ABSTRACT

of the thesis submitted for the degree of Doctor of Philosophy (Ph.D) on specialty «6D060500-Nuclear Physics»

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GENERATION AND PROPOGATION OF GAMMA RAYS IN THE MAGNETOSPHERE OF NEUTRON STARS

The thesis presents the results of gamma-ray generation due to Pb-Bi cyclic reactions as well as the propagation of gamma radiation in a strong magnetic field of a neutron star.

Relevance of the topic.

In the classical field of gamma astronomy, the atmosphere is opaque, so observations are possible only from space using satellites. Due to specialized satellites — Cos B (operating in 1975-1982), the Compton gamma observatory (EGRET tool - Energetic Gamma Ray Experiment Telescope — Telescope for an experiment in the field of hard gamma radiation, 1991-2000) , AGILE (Astro-rivelatore Gamma a Immagini, LEggero — Lightweight space telescope for imaging in the gamma range, since 2007), Space Observatory named after. E. Fermi (since 2008) —a diffuse background, point and extended sources of gamma radiation were discovered. Most point sources (if not all of them) are associated with compact objects, neutron stars and stellar mass black holes inside the Galaxy, as well as with active galactic core in which super massive black holes are located. Extended sources are represented by dense molecular clouds into which they contribute to gamma radiation. The same sources in distant galaxies apparently create an isotropic diffuse background.

A neutron star is one of the possible results of the evolution of massive stars. These compact objects are not only has an interesting astrophysical manifestations, but also of great interest for fundamental physics. Three Nobel Prizes have already been awarded for neutron star research (for the discovery of radio pulsars, for the discovery of a double pulsar and the verification of general relativity, as well as for the development of X-ray astronomy).

Currently, only 25 neutron stars have been detected in the optical and near-IR ranges, about a hundred in the gamma range and about two hundred in the X-ray range, compared with about 2,000 neutron stars in the radio range.

As a result, the available data do not yet allow us to draw certain conclusions about the mechanism of pulsar radiation in the gamma ranges. Therefore, obtaining new data on NS radiation in these ranges is very important.

The processes associated with the formation, evolution and transformation of neutron stars into a black hole are the most powerful explosive processes in the Universe: Supernovae, Hypernova, Kilonova stars and gamma-ray bursts. Due to the emergence of multi-messenger astronomy, these objects can be observed at cosmological distances and therefore use them to study the properties and structure of matter in extreme states. In recent decades, the volume of observational material has increased several times, but some key points related to the nature and mechanisms of stellar explosions and gamma-ray bursts have remained a mystery.

It is believed that the brightness of type 1a (SN 1a) at the maximum is constant, as a result of which they are perfectly suitable for the role of distance indicators in the Universe. As a result of the explosion of SN 1a, the white dwarf turns into a neutron star. But due to some problems in explaining the observational data, research is needed aimed at identifying the mechanism of explosion of (SN 1a), generating and propagating radiation at the initial and final moments of the explosion, and determining the structure of magnetic fields in gamma-ray burst jets. These questions can be answered by computer simulations of the processes occurring in the depths and on the surface of a neutron star, the mechanisms of generation and propagation of radiation in the NS magnetosphere, as well as high-precision measurements of the spectrum, intensity and polarization of star radiation. Unfortunately, polarization observations of SN 1a, especially in the early stages of shell expansion, and the intrinsic and early optical radiation of gamma-ray bursts are few. The polarization of intrinsic optical radiation from gamma-ray bursts has not yet been recorded; there are only a few measurements of afterglow polarization.

Neutron stars have no internal resources to make up for the energy that is lost by various types of radiation and over the course of millions of years it slowly fades away, turning into a dead object. However, if accretion occurs on the surface of a neutron star, it will restore its energy.

Accretion causes complex magneto hydrodynamic and nuclear processes both on the surface and inside a neutron star. Accretion launches a chain of nuclear reactions that serve as an efficient source of energy. In this case, the neutron star's crust become non-stable, which leads to the appearance of nonequilibrium processes such as the expansion of the crust, star tremors on the surface of a neutron star, and neutron diffusion processes into the inner layers. However, when accretion ends, the neutron star will again begin to lose energy. Using sensitive X-ray telescopes and special observation methods, we can detect the signatures of these processes: the temperature of a neutron star rises during accretion episodes, but then gradually

decreases. In particular, Creation of the detailed “cooling curve” of a neutron star can give a unique information of its crust, which is one of the main tasks of studying a neutron star.

Today, the available data do not yet allow us to draw certain conclusions about the mechanism of pulsar radiation in the gamma ranges, so for this reason theoretical studies of nuclear reactions occurring at these objects are intensively carried out. The cyclic nuclear reaction Pb-Bi, first considered back by D.D. Clayton, plays an important role in explaining the nucleosynthesis of heavy elements, explosions of novae and supernovae. Therefore, detailed calculations related to the nuclear reaction of Pb-Bi cycle and all its sub-cycles, as well as calculations of the intensity of gamma radiation by Pb-Bi cycle, are relevant today in explaining the mechanism of pulsed radiation in the gamma ranges Super strong magnetic fields of some neutron stars of the so-called magnetars can lead to nonlinear quantum electrodynamic effects (such as vacuum polarization), which are important for irradiative processes. Therefore, all these various properties of a neutron star are of great interest for theoretical astrophysics of non-ideal plasma physics and nuclear physics.

The aims of the thesis is to study the mechanisms of generation and propagation of gamma radiation in nonequilibrium processes on the crust and magnetosphere of the NS.

Research object.

Crust and magnetosphere of neutron stars.

Research subjects.

Generation of gamma rays by Pb-Bi cyclic reaction in the crust of neutron stars and propagation of it in the magnetosphere.

Research methods.

Analytical and numerical methods, computer simulation .

Research tasks. In order to achieve the aim the following tasks were set:

– Simulation of the cyclic reactions Pb-Bi.

– Determination of radiation intensity by Pb-Bi cycle.

– Determination of the relative delay time of the two normal modes of gamma radiation passing through the magnetosphere of a neutron star.

Main statements submitted for the defense.

– Pb-Bi cycle has additional subcycles in the neutron flux range $10^{13} - 10^{18}$ $\mathrm{neutron/cm^2}$; therefore, the complete Pb-Bi cycle in the indicated neutron flux range contains Tl206, Pb206-Pb209, Bi209-Bi210, Po210-Po211.

– The intensity of the gamma radiation of the complete Pb-Bi cycle, which takes place on the surface of the neutron star under flux of interstellar matter, is of the order of 10^{18} photon/cm^2 sec.

– Gamma radiation passed through magnetic field of neutron star splits into the two normal modes, which are delayed with respect to each other by 10^{-8} sec.

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

– Isotopic composition and Pb-Bi complete cycle was determined.

– The intensity of the gamma radiation of the Pb-Bi cycle on the surface of the ns was calculated.

– The dependence the relative time delay between two normal modes from the gamma radiation passed through magnetic field of neutron star was calculated.

Scientific and practical value of the thesis.

Determination of the Pb-Bi cyclic reactions parameters give us possibility to define several problems of the elements abundance due the stellar nucleosynthesis and clarify genesis of the gamma ray bursts.

Definition of the gamma rays propagation details through dipolar and quadrupolar magnetosphere of a neutron stars gives us alternative method of measuring parameters of the magnetic field of NS.

Reliability of the obtained results.

Reliability of the obtained results confirmed by the publications in peer reviewed scientific journals and by participation in the international conferences.

Personal contribution of the author.

With a scientific supervisors, author took part in setting the task and he proposed to consider an extended Pb-Bi cyclic reaction. He developed software package "IBIS" to work with ENDF files and to calculate the energy release during cyclic reaction. Author also wrote a code using "Mathematica" to calculate time delay of the electromagnetic pulse.

Publications.

9 publications (4 papers, 5 abstracts) were made based on the result of the study, among them 1 paper in journal indexed in Scopus (impact factor - 5.231), 3 paper in journals recommended by CCES MES RK.

The thesis approbation.

The results of the work were presented and discussed at the following conferences:

– International Conference "Proceedings of the Fourteenth Marcel Grossmann Meeting on Recent Developments in Theoretical and Experimental General Relativity, Astrophysics, and Relativistic Field Theories"(Rome, Italy, July 2018).

– Scientific Conference dedicated to the 80th anniversary of Academician of the NAS RK Abdildin M.M. Abdildin readings: Actual Problems of Modern Physics. – Almaty, 2018.

– International Scientific Conference of Students and Young Scientists « Farabi alemi». – Almaty, 2016.

– International Scientific Conference of Students and Young Scientists «Farabi alemi». – Almaty, 2017.

– International Scientific forum «Nuclear science and technologies». – Almaty, 2017.

Correlation of the work with other research projects.

The work has been carried out within the plans of the research projects of Ministry of Education and Science of the republic of Kazakhstan "Motion of rotating extended bodies in gravitational fields" (2015-2017), "Numerical study of the dynamics of test bodies in the field of extended bodies with an internal structure in general relativity (2018-2020)".

The structure and volume of the thesis

The thesis consists of an introduction, two chapters, conclusion and list of references of 149 titles. The total volume of work is 100 pages including 20 figures.