ANNOTATION

to the dissertation work of Kenzhebekova Akmaral Igilikkyzy

«Dynamics of dust particles in the surroundings of white dwarfs: orbital evolution and atmospheric diffusion», submitted for the degree of Doctor of Philosophy (PhD) in the specialty «6D061100 – Physics and Astronomy»

General description of work

The dissertation is devoted to modeling the dynamics of evaporating dust particles of silicate and graphite composition in the sublimation region of white dwarfs within the framework of the problem of enriching the atmospheres of white dwarfs with heavy elements from external sources.

Relevance of the topic

Studying extrasolar planetary systems around stars represents a fundamental scientific problem in modern astrophysics. Such systems are called exoplanetary, and within the framework of the projects COROT (Convection Rotation and planetary transits), the NASA community (National Aeronautics and Space Administration) Kepler, WISE (Wide-field infrared survey Explorer), TESS (Transiting Exoplanet Survey Satellite) and GAIA (Global Astrometric Interferometer for Astrophysics) observes them and studies their properties using modern spectrometric and photometric methods, which makes a significant contribution to science. Currently, the most direct way to study the composition of exoplanetary material is to analyze the metal contamination of white dwarfs. This is because more than a quarter of white dwarfs accrete rocky materials into their atmospheres, driven by the star's strong gravity. According to observations of the GAIA mission, lines of alkali metals and other heavy elements were found in the spectrum of more than 500 white dwarfs. However, only 1-3% of them produce an observable excess of infrared (IR) emission from dust particles within the tidal radius of the white dwarf, indicating the presence of a rotating dust disk. However, recently, the evidence for metal pollution in white dwarfs and their connection to surrounding planetary systems has been growing. These planetary systems near white dwarfs provide important information about the composition of exoplanets that other observation methods cannot obtain.

According to the theory of evolution, all stars with masses on the order of the Sun end their evolution as white dwarfs. Naturally, these stars also include our Sun, so white dwarfs are key objects of study when studying the evolution of the Solar System in real-time. On the other hand, studying polluted white dwarfs makes it possible to determine planetary systems' properties and chemical composition outside the solar system. At the same time, some questions remain relevant, such as the lifetime of dust particles and the structure and evolution of dust disks. Our

research task is to model the dynamics of external dust matter during accretion onto the surface of a star, because of which the star's atmosphere is enriched with heavy elements - metals.

Thus, based on the above, the dissertation work is devoted to studying the dynamics of dust particles around polluted white dwarfs.

Connection of the dissertation with other scientific projects and developments.

The work was carried out within the framework of plans for research projects of the Ministry of Education and Science of the Republic of Kazakhstan according to priority: Scientific research in the field of natural sciences on the topic of grant funding: IRN AP08956243 "FEB scenario for exoplanetary systems based on the theory of catastrophic thermal destruction of small bodies", execution time 2020 - 2021, state registration No. 0120RK00267. The work is related to previous developments under the targeted funding program BR05236322 of the Ministry of Education and Science of the Republic of Kazakhstan for 2018-2020. and the target scientific and technical program BR05336383 of the Aerospace Committee of the Ministry of Defense and Aerospace Industry of the Republic of Kazakhstan for 2018-2020; IRN BR18574080 - "Research of fundamental and applied problems of plasma physics, plasma-like media to solve problems of modern energy and obtain new functional materials" for 2018-2020.

The purpose of the dissertation is to study the dynamics of evaporating dust particles by modeling their orbital motion during the accretion of particles from an external dust cloud onto the surface of a star.

Two stars with signs of the presence of external matter were selected to solve the problem:

1) white dwarf G29-38, with a surface temperature of about 11600 K, which has an IR excess of radiation due to the presence of hot dust;

2) cold dwarf J1644–0449 with a temperature of 3800 K, in which spectral lines of lithium and other alkali metals are detected, but no IR excess emission exists.

The following **research tasks** are consistently solved to achieve the goal of the dissertation:

1. Perform calculations of **effective** absorption **factors** and radiation pressure according to the Mie theory depending on the radiation wavelength, material, and granule radius for silicate and graphite composition particles in the size range from 0.01 μm to 100 μm.
2. Based on calculations of dust particles' thermal balance, **the particles' heating temperatures are determined** depending on their radius, material, distance to the star, and other related parameters. Calculations of the thermal balance of dust particles use the theoretical Planck radiation function as a model of the radiation of the star and the thermal radiation of the dust particle, taking into account the energy loss due to evaporation using the real parameters of each material obtained from the results of calculations according to the Mie theory.
3. Investigate the **influence of the star's radiation pressure** on dust particles using the data of the average radiation pressure factor obtained from the results of calculations according to the Mie theory and the ratio of the radiation

pressure force to the gravitational force depending on the radius of the dust particle and the material for each star.

4. Analyze the **dynamic evolution of particles**. A joint solution of the system of differential equations of motion and the equation of granule evaporation is performed to do this, and the trajectory of a dust grain in an exoplanetary system is calculated with the given parameters of each star: mass, radius, and surface temperature.

5. Calculation of diffusion coefficients in the atmosphere of polluted white dwarfs using the Chapman-Enskog method.

The object of study. Dust particles that are located near the following astrophysical objects: white dwarf G29-38, and cool dwarf WD J1644–0449.

Subject of study. The orbital evolution of dust particles in the sublimation region near the stars under study depends on their star temperature, radius, material, current distance from the star, and the initial radius of the particles in the system of each selected star.

Research methods. When solving the problems necessary to achieve this goal, calculations are carried out of the temperature balance and orbital evolution of basalt and graphite dust particles in the sublimation region of white dwarfs. The parameters characterizing the interaction of spherical dust particles with radiation were calculated according to the Mie theory based on complex refractive indexes obtained from experiments for graphite and the silicate material we selected - basalt. The Chapman-Enskog method and particle interaction model were used to calculate the diffusion coefficient.

The novelty of the work. As part of this dissertation, the following results were obtained for the first time for dust particles near the white dwarfs G29-38 and WDJ1644–0449:

- the temperature distribution of basalt and graphite particles was obtained depending on the radius of the particle and the distance to the star;
- calculations of the dynamic evolution of particles were performed based on solving a system of differential equations of motion and the equation of evaporation of a dust particle. Calculations of the trajectory of dust particles in the range of radii from 0.01 μm to 100 μm were performed in two exoplanetary systems during the sublimation process until complete evaporation of the particles was achieved. Calculations were performed for circular and parabolic orbits;
- the boundaries of zones of complete evaporation of basalt and graphite particles were obtained for each star.
- micron-sized dust particles moving in parabolic orbits can directly hit the surface of the cold dwarf WD J1644-0449 without achieving complete evaporation.

Scientific and practical value of the dissertation. The results obtained significantly contribute to solving the problem of enriching the atmospheres of white dwarfs with heavy elements from external sources. They can be used in studying exoplanetary systems and to understand the evolution of astrophysical objects such as neutron stars, white and brown dwarfs, and giant planets. The study of diffusion in the atmosphere of white dwarfs allows us to determine the dynamic and transport properties of warm dense matter in white dwarfs.

Main provisions submitted for defense:

1. For dust particles with a size of $0.1 \div 100$ microns moving in circular orbits around the white dwarfs G29-38, WDJ1644-0449, parameters taken from GAIA Data Release 2, there are dust-free zones, the sizes of which are: for graphite particles - $0.16R_{\odot}$ near white dwarf G29-38 and $0.0195R_{\odot}$ near WDJ1644-0449, for basalt particles – $0.52 - 0.65R_{\odot}$ near G29-38 and $0.039R_{\odot}$ near WDJ1644-0449.

2. Dust particles of basalt material with an initial radius of more than 300 μm and graphite material with a radius of more than 0.3 μm, moving in parabolic orbits, fall directly onto the surface of the cold dwarf WD J1644-0449 without achieving complete evaporation.

3. In the region of the nonideality parameter $\Gamma < 1$, the diffusion of carbon in the shells of white dwarfs occurs 10 times faster than the diffusion of silicon.

Author's personal contribution. The author was directly involved in formulating the research problem together with scientific consultants, carrying out numerical calculations, making comparisons and analyzing the results obtained, preparing conclusions, presenting the results at international conferences, and preparing the results of the work for publication.

Reliability and validity of the results obtained.

Well-known physical models and proven mathematical methods were used in the dissertation work. Also, the reliability and validity of the results obtained are confirmed by publications in non-CIS journals with a high impact factor and in publications recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan and in the proceedings of international scientific conferences in the near and far abroad.

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

– at an international conference of «XXXIV International Conference on Phenomena in Ionized Gases» (2019, Sapporo, Japan);

– at the international conference of students and young scientists "Farabi Alemi" (2019, Al-Farabi Kazakh National University, Almaty);

– at the international conference of students and young scientists "Farabi Alemi" (2020, Al-Farabi Kazakh National University, Almaty);

with professors: S.A. Mayorov (Russia) within the framework of international cooperation, Serebryansky A.V. (Kazakhstan, V.G. Fesenkov Institute of Astrophysics) as part of the internship program.

Publications. Based on the materials of the dissertation work, 6 printed works were published: 5 - in journals from the List of Committee for Quality Assurance in the Field of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan for publishing the main results of dissertations for the scientific degree PhD and 1 articles in non-CIS journals with a high impact factor, included in the international information resources Web of Science (Clarivate Analytics, USA) and Scopus (Elsevier, Netherlands); 5 works in collections of international scientific conferences.

An article with a high impact factor in the Clarivate Analytics database or in publications included in the international scientific database Scopus:

1. Shestakova L.I., Serebryanskiy A.V., Kenzhebekova A.I. On the survival of dust grains in the sublimation zone of cold white dwarfs // Monthly Notices of the Royal Astronomical Society. – 2022. – Vol.514(1). – P.997-1005.

Articles in publications recommended by Committee for Quality Assurance in the Field of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan:

1. Shestakova L.I., Serebryanskiy A.V., Kenzhebekova A.I. Dynamics of dust grain in the sublimation zone of cold white dwarfs // Reports of the NAS of the republic of Kazakhstan.– 2022. – Vol.1 (341). – P. 130-136.
2. Шестакова Л.И., Кенжебекова А.И. Сублимация пылевых частиц вблизи белого карлика G29-38 // Известия НАН РК, серия физико-математическая. – 2021. – №3 (337). – С. 156 – 166.
3. Kenzhebekova A.I., Bastykova N.K, Kodanova S.K., Ramazanov T.S., Maiorov S.A., Moldabekov Z.A. Destruction of a dust particle in the white dwarf atmosphere // The Japan Society of Applied Physics. – 2020. – Vol. 59(4). – SHHA04.
4. Skvortsova N. N., Maiorov S. A., Malakhov D. V., Stepakhin V. D., Obraztsova E. A., Kenzhebekova A.I. Shishilov O. N. On the dust structures and chain reactions induced over the regolith by gyrotron radiation // JETP Letters. – 2019. – Vol.109. (7). – P. 441-448.
5. Кенжебекова А.И., Коданова С.К. О левитации пыли над поверхностью Луны // Вестник КазНУ, серия физическая. – 2019. – №2(69). – С. 47-52.

Scope and structure of the dissertation. The dissertation consists of an introduction, 4 sections, a conclusion, and a list of sources used from 163 titles, containing 90 pages of introductory computer text, including 37 figures and 5 tables.