ABSTRACT

of the dissertation submitted for the degree of
Doctor of Philosophy (PhD) in the specialty «6D060400 – Physics»

ZHAMI BAKYTZHAN

INVESTIGATION OF HOT ROTATING WHITE DWARFS IN GENERAL RELATIVITY

The PhD dissertation is devoted to the theoretical research of properties of stable white dwarfs (WDs) with a main focus on the effects of general relativity (GR), finite temperatures, nuclear composition and rotation.

The relevance of the topic.

A white dwarf or degenerate dwarf is one of the classes of compact objects which are the end-products of stellar evolution. In general, there are three main classes of compact objects: WDs, neutron stars (NSs) and black holes (BHs). These objects are called compact objects because of their large masses and small sizes and, correspondingly, high densities. A WD is the final stage in the evolution of main sequence stars with masses from $0.07\,M_{\odot}$ to $8\,M_{\odot}$ (even up to $12\,M_{\odot}$ according to some studies). This range covers the overwhelming majority of normal stars formed in our galaxy (the Milky Way), including our Sun, and that is why WDs will present the most common end-products of stellar evolution. The lower limit of a main sequence star mass is associated with the impossibility of the occurrence of a thermonuclear helium synthesis reaction. If the mass of the main sequence star is more than the upper limit it will become a NS, not a WD. It is thought that more than 97% of the normal stars in our galaxy will finally end as a WD.

WDs are important to understand the expansion of the universe in cosmology in terms of type Ia supernova explosions, since they can provide independent information about the age of our galaxy and their distribution contains information about star formation history and subsequent evolution. Also, type Ia supernovae are used as standard candles in astronomy to estimate distances to remote galaxies and study the nature of dark energy. Since the progenitors of white dwarfs lose carbon, nitrogen and oxygen on the stage of the main sequence star, they make a significant contribution to the chemical evolution of our galaxy, and possibly are an important source of life sustaining chemical compounds. Thus, all these facts fully justify **the relevance** of this PhD thesis. Therefore, it is important to study the

formation, physical properties, stability and evolution of WDs and to construct a realistic model for them.

The purpose of the dissertation is to investigate the properties of equilibrium configurations of white dwarfs with a main focus on the effects of general relativity, finite temperatures, nuclear composition and rotation.

Research tasks. In order to achieve the purpose of the dissertation the following research tasks have been posed:

- To study both interior and exterior metrics of Einstein's field equations in order to describe gravitational field of white dwarfs;
- To study the effects of general relativity, finite temperatures and nuclear composition on the structure of non-rotating white dwarfs;
- To study the influence of rotation on the structure of white dwarfs both in Newtonian gravity and general relativity;
- To study dependence of I-Love-Q and I-Love-e relations in the case of rotating white dwarfs with different equations of state.

The object of the research.

Equilibrium configurations of cold and hot, static and rotating, classic and relativistic white dwarfs.

The subject of the research.

The main parameters of stable, cold and hot, static and rotating white dwarfs such as mass, radius, central pressure etc.

Research methods.

The methods of tensor analysis and general relativity, the numerical methods for integrating differential equations, the method of perturbation theory and the Hartle formalism are used.

The main provisions submitted for the defense:

1. The mathematical and physical equivalence of the approximate stationary axially symmetric the Hartle-Thorne and Sedrakyan-Chubaryan solutions of Einstein field equations (up to second order in angular velocity) that describe the gravitational field of astrophysical compact objects including white dwarfs in the limiting case of slow rotation and small deformation.

2. The effects of general relativity become significant in the mass-radius relation for white dwarf masses closer to the Chandrasekhar limit, thermal effects are most clearly pronounced for white dwarf masses lower than the Chandrasekhar

limit, while rotation and nuclear composition are important for the entire mass range of white dwarfs.

3. The core temperatures of white dwarf-satellites in the binary systems of millisecond pulsars PSR J1738+0333, PSR J1012+5307 and PSR J1911-5958A estimated to be in the range $(1.55\text{-}6.5)\times10^7$ K, $(1.4\text{-}2.4)\times10^7$ K and $(0.4\text{-}9.5)\times10^7$ K, respectively.

4. The I-Love-Q (the moment of inertia, the rotational Love number and the quadrupole moment) and I-Q-e (the moment of inertia, the quadrupole moment and the eccentricity) relations are universal and independent of the equations of state (Chandrasekhar and Salpeter equations of state) of white dwarfs.

Scientific novelty. The following results have been obtained for the first time within this dissertation:

– A set of algebraic expressions relating the total mass, angular momentum and mass quadrupole moment of the Hartle-Thorne solution with the integration constants of the Sedrakyan-Chubaryan solution. Alternatively, the relevant multipole moments of both solutions have been calculated and it has been shown that they are identical. The mathematical and physical equivalence of the two metrics has also been proven.

– The mass-radius relations of white dwarfs taking into account the effects of general relativity, finite temperatures, nuclear composition and rotation were calculated.

– The core temperatures of white dwarf-satellites in the binary systems of millisecond pulsars PSR J1738+0333, PSR J1012+5307 and PSR J1911-5958A, have been estimated using the graphical method.

– The I-Love-Q and I-Love-e relations for white dwarfs have been shown to be universal and independent of the Chandrasekhar and Salpeter equations of state.

Scientific and practical value of the dissertation. The obtained results can be directly used to explain the observational data in the analysis and in the investigations of problems in astronomy, relativistic astrophysics, physics of white dwarfs and cosmology.

Reliability and validity of the results. The well-known physical models, mathematical methods approved and generally accepted in scientific community have been used in the thesis. The results obtained in the thesis are in good agreement with the ones in the literature and observational data. Furthermore, the reliability and validity of the thesis results are confirmed by publications in the journals with high impact factors indexed by Scopus and Web of Science and in the journals recommended by the Committee for the Control of Education and

Science of the Ministry of Education and Science of the Republic of Kazakhstan and in the materials of local and foreign international scientific conferences.

The personal contribution of the author. The author was directly involved in setting the research task together with scientific advisers, carrying out all the analytical and numerical calculations, doing comparisons and analysis of the results, summarizing conclusions, presenting the obtained results at the international conferences, preparing the results of the work for publications.

Publications. According to materials presented in the dissertation 30 works have been published in total. 6 articles were published in the international journals and conference proceedings indexed in Scopus (Elsevier, Netherlands) and Web of Science (Clarivate Analytics, USA). 7 articles were published in journals recommended by Control Committee of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan. 1 article was published in the scientific journal of the Republic of Kazakhstan. 16 abstracts and articles were published in the materials of local and foreign international scientific conferences.

Approbation of the dissertation. The results of the work were presented and discussed at the following foreign and local international conferences:

– XII-th International Conference on Gravitation, Astrophysics and Cosmology, Dedicated to the centenary of Einstein's General Relativity theory (Peoples' Friendship University of Russia, Moscow, Russia, June 28-July 5, 2015);

– The Fourteenth Marcel Grossmann Meeting on Recent Developments in Theoretical and Experimental General Relativity, Astrophysics, and Relativistic Field Theories (Sapienza University of Rome, Rome, Italy, July 12-18, 2015);

– The V-th International scientific conference «Physics and Physical Education: Achievements and Development Prospects» (Kyrgyz National University, Bishkek, Kyrgyzstan, September 21, 2015);

– 9-th Alexander Friedmann International Seminar on Gravitation and Cosmology and 3-rd Satellite Symposium on the Casimir Effect (Saint Petersburg, Russia, June 21-27, 2015);

– 9-th International scientific conference «Modern achievements of physics and fundamental physical education» (Al-Farabi Kazakh National University, Almaty, Kazakhstan, October 12-14, 2016);

– Supernovae, Hypernovae and Binary Driven Hypernovae, An Adriatic Workshop (International Center for Relativistic Astrophysics Network, Pescara, Italy, June 20-30, 2016);

– Phenomenology of Strong Gravity Workshop (Nazarbayev University, Astana, Kazakhstan, September 14-16, 2016);

– 5-th International conference on Cosmology, Relativistic and Nuclear Astrophysics (Al-Farabi Kazakh National University, Almaty, Kazakhstan, October 31-November 4, 2017);

– International Scientific Conference dedicated to the 80-th anniversary of Academician of the NAS RK Abdildin M.M. Abdildin readings: Actual Problems of Modern Physics (Al-Farabi Kazakh National University, Almaty, Kazakhstan, April 12-15, 2018);

– International scientific conference of students and young scientists «FARABI ALEMI» (Al-Farabi Kazakh National University, Almaty, Kazakhstan, April 13-16, 2015; April 14-16, 2016; April 10-13, 2017; April 10-13, 2018; April 8-11, 2019);

– The 6-th International Workshop «Nuclear Physics, Nuclear Astrophysics and Cosmic Rays» (Al-Farabi Kazakh National University, Almaty, Kazakhstan, April 16-18, 2019).

Relation of the dissertation topic with the planned scientific researches. The dissertation work has been carried out within the plans of the following research projects of Ministry of Education and Science of the Republic of Kazakhstan:

1) «Investigation of white dwarfs taking into account temperature and rotation in general relativity» (2015-2017, 3101/GF4, State registration No. 0115RK01047);

2) «Investigations on rotating and deformed objects in general relativity and relativistic astrophysics» (2013-2015, 1597/GF3, State registration No. 0113PK00369).

The volume and structure of the dissertation. The dissertation consists of a title page, content, abbreviation list, introduction, five sections, conclusion and reference list with 161 sources. It contains 7 tables and 65 figures. The total volume of the dissertation is 135 pages.