk, i.e. the amount of rest mass of the disk that is converted into radiation.

Scientific novelty of the dissertation results.

For the first time in this work:

1 The angular velocity and the angular momentum of the test particles in the accretion disk in the presence and absence of dark matter with anisotropic pressure in the gravitational field of the static supermassive black hole are obtained.

2 The energy of the test particle, the radiating flux and the differential luminosity of the accretion disk in the presence and absence of dark matter with anisotropic pressure around the static supermassive black hole are calculated.

3 The spectral luminosity of the accretion disk was compared in the presence and absence of dark matter around the black hole.

4 The dependence of the radiation efficiency of the source on the dark matter pressure anisotropy parameter is found for various densities.

The main provisions for the defense.

1 The anisotropy of dark matter pressure leads to a decrease in the angular velocity and angular momentum of test particles in the accretion disk depending on radial distance compared to a black hole without dark matter.

2 The value of energy of test particles, the electromagnetic radiation flux, and the differential luminosity of the accretion disk around a static black hole in the presence of dark matter with anisotropic pressure at small distances exceed in magnitude and, as the distance increases, decrease relative to the values characteristic of a black hole without dark matter.

3 The dependence of the spectral luminosity of the accretion disk on the sign of the anisotropy parameter of dark matter pressure: a) for positive values of the anisotropy parameter, the luminosity in the entire radiation frequency range exceeds the characteristic values for a black hole without dark matter; b) for negative values of the anisotropy parameter, the luminosity of the accretion disk at low frequencies is less, and on large ones more, compared to a black hole without dark matter.

4 The radiation efficiency of an accretion disk in the presence of dark matter increases in the range 5.85-5.87% with decreasing anisotropy parameter, while the efficiency for a black hole without dark matter is 5.72%.

Practical and theoretical importance of the dissertation.

The results obtained in this dissertation make a significant contribution to the modern understanding of the optical and kinematic effects of dark matter. 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 on the Control of Education and Science of the Ministry of Education and Science 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, 18 publications were published: 2 in journals from the List of CCSES MES RK for publication of the main results of the thesis for the PhD degree, 1 in English-language journal of Kazakhstan and 5 articles in foreign journals with impact factor included in the international information resource Web of Science (Clarivate Analytics) and Scopus, 10 abstracts in the Proceedings of International Scientific Conferences.

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

– at the 2nd Annual Meeting of the Kazakh Physical Society (2019, Almaty, Kazakhstan);

– at the International Conference of Students and Young Scientists "FARABI ALEMI" (2019-2022, Al-Farabi Kazakh National University, Almaty);

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

– at the Kazakh-Uzbek seminar on the topic: “Accretion disk luminosity for black holes surrounded by dark matter with anisotropic pressure” (18.03.2022);

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, 4 sections, conclusion and list of references from 212 titles, contains 106 pages of basic computer text, including 60 figures, 93 formulas and 13 tables.